TULE RED MARSH RESTORATION PROJECT

HYDRAULIC AND GEOMORPHIC BASIS OF DESIGN REPORT

Prepared for:

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DISCLAIMER

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Glossary of Terms

Levee	Surround berm to prevent landward flooding (not tied to spec. frequency of flood event)
MHHW	Mean Higher High Water (The average of all higher high water heights)
MHW	Mean High Water (The average of all high water heights)
MTL	Mean Tide Level (The arithmetic mean of mean high water and mean low water)
MSL	Mean Sea Level (The arithmetic mean of hourly sea levels)
MLW	Mean Low Water (The average of all the low water heights)
MLLW	Mean Lower Low Water (The average of the lower low water heights)
Neap Tide	A tide that occurs when the difference between high tide and low tide is at its smallest
NOAA	National Oceanic and Atmospheric Administration
OCAP	
Spring Tide	A tide that occurs when the difference between high tide and low tide is at its largest

1.0 INTRODUCTION

1.1 Background and Objectives

The Tule Red Marsh Restoration Project (hereinafter Project) will restore approximately 420 acres of managed marsh in Suisun Bay to a natural unmanaged tidal marsh. The Project is being funded by the State and Federal Contractors Water Agency (SFCWA) to meet goals outlined in the State of California's Bay Delta Conservation Plan (BDCP) as well as the U.S. Fish and Wildlife Service's (USFWS) Biological Opinion (BO) issued as part of the Long-Term Operational Criteria and Plan (OCAP) for coordination of the Central Valley Project and State Water Project. The BDCP California Eco Restore program provides a goal of 9,000 acres of tidal and sub-tidal habitat restoration. The USFWS BO consults on the Delta Smelt and provides five reasonable and prudent alternatives (RPA). RPA Component 4 requires 8,000 acres of intertidal and associated subtidal habitat to be restored in the Sacramento River Delta and Suisun Marsh.

The Project also falls within the footprint of the Suisun Marsh Habitat Management, Preservation and Restoration Plan (SMP). The SMP is an interagency plan to address habitat and ecological processes, public and private land use, levee system integrity, and water quality through tidal restoration and managed wetland activities. The objectives of the SMP are to 1) restore over 5,000 acres of tidal marsh, 2) protect and enhance over 40,000 acres of managed wetland, 3) improve ecological processes and reduce stressors such as invasive species, 4) maintain waterfowl heritage and expand sporting opportunities, and 5) maintain and improve the marsh levee system integrity, and to protect water quality. In addition to restoring the managed marsh to a tidal marsh, specific project components are functional design components intended to meet the various objects of the SMP. These components are explained in detail in Chapter 3.

The key objective of the project's design is to sustainably restore natural tidal marsh processes to the Project site while meeting the objectives of the SMP. SFCWA contracted Westervelt Ecological Services (WES) to develop and implement the restoration plan. Northwest Hydraulic Consultants (NHC) is a sub-consultant to WES responsible for the hydraulic and geomorphic design of the project for meeting the ecological goals of the project. This report provides the hydraulic and geomorphic basis of design for the Tule Red Marsh Restoration Project.

1.2 Project Datum

All elevations referred to in this report are relative to the North American Vertical Datum of 1988 (NAVD88) unless otherwise stated. The National Oceanic and Atmospheric Administration (NOAA) operates the Port Chicago gage in Suisun Bay (Gage # 9415144). NOAA provides verified six minute water levels dating back to 1996 and tidal datum for the Port Chicago site. Table 1.1 provides the tidal datum relative to NAVD88.

Table 1.1: Tide elevations with respect to current datum.

Datum	Elevation Relative to NAVD88 Datum (ft)
MHHW	6.0
MHW	5.5
MTL	3.7
MSL	3.7
MLW	1.8
MLLW	1.1

1.3 Report Organization

This report is organized into six chapters. Chapter 2 of this report describes the Project site in detail. This chapter includes discussion of the origin and historic management of the project marsh, historic and on-going shoreline accretion, existing marsh elevations, soil types, and vegetation. Chapter 3 presents the conceptual marsh design. The chapter presents the hydraulic and geomorphic design objectives, as well as discussion of each of the primary concepts of the design. Chapter 4 discusses the hydraulic and geomorphic analyses used to evaluate and design the conceptual design. Chapter 5 discusses Project implementation and expected adaption of the Project over time. Chapter 6 provides references noted throughout the report.

2.0 PROJECT SITE

2.1 Project Setting

The Tule Red Marsh Restoration Project site is located on the eastern shoreline of Grizzly Bay. Grizzly Bay is an embayment in the northeast portion of Suisun Bay in the northeastern portion of the San Francisco Bay. The Sacramento-San Joaquin River Delta flows directly into Suisun Bay. The project site is in the low salinity zone where juvenile delta smelt are known to rear and mature (OCAP). Figure 2.1 shows the Project site location and its proximity to the Port Chicago tide gage.

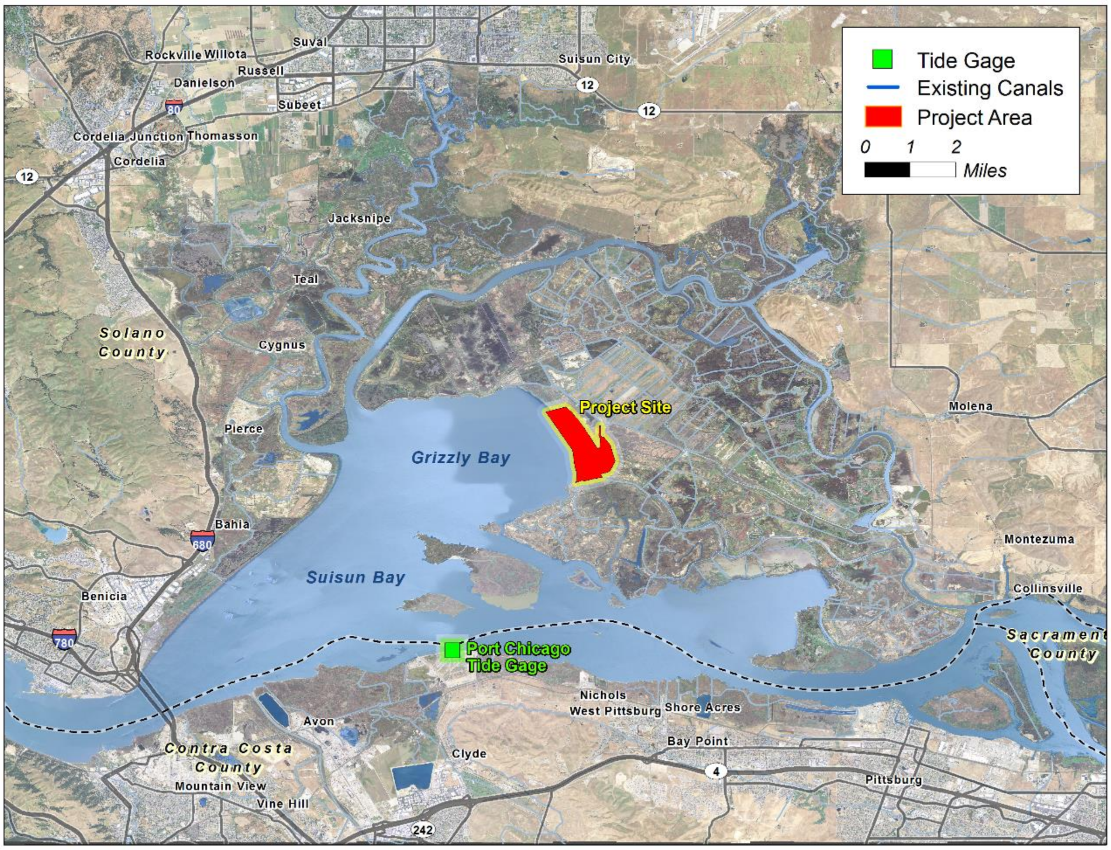

Figure 2. 1: Tule Red project location within Suisun Bay.

The site was historically and is currently managed as the Tule Red Duck Club. The site is seasonally flooded and drained through existing artificial channels for vegetation management. Figure 2.2 shows the layout of the existing site. Human made berms and roadways separate the project site from the adjacent properties to the east. Ditches along the toe of these berms are used for flooding and draining the site. Two tide gates are used to control inflow and outflow from the site. A natural berm extends along the western shoreline edge of the property and protects the site from tidal inundation during typical high tides. King tides and high spring tides with westerly winds do overtop the outboard natural marsh berm.

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Legend

- Tide Gates
- Existing Canals
- Project Area
- Man Made Berms
- Natural Marsh Berm

DATA SOURCES:
NAIP Color Orthoimagery, 5/20/2012-5/22/2012.
Esri StreetMap, 2012.

SCALE - 1:12,000

0 500 1,000 1,500 Feet

N

Coordinate System:
NAD 1983 California State Plane Zone 2
Units: feet

Job: 5001024

Date: NOVEMBER 2015

FIGURE 2.2

Tule Red Tidal Restoration Project

Project Site Layout

ABC, P:\500059_Tule_Red_Concept\GIS\Workmaps\Report_Figures\Figure_2-2_Project_Site_Layout.mxd

2.2 Historic Marsh Development

Conceptualizing marsh restoration plans necessitates the analysis of existing site conditions and the historical evolution of the landscape. Anthropogenic impacts on the Suisun Marsh began in the late 1800’s when the marshlands were diked and managed for agricultural purposes. Soon after, the land use changed from agricultural activities to managed wetlands for use as duck hunting clubs (DWR, 2001). An 1873 Geological Survey of California Map of the San Francisco Bay Area shows the project site was open water during this time. Figure 2.3 shows the project site with historic shorelines from published maps overlaid on a recent aerial photo. Much of the Project site developed marsh vegetation between about 1950 and 1980 and the site and its vegetation continue to expand today through shoreline accretion at a rate of about an acre per year. Historic maps of the project site are provided in Appendix A.

Table 2.1 provides the average distance per year that the shoreline has moved out into Grizzly Bay over time. Warner et al (2004) showed Grizzly Bay as a sediment sink. Sediment suspended by wind waves and tidal currents in San Pablo Bay and the Carquinez Straits are transported into Grizzly Bay’s shallow embayment due to asymmetric tides and floodtide pulses. Wind waves from prevailing westerly winds help push the sediment up into the edges of the marsh vegetation. As the edge of the marsh accretes, the vegetation grows further out into the marsh moving the location of deposition seaward. The transport of sediment from the Sacramento San Joaquin Delta has decreased (Wright and Schoelhammer, 2004) in recent decades, and the rate of shoreline accretion has also decreased over these same time periods. It should be noted that although the total amount of sediment transported to Suisun Bay has decreased, estimated sediment loads from the Delta vary from 1 million to 2 million tons per year (Wright and Schoelhammer, 2004; Shvidchenko et al., 2004), which are appreciable and will continue to provide suspended sediments to the Grizzly Bay region. The effects of variation in future sediment delivery for the site’s morphological evolution is discussed in Section 5.4.

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Legend

- 2012 Shoreline
- 1970s Shoreline
- 1950s Shoreline
- 1900s Shoreline (white)
- 1873 Shoreline

DATA SOURCES:
NAIP Color Orthoimagery, 5/20/2012-5/22/2012.
Esri StreetMap, 2012.

SCALE - 1:36,000
0 1,000 2,000 3,000 Feet
N

Coordinate System:
NAD 1983 California State Plane Zone 2
Units: feet

Job: 5001024

Date: NOVEMBER 2015

FIGURE 2.3

Tule Red Tidal Restoration Project

Historic Shorelines

ABC, P:\500059_Tule_Red_Concept\GIS\Workmaps\Report_Figures\Figure_2-3_Historic_Shorelines.mxd

Table 2.1: Historical Rates of Shoreline Accretion

Time Period	Average Accretion Lengh (ft)	Average Annual Accretion Rate (ft/yr)	Average Annual Maximum Accretion Rate (ft/yr)
1873 – 1906-07	6,563	196	253
1906-07 – 1941	4,023	117	152
1941 – 1978-79	1,238	33	40
1978 – 2012	214	6.5	10

2.3 Existing Marsh Soils

WES contracted Hultgren-Tillis Engineers (HTE) to perform a geotechnical investigation of the soils at the Project Site. Test pits were dug at eight different locations throughout the project site. The test pits were dug about 7 to 9 feet below the existing grade, with the existing grade elevation at the test pits typically varying between 4 and 5 feet NAVD 88. The test pits showed the marsh is predominately composed of sandy silts and silty sands. Visual inspection of the excavated material did not show evidence of large episodic deposition nor appreciable accumulation of organic materials (e.g. peat or decayed vegetation). The sediments appeared to be deposited in thin horizontal horizons of less than 3 mm in thickness with generally uniform sediment characteristics.

2.4 Existing Marsh Plant Types

Existing vegetation on the Project Site includes vegetation typical of brackish marshes in Suisun Bay. The natural berm and much of the marsh plain is densely vegetated with Phragmites. Stands of native Tule are also found in the marsh plain. Native Tule and Cattail are found along the edges of the existing drainage ditches. Pickleweed is also found in several locations throughout the existing managed marsh.

2.5 Existing Marsh Elevations

WES completed topographic surveys of the site in 2013 and 2014. The topographic surveys included RTK ground surveys as well as aerial photogrammetry. Figure 2.4 shows the elevations of the existing site. The marsh plain is relatively flat, with a slight slope down from west to east. Marsh plain elevations are generally between 4 to 5 feet in elevation. The natural marsh berm is at elevation 6.5 feet, while the human made berms on the eastern edge of the site average about elevation 10. The primary drainage canals have an invert elevation at about 0 to 2 feet. The existing drainage channel bottoms are smaller than the individual pixel resolution so are not plotted on Figure 2.4

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Legend

Elevation (in NAVD88)

Below 0	2 - 3	5 - 6
0 - 1	3 - 4	6 - 7
1 - 2	4 - 5	7 +

DATA SOURCES:
NAIP Color Orthoimagery, 5/20/2012-5/22/2012.
Esri StreetMap, 2012.

SCALE - 1:12,000
0 500 1,000 Feet
N

Coordinate System:
NAD 1983 California State Plane Zone 2
Units: feet

Job: 5001024

NOVEMBER 2015

FIGURE 2.4

Tule Red Tidal Restoration Project

Existing Elevations

ABC, P:\5000059_Tule_Red_Concept\GIS\Workmaps\Report_Figures\Figure_2-4_Existing_Elevations.mxd

3.0 RESTORED MARSH CONCEPT

3.1 Overview

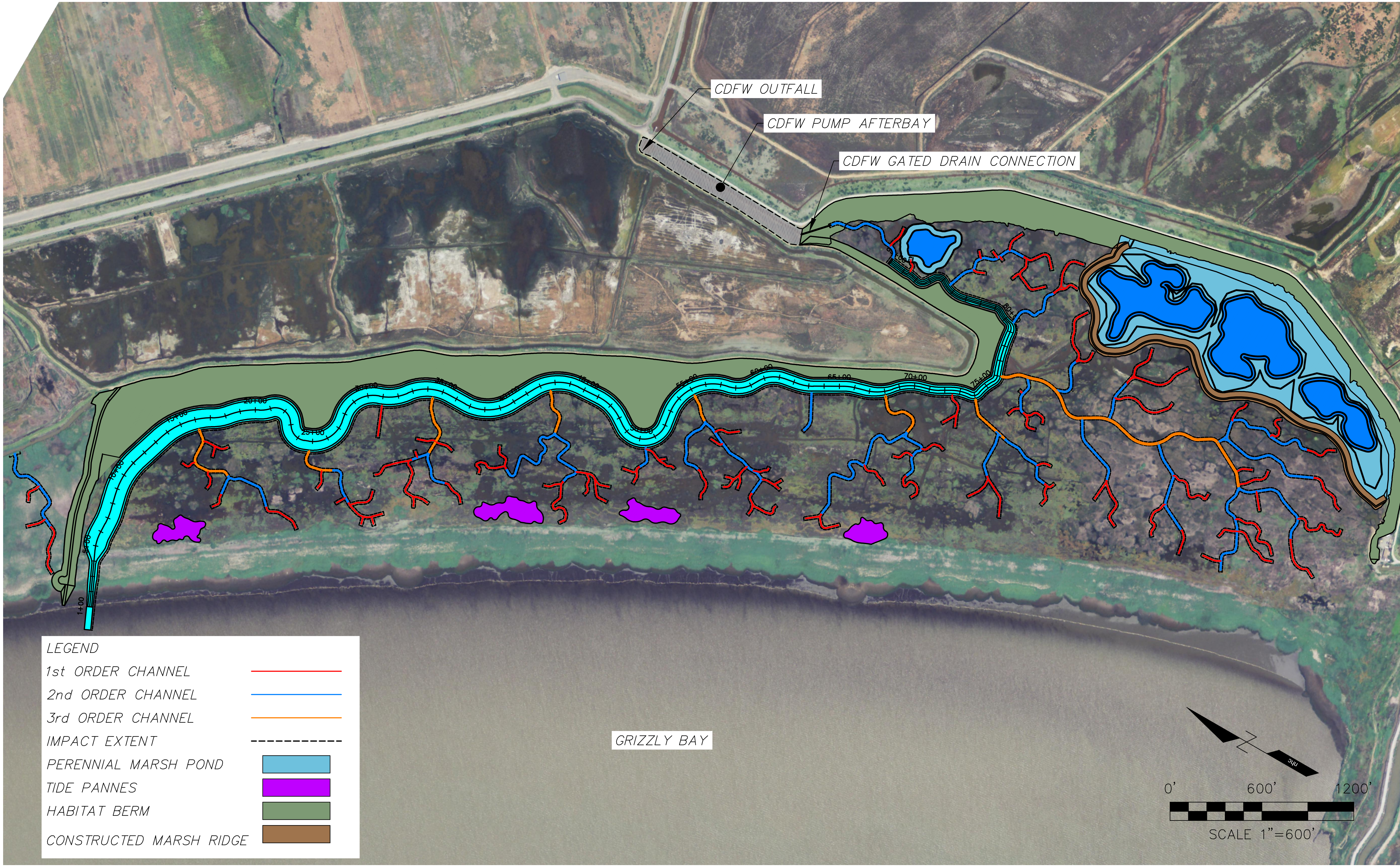
Figure 3.1 provides the conceptual site design. The proposed concept is based on a process-based design that restores full tidal exchange to the Project site. Tidal exchange is the driving process that creates and sustains tidal wetlands (Siegel et al. 2010). Key elements include inundation regime (timing, frequency, depth, duration), sedimentation processes (erosion of tidal channel boundaries, transport through tidal channels, deposition on marsh plain surfaces), and exchange of nutrients. Restoring the tidal exchange process is allows the establishment and growth of brackish marsh vegetation such that associated food web and other ecological processes occur naturally in the restored tidal marsh system.

Functional design concepts such as a habitat berm along the existing human made berm and roadway on the landward boundary of the property, as well as large ponds on the southeastern edge of the Project site are also included in the design. These functional design concepts are intended to provide opportunities for addressing objectives in the SMP and Biological Opinion for the State and Federal water projects. In addition to providing transitional upland habitat around the marsh site, the habitat berm will also improve the existing marsh levee system integrity by increasing the stability of the existing human made berm and roadway. The pond site improves ecological processes and reduces stressors from invasive species by providing adequate residence times for cultivating and rearing zooplankton. The longer residence time provided by the ponds allows sufficient time for zooplankton growth, becoming large enough to bypass the invasive overbite clam (Moyle, 2015). These and other major design components are discussed in the following sections.

3.2 Breach of Natural Marsh Ridge

The natural marsh ridge and human berms currently prevents the site from flooding and draining during typical tides. Investigation of historic maps and review of existing marshes show tidal channels entering marshes on the northeastern edges of San Pablo and Grizzly Bay typically entering marshes from backwater sloughs. Prevailing winds through much of the year come from the west and southwesterly directions and wind driven waves directly buffet these shorelines. Due to this observation and the ongoing shoreline accretion (Section 2.2 and Appendix A), the initial conceptual design considered using the existing artificial channels for flooding and draining the site. The locations of these existing channels have been been fairly stable over the past 100 years.

Odell et al (2008) provides geomorphic relationships for mature marshes in the San Francisco Bay estuary. The relationships in Odell et al (2008) show mature marshes with the Project site drainage area are typically drained by a 4^{th} or 5^{th} order channel with a top width of about 160 feet, and depth of about 10 feet below MHW. The existing channels within the site have top widths of about 20-30 feet, and a depth of about 4-5 feet below MHW. The discrepancy between the empirical mature marsh channel dimensions and existing channel dimensions suggests the existing channels are undersized, would provide only muted tidal exchange on the Project site, and could significantly widen and deepen if tidal fluxes were large enough to induce erosion. Due to the proximity of the existing artificial channels to the human made berms and roadways protecting the neighboring parcels, and the proximity of a water supply canal along the far side of the berm from the existing artificial channels, using the artificial channels could increase the flood risk and operations of existing infrastructure in Suisun Bay. This risk was considered unacceptable, and alternate tidal entrance channel configurations were considered.


CDFW OUTFALL
CDFW PUMP AFTERBAY
CDFW GATED DRAIN CONNECTION
GRIZZLY BAY
LEGEND
1st ORDER CHANNEL
2nd ORDER CHANNEL
3rd ORDER CHANNEL
IMPACT EXTENT
PERENNIAL MARSH POND
TIDE PANNES
HABITAT BERM
CONSTRUCTED MARSH RIDGE
0'
600'
1200'
SCALE 1"=600'

The empirical relationships also confirm the anecdotal evidence that the existing artificial channels are undersized for providing full tidal exchange on the Project site. The on-site caretaker typically opens the tide gates on multiple subsequent high tides to completely flood the site. Similarly, the caretaker opens the gates on multiple subsequent low tides to completely drain the site. Results of two-dimensional ADH modeling of this concept (Chapter 4), showed the channels were unable to provide full tidal exchange at the site. The ADH model also showed the additional tidal flux in the north channel shared with other adjacent properties would backwater neighboring properties during low tides. This would likely impair their drainage operations and this risk was considered unacceptable.

The proposed concept instead includes a breach through the natural marsh ridge directly into the bay. Numerous breach locations were evaluated through the site. The southern edge of the site is slightly lower than the northern edge of the site. The on-site caretaker noted that due to soft soils it is difficult and sometimes impossible to get maintenance equipment in this region of the site, and maintenance work in the summer of 2014 with ideal conditions (fully drained and dry marsh) still required a special amphibious excavator to perform the work. Due to constructability and maintenance access concerns (See Section 3.6), the breach was moved away from this area. Breach designs in the center of the site were also considered, but were less favorable than having a breach on the North side of the property due to a lower residence time and maintenance access concerns.

The proposed breach location is to be located on the northern edge of project site. This location minimizes required excavation across the marsh plain (minimizing construction impacts), and will have a marsh berm constructed along its edge to serve as maintenance access. The proposed inlet channel is to be excavated to a depth of -2 feet NAVD88 to inhibit the growth of vegetation within the channel. The initial channel width is 50 feet which will provide full tidal exchange immediately when constructed. The channel is expected to self-adjust to a final equilibrium width of about 160 feet and invert of -5 feet NAVD88 within 7 years after construction (Section 4.4). Shear stresses are significantly above those required to keep sediment suspended through the range of tidal exchange indicating in-channel deposition is unlikely to occur (Chapter 4).

The single northern channel inlet will provide the only hydraulic connection to the bay. The project site marsh plain is at an elevation of about 4 feet to 5 feet. Being below MHW and above MSL means the marsh plain will be flooded and drained on each high tide cycle. The volume of water required to flood the project site will result in peak flows over 1,500 cfs each time the site floods and drains. Based on the constant flushing and shear stresses computed from the hydraulic modeling, fine sediment deposition in the tidal inlet channel inlet is not expected to occur (Section 4.4). Vegetation is not evident in nearby tidal channels below about MSL and is not expected to encroach into the channel due to the depth and erosion and entrainment of sediment deposition on the tidal channel margins. Nonetheless, the project includes an access road out to the channel inlet site to provide access if unanticipated sediment deposition in the tidal inlet channel occurs.

Concerns with the stability of the breach remaining open have been expressed due to difficulties at with breach closing at Crissy Field. The Crissy field project site is located near the Golden Gate. Tidal flux into and out of the entire San Francisco Bay flows past the breach location at Crissy Field. This flux creates longshore currents which push sediment into the breach via littoral processes. The tidal flux into and out of the Crissy Field Marsh are less than 1% of the total flux pushing sediment along the shore. In contrast, the Project site is at the edge of a shallow estuary with minimal longshore currents. The tidal flux into and out of the Tule Red is the dominant flow pattern and aligned with the flux into and out of the site during the ongoing tidal fluctuations and flows.

Additional concerns with the stability of the breach remaining open have been expressed due to breach closings at projects located along Highway 37, Sonoma Creek, and the Muzzi Marsh near Corte Madera project sites in northeastern San Pablo, northern San Pablo, and northwestern San Francisco Bays, respectively. These sites were constructed into old bay muds with higher shear strengths than the more recently deposited sediments found at the Tule Red Project site. The higher shear strength reduces erosion rates of the native sediments, and duration when erosion occurs. These sites were also constructed into a higher marsh plain (elevations about 5.5 to 6 feet) without an established tidal network throughout the high marsh plain. The tidal flux is therefore limited at these sites along San Pablo Bay as the volume of water inundating the site is less due to the higher marsh plain elevation and the lack of tidal channels. The Tule Red Project is being constructed on a lower marsh plain lower than the MHW and with a fully excavated tidal network, providing significant tidal prism volume and associated tidal flux to provide flushing flows throughout the constructed tidal channel network. Results of the hydrodynamic model (Chapter 4) show shear stresses in the channel are adequate to provide erosion, and sufficiently high to inhibit deposition of fine suspended sediments on the margins of the constructed tidal channels.

3.3 Tidal Channel Network

The tidal channel network provides low resistance pathways through the densely vegetated marsh surface allowing flooding and draining with each tide cycle. Tidal networks form as a function of the tidal regime, vegetation type, sediment characteristics, and marsh elevations. The tidal channels also create pathways through the marsh plain allowing sediment to reach further out across the Project site.

A long channel from the channel inlet through the natural marsh ridge (Section3.2) was sized using empirical relationships from Odell et al (2008) and confirmed with hydrodynamic modeling. The width and depth of the channel decreased from the channel inlet to the back of the site as the contributing marsh area and tidal prism decreased. The single high order channel connection is typical of other marsh sites in Suisun Marsh (Honkers Bay, Browns Island, et al). Lower order channels (smaller distributary channels) extend from the large higher order channel and provide additional connections between the marsh plain surface and the tidal channel network.

The layout and channel density of the lower order channels is based on nearby marshes in Suisun and lower Sacramento River Delta. Low order drainages from these sites were scaled per drainage basin area using Odell et al (2008) relationships, and confirmed with reference site measurements in the Suisun Bay region. A two-dimensional hydrodynamic model was run of the final channel layout to quantify the hydraulic response of the channel layouts (Chapter 4). The model included a roughened marsh surface accounting for the establishment of the marsh vegetation with channel network throughout the marsh plain. The model was run for both typical spring and neap tides to evaluate channel stability. The results of this analysis are discussed in Chapter 4.

Various construction alternatives were evaluated for developing lower order channels off of the single high order channel. These alternatives varied from allowing full natural development of channels, to starting short lengths of low order channels to promote natural development, to more extensive excavation of tidal channels. As discussed in Chapter 4, comparison of hydrodynamic model results and existing soil information showed natural development of the low order channels would take on the order of decades. Due to the presence of Phragmites and their robust root structures currently at and near the project site, the tidal channels may not develop at all. The design will include full excavation of the tidal channels to provide additional tidal prism volume and tidal flux to provide full tidal exchange across the Project site.

3.4 Tidal Ponds and Pannes

The tidal ponds located in the southern edge of the site are a functional design component designed to increase onsite production of zooplankton. Moyle (2015) identified a preferred onsite residence time of about 14 days to allow zooplankton to reach an optimal size for foodweb production. The OCAP BO notes invasive overbite clams may colonize near marsh entrances and filter smaller copepods out of the water column, thus limiting the foodweb production and export from the marsh system. An approximate 14 day residence time allows zooplankton to grow large enough to pass the clams. Without the onsite ponds, the elevation of the marsh surface and tidal channel network is such that the majority of the site floods and drains diurnally and limits the mean residence time to about 3-9 hours.

The proposed concept includes a marsh ridge constructed up to elevation 5.5 feet NAVD88 (MHW) to create the largest pond. The marsh ridge will have gently sloping side slopes with a 10 foot top width and will be vegetated. The interior pond elevations will be excavated down to 2 feet NAVD88 in most areas, with deeper sections down to 0 feet NAVD88. The ridge will impound water behind it when tides are below 5.5 feet NAVD88, and will allow mixing of tide water when tides exceed 5.5 feet. Peak high water elevations during neap tides are only about 5.5 feet, providing some daily connection and exchange between the pond and the marsh. During spring tides, high tides reach elevations of close to 7 feet NAVD88. Assuming a reactor type model mixing model for the pond, median residence time of the ponds is computed to vary between 6 to 14 days.

A water budget was evaluated for the impounded pond following the framework of Lionberger et al. (2004). The model assumed no precipitation and peak evaporation/evapotranspiration losses of 6mm/day. The model evaluated conditions where groundwater loss occurred, and where infiltration may become minimal due to clogging of pores by microbial slimes and colloidal soils (Lionberger et al 2004). The model showed the pond was unlikely to dry during periods of low tides and high evaporation rates, and that salinity levels in the ponds would remain 1% to 15% higher than baseline conditions in Grizzly Bay. Section 4.7 provides discussion of the analysis of the residence time and water balance analyses for the ponds and tidal pannes.

Another smaller pond is also located in the southeastern corner of the project area. This pond is fed by a small channel with invert of 2.5 feet NAVD88. This pond will have a typical residence time between 15-20 hours. The purpose of this pond is to provide habitat diversity and a comparison for the larger impounded pond. The pond will be directly connected to the tides. The sedimentation rates in the pond are expected to be about 0-0.25 ft/year, thus faster than sea level rise rates. The pond may maintain its function, or gradually infill and vegetate over the next 10 years.

Tidal pannes, or alternatively categorized “mud barrens” (Mitsch and Gosseling, 1993) are located within the higher marsh plain elevations. The pannes will be surrounded by gently sloping marsh ridges with top elevations of 6.5 feet and are designed to flood only on spring tides. The tidal pannes will have a mean residence time of about a month. Due to change in duration of inundation and variability in topography nearby, as well as increased salinity levels, the pannes are intended to provide physical habitat and vegetation diversity within the marsh plain. The pannes will occasionally dry during the year, and will produce peak salinity levels about 2 to 5 times the baseline condition of Grizzly Bay.

3.5 Habitat Berm

The habitat berm surrounding the site is a functional design to meet the stipulations of the Suisun Marsh Plan (SMP). The SMP requires new levees or improvement of existing levees that will protect adjacent property owners from potential increases risk of flooding. Habitat levees that include berms that will provide protection from wind and wave action as well as provide opportunities for high marsh and upland transition habitat meet these stipulations. The habitat berms will be placed along the seaward length of existing interior levees at slopes of 10% or flatter. The habitat berms will be vegetated with native plants capable of providing erosion protection due to wind waves.

3.6 Maintenance Access

The breach though the natural marsh berm must remain open to allow full tidal exchange on the project site. Although empirical and numerical analyses indicate the breach is unlikely to close due to sediment deposition, uncertainty in design and potential unforeseen natural impediments may occur (log jams, flotsam, beaver dams, etc), which could inhibit the ability of the breach to function. A habitat/access berm is to be constructed off the edge of the existing northern berm (which runs west to east) and along the new breach channel. The habitat/access berm will allow large construction equipment access to remove unforeseen impediments from the breach channel, and to perform maintenance if necessary to keep the breach open.

4.0 HYDRAULIC AND GEOMORPHIC ANALYSES

4.1 Design Methodology

A two-step design process was used to develop the concept design discussed in Chapter 3. The first step quantified properties of existing fully tidal natural marshes. This step focused on empirical relationships, visual observations, and morphological measurements of nearby mature marshes. The results of this exercise provided a conceptual design, including channel layout and channel dimensions.

The second step of the design process incorporated the local tidal regime, vegetation, and soil properties into numerical and analytical models to test the performance of the layout derived from the first step. The objective of the second step was to determine if the concept design from the first step would provide full tidal exchange to the site, if the tidal channels would remain stable, and to quantify excavation and material placement for construction of a tidal marsh system that provides full tidal exchange. Proposed as-built designs were modeled using the two-dimensional depth averaged hydrodynamic (ADH) model. The ADH model allowed for testing the tidal channel's ability to provide full tidal exchange through the site given the local tidal characteristics adapted from Port Chicago tide records, vegetation roughness on the marsh plain, and proposed channel layout. Hydraulic shear stresses from the model were compared to sediment properties estimated to be characteristic for the Project site to ensure excavated channels were not depositional, and to determine rates of erosion if channels were not fully excavated.

This Chapter provides results of this methodology as well as other ancillary analyses used to evaluate and develop the design. The ancillary analyses include estimation of the development of low order channels across the floodplain (Section 4.6). The objective of this analysis was to determine if low order channels could naturally develop in time scales appropriate for project performance or would such tidal channels need to be excavated to provide the desired food web export processes for the restored tidal marsh. A water balance and associated residence time analysis was performed for the ponds and pannes proposed for the site (Section 4.7). The objective implementing ponds and pannes on site was to increase residence time for on-site for zooplankton development, and to address hyper-salinity and fish stranding issues within the ponds.

4.2 Empirical Marsh Relationships and Analog Sites

Odell et al (2008) provides empirical geomorphic relationships for tidal channels observed at mature marshes in the San Pablo Bay area. These relationships include channel order vs. drainage basin area, channel bifurcation ratio vs. channel order, channel width vs. drainage basin area, and channel depth vs. drainage basin area. The tidal regime, elevations, and sediment characteristics (fine sediment) of the San Pablo marshes are comparable to the project site, although the sediment deposits and tidal marshes in San Pablo bay are older and have higher cohesive strength than those that at the project site. The dominant vegetation at the two locations also vary (salt marsh vs. brackish marsh). The Odell et al (2008) relationships were verified with observations of mature marshes in Suisun Bay and the lower Sacramento River Delta and were applied to the layout of the project site. Appendix B provides a comparison of Odell et al (2008) relationships to the Honker Bay marsh located in Suisun Bay.

Odell et al (2008) provides the following relationships for channel top width, w, in feet as a function of the drainage area, A, in acres and channel depth, d, in feet as a function of top width.

$$w = 1.87A^{0.76}$$

$$d = 1.91w^{0.33}$$

An initial channel layout was developed using analog marsh sites in and around Suisun Bay. Relationships in Odell et al (2008) were then used to determine channel width and invert for tidal channels. To standardize the channel layouts for ease of construction, standard dimensions were developed for first, second, and third order channels. Table 4.1 provides the drainage area, top width, and channel depth for channels of various orders.

Table 4.1: Low Order Channel Design Dimensions

Channel Order	Drainage Area (acres)	Channel Width (feet)	Channel Invert (NAVD88 feet)
1st	1.5-4	4	2.5
2nd	4-9	8	1.5
3rd	9-15	12	0.0

4.3 Hydraulic Modeling

ADH is a numerical model developed by the U.S. Army Corps of Engineers Engineer Research and Development Center. The model is two-dimensional depth-averaged hydrodynamic model. A two-dimensional model was chosen to evaluate the distribution of flow across the relatively higher and rougher marsh surface relative to proposed marsh channels. ADH was chosen specifically as it includes a roughness boundary condition for emergent rigid vegetation for modeling flow on in inundated marshes. The model was run for both spring and neap tide conditions and provided depth and depth-averaged velocity at points throughout the project site.

The model was developed using the topographic survey data collected by WES and a 2003 NOAA bathymetric survey of Suisun Bay. Project features such as channels, ponds, and berms were added to the survey data to create a project surface. The project surface was projected onto a two-dimensional computational mesh. The computational mesh extended from about 3,000 feet offshore of the Project site to the berm along the eastern and southern edge of the Project site. Figure 4.1 shows the model extents and existing hydraulic roughness properties.

Figure 4.1: ADH model extents and material types for project conditions

ADH uses different material types assigned to areas of the computational mesh to account for spatial variability in hydraulic roughness. Hydraulic roughness is how ADH accounts for momentum loss for flow over both tidal channel surfaces and for flow over and through dense tidal marsh vegetation. The Project model used five different material properties to represent different roughness conditions in the project. The different materials are representative of different land cover and vegetation types expected on the site.

The fourth-order channel along the north and northeastern margin of the project site is to be constructed with an invert well below MLLW. The channel is expected to have a muddy, unvegetated bottom and vegetated banks. Similarly, the constant inundation of the interior of the ponds is expected to inhibit most vegetation from establishing within the ponds. The fourth-order channel, ponds, and open bay are all modeled with a Manning's n value of 0.02 indicative of the relatively low roughness for mud bottomed channels. This value is typical of low gradient tidal channels rivers with minimal vegetation or bed forms.

The marsh plain was assigned a material property that directly computes momentum loss as a function of exposed surface area and stem density of emergent vegetation. The marsh material assumes vegetation does not become fully submerged and remains rigid during tide cycles. The marsh plain at the Project site is assumed to be a mix of invasive Phragmites (*Phragmites Australias*) and native tule (*Schoenoplectus Californicus* and *Schoenoplectus Actutus*). Observation of these plants near the Project site show typical stem diameters around 0.05 feet in stands of about 15 to 20 stems per square foot. To account for additional blocked area from leaves, the material property for the marsh plain was input as assuming twenty 0.1 foot diameter stems per square foot. Similarly, the low order channels across the marsh plain would have narrow bottom widths with well vegetated banks. These channels were assigned with similar stem diameters but with a reduced stem density of 1 stems per square foot.

Observed spring and neap tide water surface elevations from the Port Chicago gage were assigned to the western boundary of the model. The temporal fluctuation of this water surface was the only external boundary condition assigned to the model. The model would be run for 3 to 4 full tidal cycles to ensure the model was adequately warmed-up. Figure 4.2 shows the boundary conditions applied for the spring and neap tide conditions.

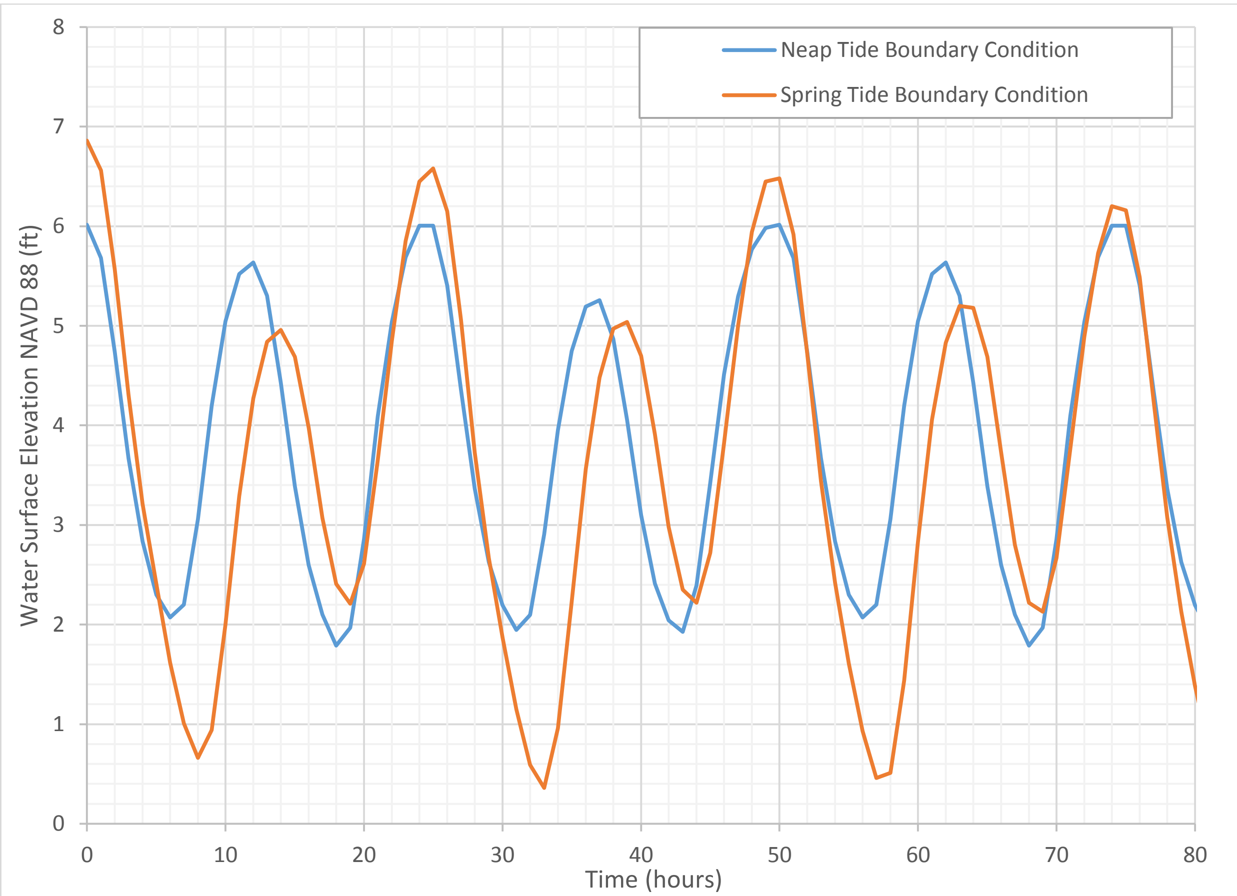


Figure 4.2: Tidal boundary conditions applied to ADH model

As discussed in Section 5.2, the initial construction of the fourth-order channel at the breach will not be constructed to its full equilibrium width as it reaches Grizzly Bay. To limit impacts and construction costs, the subtidal mud flat channel will not be excavated across the long mud flat but will instead be allowed to naturally develop through local scour processes. Figure 4.3 shows the topography for this as-built scenario. The as-built scenario is representative of the expected elevations and channel widths immediately after construction. The second scenario is representative of the site layout with all channels at equilibrium widths and depths. Figure 4.4 shows the topography used in this modeling scenario.

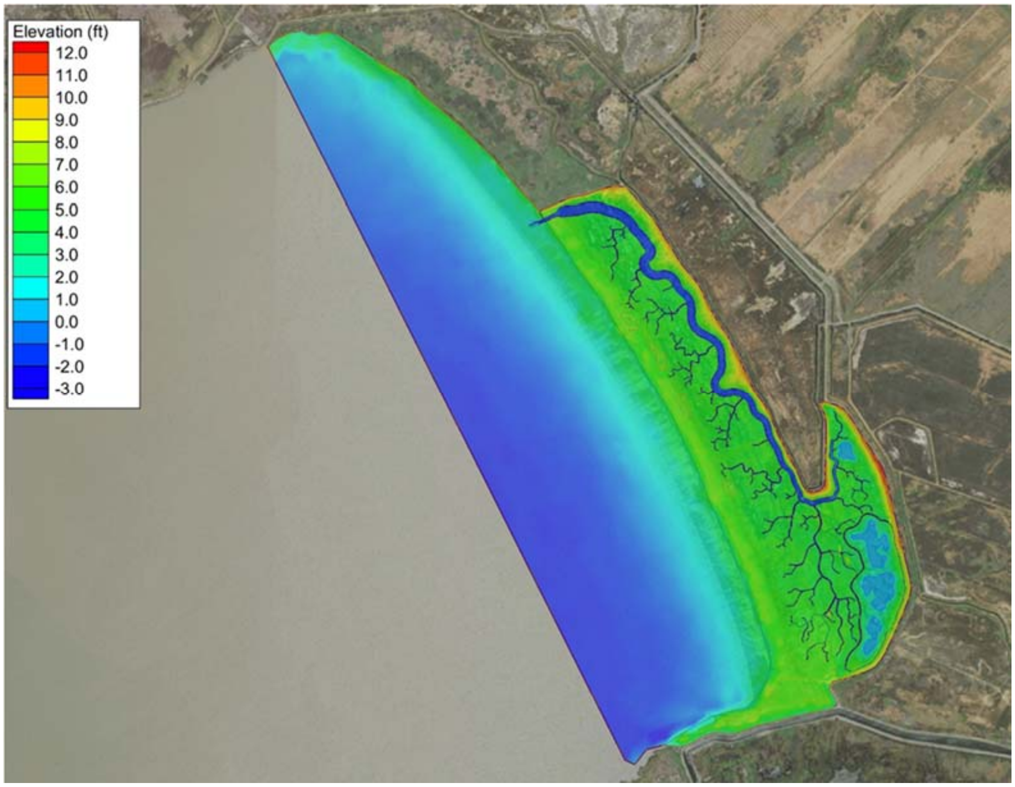


Figure 4.3: As-built model topography, note undersized entrance channel and no tidal mudflat channel

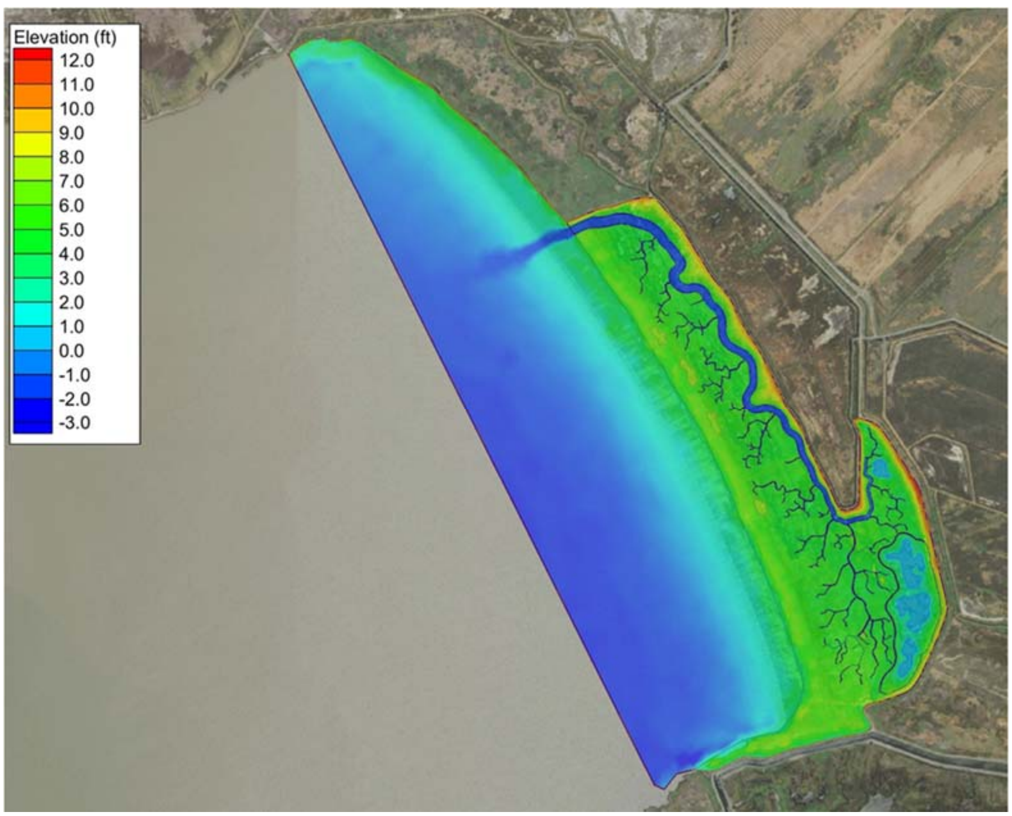


Figure 4.4: Future conditions model topography, note fully developed entrance channel and tidal mudflat channel

4.4 Hydraulic Performance

Figure 4.5 shows the water surface elevation computed from the ADH model relative to the applied boundary condition for the as-built condition. The first 10 hours of results show the model warm-up as the initial model conditions were assumed to be a constant water level. The results show the channel does not fully drain to the MLLW elevation. This is due to the existing mud flat outside of the Project area being at elevation 2 and preventing the site from fully draining. The timing and magnitude of the high tide in the breach entrance is in phase with the boundary condition. Some tidal muting is noted at the southeastern terminus of the 4th order channel where the high tide elevation is about 0.2 feet lower than the boundary condition, however the tides still rise and fall to depth adequate to flood and drain the marsh plain (approximately elevation 4-5.)

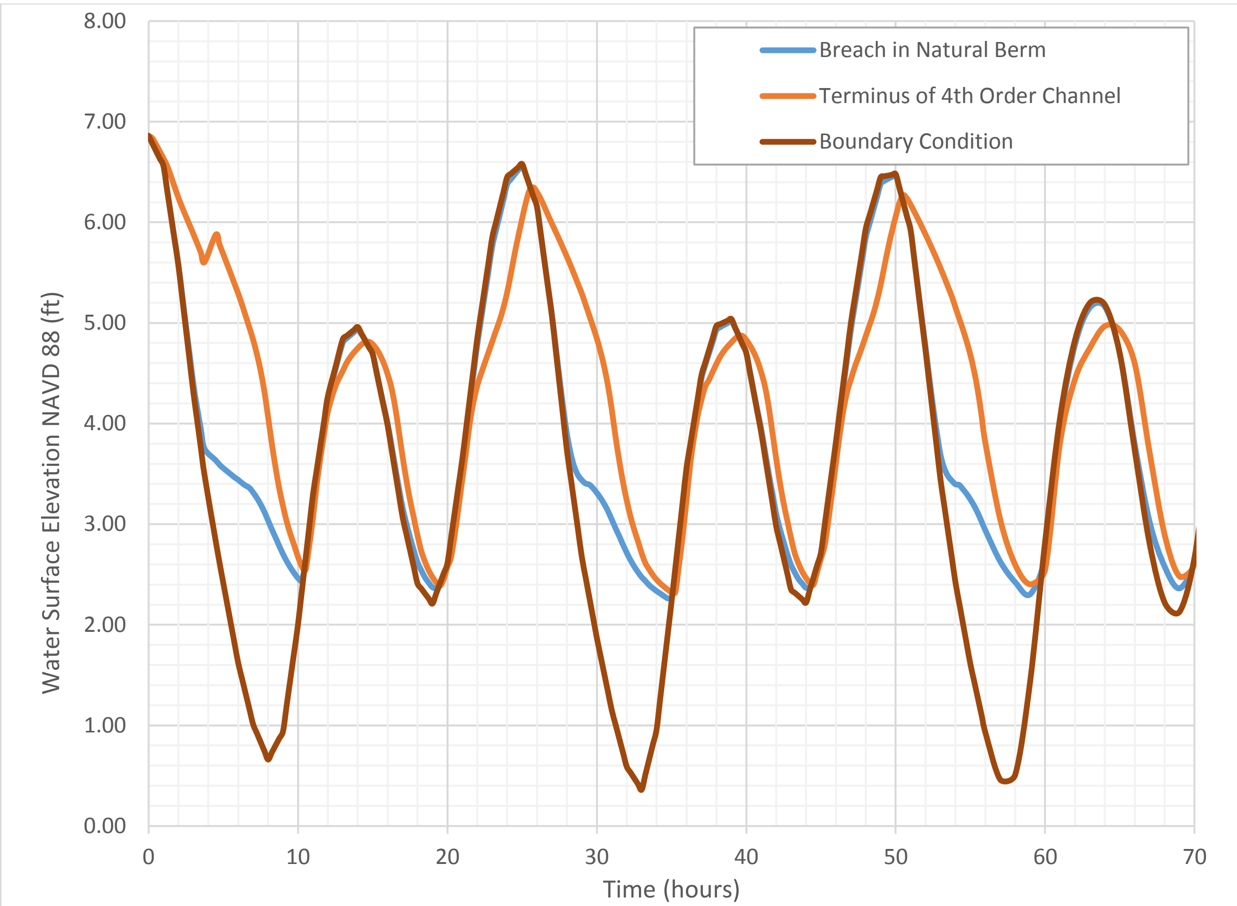


Figure 4.5: Computed water surface elevations in the 4th-order channel at the breach in the natural berm, and on the terminus of the 4th-order channel for the as-built model with spring tide boundary condition.

Figure 4.6 shows the water surface elevation outputted from the ADH model relative to the applied boundary condition for the future condition. The output shows water surface elevations in the entrance to the marsh match the applied boundary condition. The water surface elevations in the back of the marsh match the magnitude of the applied boundary condition for MHW and MLW, and are within 0.2 feet of MLLW and MHHW. The timing of when the peak high and low waters occur are delayed about an hour relative to the boundary condition, but durations of inundations of various elevations closely follow the tidal marsh conditions. The plot shows the site fully flooding and draining.

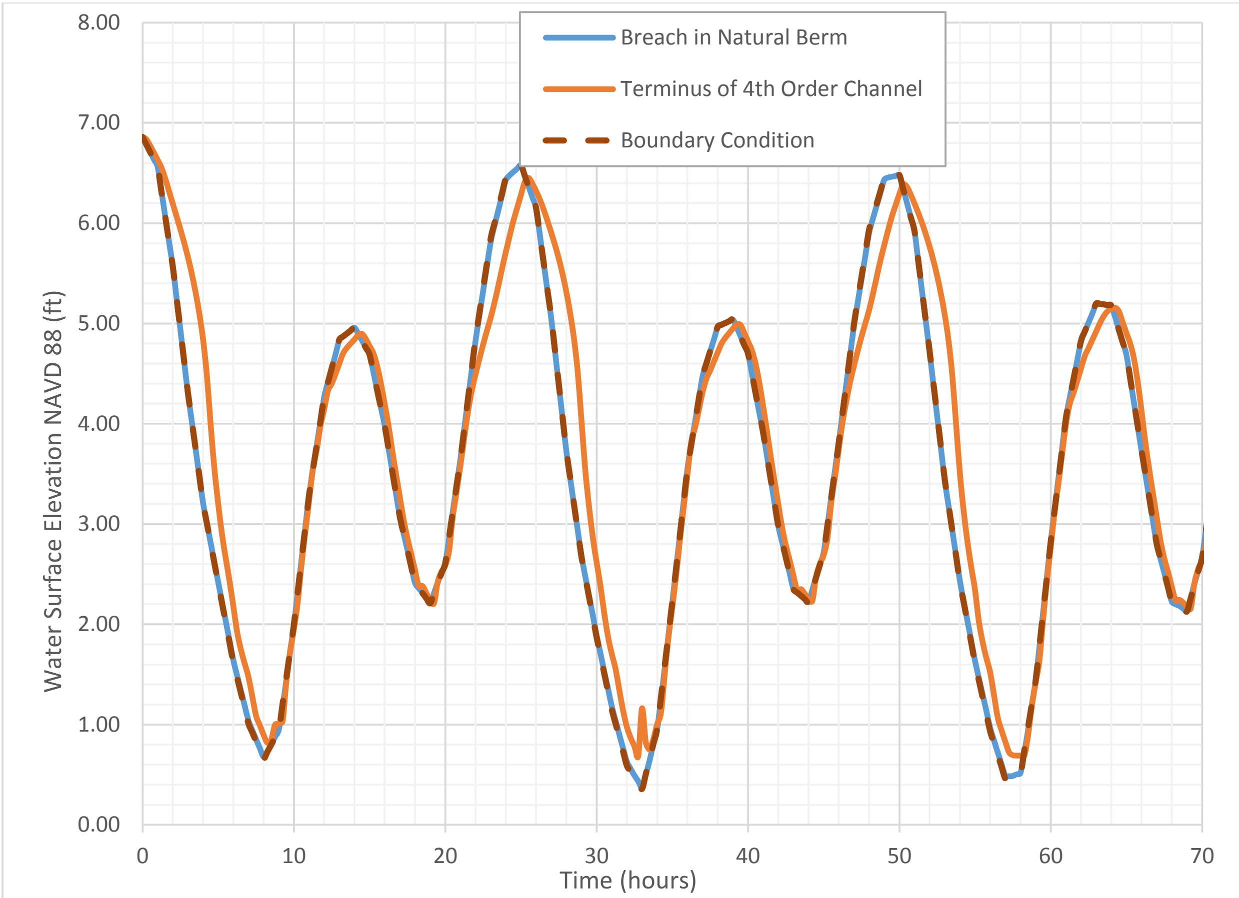


Figure 4.6: Computed water surface elevations in the 4th-order channel at the breach in the natural berm, and on the terminus of the 4th-order channel for the future condition model with spring tide boundary condition.

4.4 Channel Stability

Erosion occurs when shear stress exerted by a fluid over a channel surface exceeds the critical shear stress of the channel bed material. Tidal fluctuations flooding and draining the marsh are the driving forces of shear stress in a tidal marsh channels. As a response to this shear stress, bed material erodes from the channel bed and becomes entrained in the current. This causes the channel to become deeper with steeper side-slopes. Eventually, the channel's side-slopes will become unstable and will slough off into the channel, making the channel wider. Entrained sediment particles from the channel surface settle when their fall velocity is greater than the turbulent forces suspending the sediment particles, a process referred to as deposition. Hydraulic output from the ADH model was coupled with sediment properties to evaluate whether deposition or erosion were likely to occur in the constructed channels.

Hydraulic bed shear stress, τ, is computed as a product of water density, ρ (1.94 slug/ft^3), and the shear velocity, u_* (ft/s). Shear velocity can be computed as a function of depth-averaged velocity, *u* (ft/s), flow depth, *H* (ft), the constant acceleration due to gravity, *g* (32.2 ft/s^2), and skin roughness computed as a function of Manning's n value (0.020) and the Manning's constant, φ_n (1.486 for imperial units). The depth-averaged velocity and depth values were output from the ADH model.

$$\tau = \rho u_*^2$$

$$u_* = \sqrt{\frac{gn^2}{\varphi_n^2 H^{1/3}}}\,u$$

Shear stress and shear velocities computed with ADH were compared to critical shear stress and fall velocities of the typical marsh sediments. The Project marsh is composed of predominately silt with some sandy silt and clay present (Section 2.3). Warner et al (2004) used a critical shear stress for erosion of 0.001 psf (0.05 Pa) and settling velocity of 0.00015 ft/s (0.5 mm/s) for sediment in Grizzly Bay. These values are consistent with values typically used for non-cohesive silt particles. Inputting the fall velocity of the silt into the shear stress equation computes a critical shear stress for deposition of about $4.3(10^{-8})$ psf. Deposition is expected to occur if the shear velocity (a measure of turbulence intensity) is less than the fall velocity, or similarly if the hydraulic shear stress is less than $4.3(10^{-8})$ psf.

Figure 4.7 shows the hydraulic shear stress in the undersized section of the 4th-order channel near the breach through the natural ridge in the as-built conditions. The figure shows the hydraulic shear stress is frequently up to two orders of magnitude larger than the critical shear stress for erosion (0.001 psf) and is well above this value through much of the tidal cycle. Thus erosion is likely to occur. Since the channel is undersized relative to expected equilibrium channel size (Section 4.2), this result is reasonable and consistent with observations of tidal channel geometry in the region. Similarly, the hydraulic shear stress is rarely below the minimum shear stress where deposition is likely to occur. This indicates the entrance channel is unlikely to be depositional and will not fill in due to sediment deposition over time.

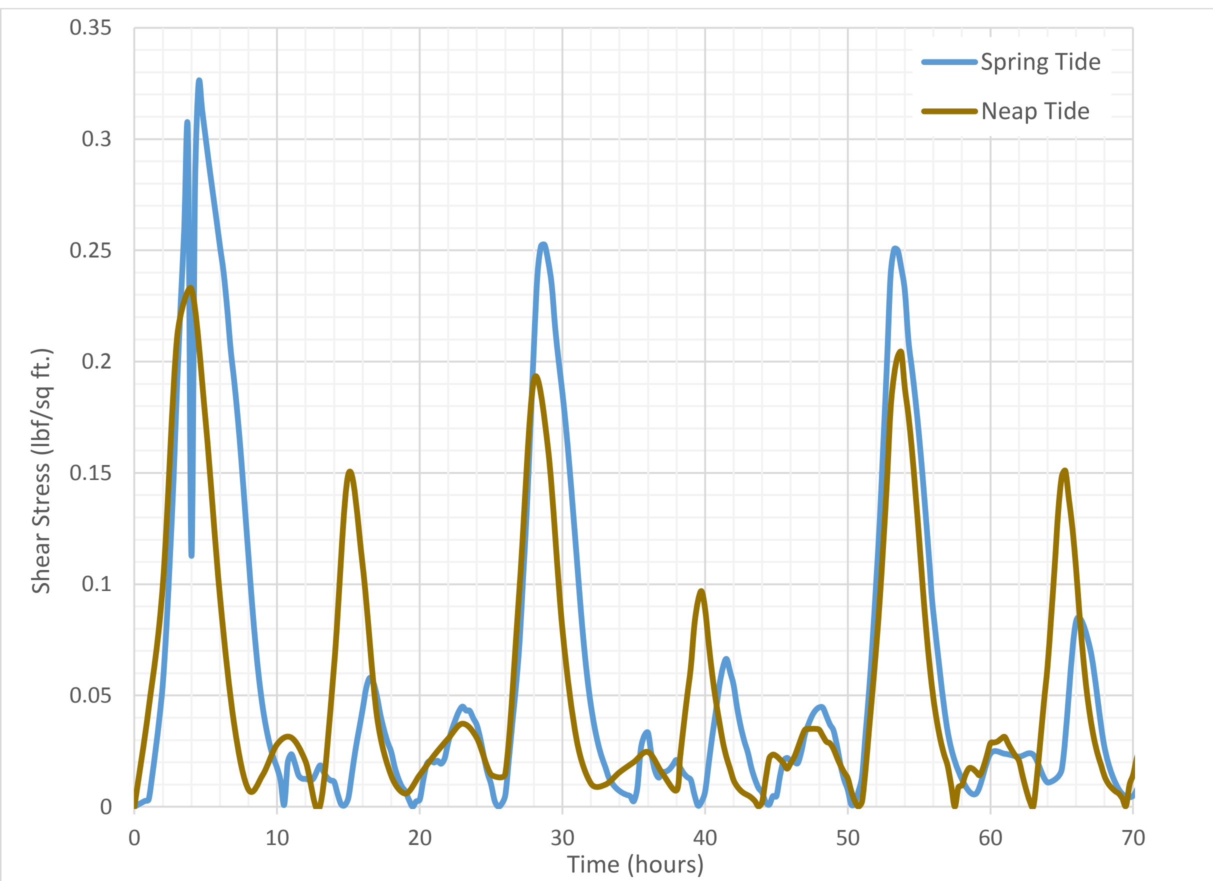


Figure 4.7: Shear stresses in the 4th order channel in under-excavated section near breach through natural marsh ridge. Note the first 10 hours are during the model warm-up.

Figure 4.8 shows the hydraulic shear stress at a point in in the 4th order channel near the center of the marsh. Unlike the section of channel at the marsh entrance, this section of channel was excavated to the expected full equilibrium size. Shear stress values are reduced from those computed for the entrance channel, however the shear stress is still greater than the critical shear stress for erosion for much of the duration of both spring and neap tide cycles. The computed shear stress is also much greater than the critical shear stress for deposition, indication the possibility of slight erosional adjustments of channel dimensions, and that this location will not experience significant depositional processes as well.

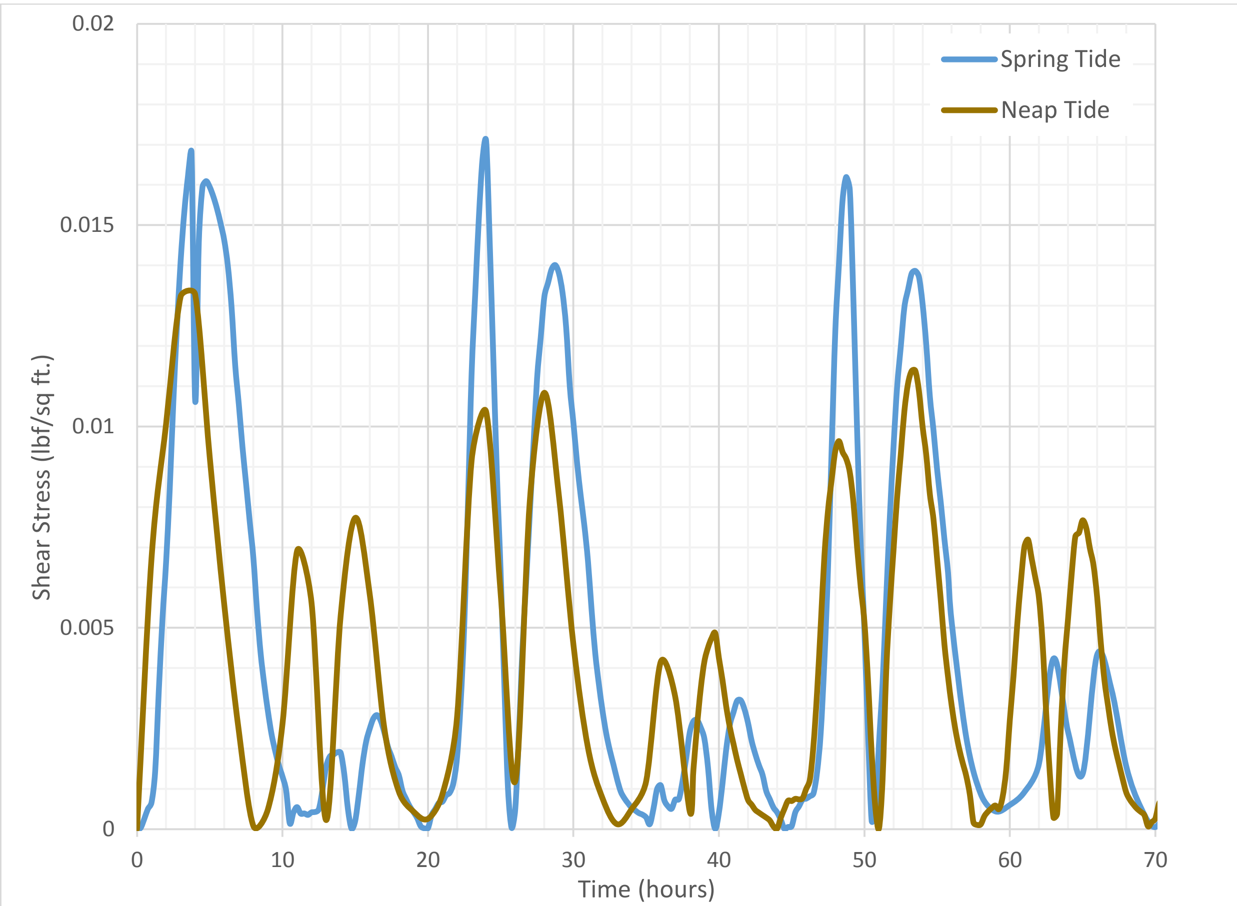


Figure 4.8: Shear stresses in the 4th order channel in a fully-excavated section of channel about halfway through the project site. Note the first 10 hours are during the model warm-up.

Figure 4.9 shows the hydraulic shear stress at point in the 4th order channel near its terminus on the eastern extent. The shear stresses are reduced relative to the previous two plots. The plot shows the shear stresses in the channel greater than or near the critical shear stress for erosion through the majority of the duration of the spring tide and neap tide simulations. The shear stresses do not fall below the threshold where deposition is expected to occur, indicating the channel is likely stable in its existing shape.

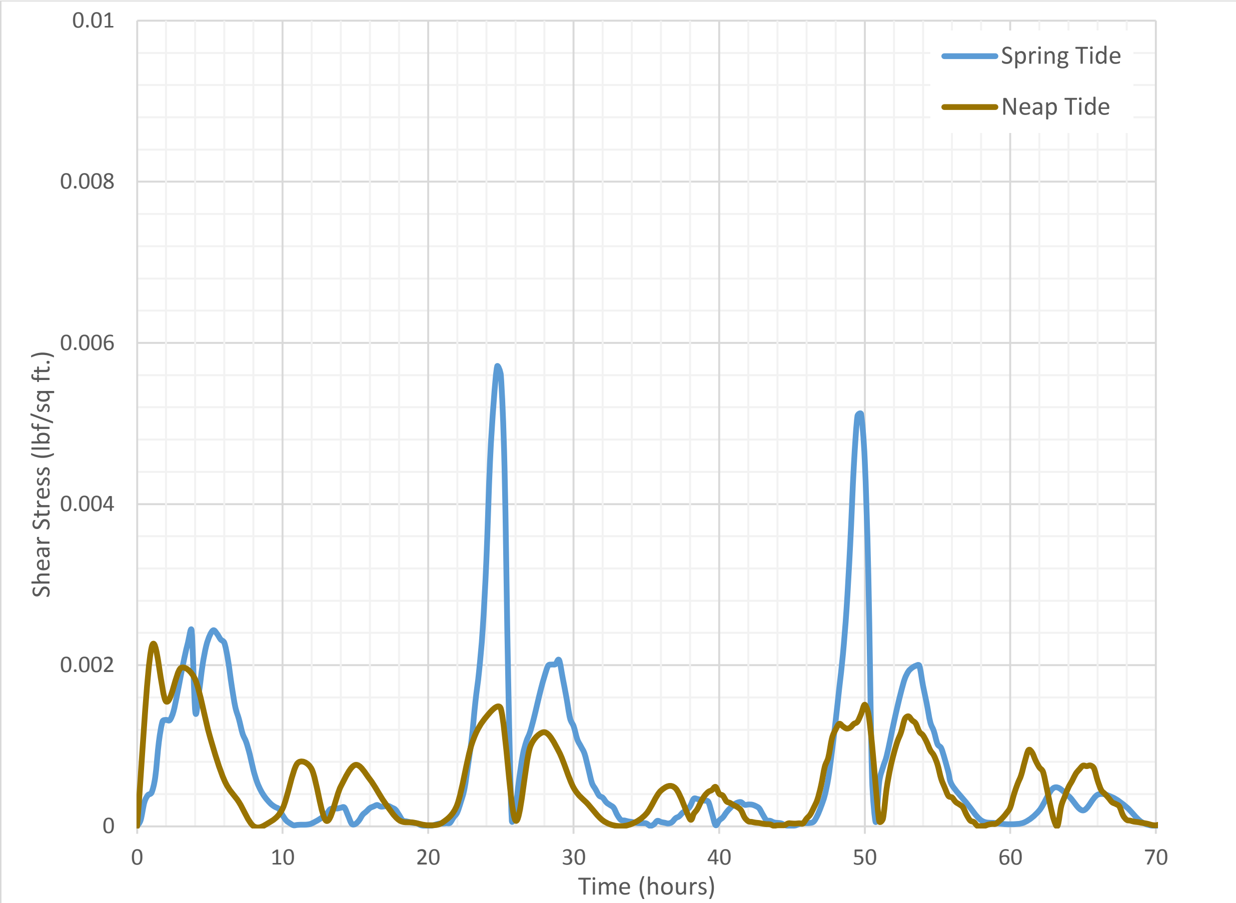


Figure 4.9: Shear stresses in the 4th order channel in a fully-excavated section of channel near the southern terminus of the 4th-order channel. Note the first 10 hours are during the model warm-up.

Computed shear stresses in the lower order channels were also computed. The shear stresses were generally less than the critical shear stress for erosion. On average, the channels were depositional about 20% of the duration during as-built conditions, and about 5% of the duration during the future conditions model. This indicates the channels may be slightly oversized and experience minor sediment deposition. Adjusting the durations used in the suspended sediment deposition calculations (Section 5.4), the channels may see between about 0.6 inches of deposition per year under as-built conditions, and about 0.2 inches per year in the future condition upon establishment of full tidal exchange through the breach entrance channel. More discussion on the potential for channel adjustment and evolution of these channels is discussed in Section 4.6.

4.5 Evolution of the Under-excavated 4th-Order Channel Section

The final section of the 4th order channel connecting the Project site to Grizzly Bay will not be constructed to full equilibrium width or depth. This final section of channel will be intentionally undersized for constructability concerns discussed in Section 5.1. The constructed channel will have a top width of 50 feet (relative to the equilibrium width of 160 feet) and only be constructed to a depth of 7 feet below the existing marsh plain (equilibrium depth is 10 feet below the marsh plain elevation). The mud flat outside of the channel will also not be excavated to initially provide a subtidal mud flat channel. Instead, the entrance to the marsh will naturally develop its final channel width and depth over time. This section provides analysis and discussion on the length of time expected before the channel reaches equilibrium.

The total mass of sediment per foot of channel was estimated by comparing the excavated and equilibrium channel cross-sections. The proposed channel area is about 250 square feet, or about 18% of the expected equilibrium channel area of 1400 square feet. Reported dry bulk densities in the region range from about 30 pcf for loosely deposited sediment on Browns Island (Ganju et al 2005) to 40 pcf for surface deposits in Grizzly Bay (Warner et al 2004). The deposits on the Project Site are mineral deposits which have settled and compacted over time and are expected to have a bulk density between about 80 pcf to 100 pcf. It is expected that about 18,000 to 23,000 tons of sediment will be eroded from the constructed channel margins through natural processes for the entrance and 4th order channel to reach its equilibrium width.

Erosion rate, E (lb/ft^2/s), is often estimated as a product of the excess shear and erosion rate constant, M (lb/ft^2/s). The excess shear is the difference between the applied shear stress and the critical shear strength, normalized by the critical shear strength.

$$E = M\left(\frac{\tau - \tau_{cr}}{\tau_{cr}}\right), \text{ for } \tau > \tau_{cr}$$

A range of erosion rate values are published based on studies in the San Francisco Bay area (Odell et al., 2008). These values range from $6(10^{-7})$ lb/ft^2/s to $1(10^{-3})$ lb/ft^2/s. Odell et al (2008) determined a value of $6(10^{-6})$ lb/ft^2/s, while Warner et al (2004) used a value of $1.8(10^{-5})$ lb/ft^2/s in Grizzly Bay, approximately twice the value identified by Odell et al. Many of the values reported in Odell et al (2008) were derived from studies in the salt marshes of San Francisco Bay which have highly cohesive and consolidated marsh soils. The Warner et al (2004) value is higher and likely indicative of the different non-cohesive and lesser consolidated materials in Grizzly Bay. It is also understood some uncertainty exists in the critical shear stress and applied shear stress for cohesive sediment transport calculations (Mehta and McAnally, 2008).

A Monte Carlo approach was used to account for the range of uncertainties in the bulk density, critical shear stress, computed shear stress, and erosion rate constant. The Monte Carlo simulation used hydraulic output from the spring and neap tide calculations. Since the computed shear stress is a function of the Manning's n value, a Manning's n value was randomly chosen from a normal distribution centered on a value of 0.02 with a standard deviation of 0.003 to compute shear stress. A temporally averaged shear stress value was computed from this time series and averaged with the chosen critical shear strength. This assumes the average shear stress at equilibrium is equivalent to the critical shear stress, and provides an average applied shear stress over the period of evolution from as-built to final channel equilibrium. The critical shear strength was chosen randomly from a normal distribution centered on a value of 0.001 psf with a standard deviation of 0.0005 psf. These values were paired with an erosion rate constant randomly chosen from a normal distribution centered on $1.8(10^{-5})$ lb/ft^2/s with standard deviation of 0.5 (10^{-5}) lb/ft^2/s to determine an average erosion rate. The total mass of material to be eroded was computed by randomly selecting a bulk density from normal distribution centered on 90 pcf with a standard deviation of 5 pcf. The total mass to be eroded was divided by the erosion rate to determine a duration to equilibrium. This analysis was repeated 10,000 times to produce a data set of durations.

The analysis was run for various active channel widths. As the channel widens, the area of channel available for erosion increases. Although the analysis assumes sediment availability for erosion, the availability of sediment may be somewhat episodic as it relies on geotechnical failures such as sloughing and bank failure to widen the channel. The results of the Monte Carlo simulation were more sensitive to channel width than to changes in critical shear stress and applied shear stresses. Table 4.2 shows the durations to equilibrium using the averaged shear stresses from the as-built model runs for three bottom widths. The most representative column is the bottom width=70 feet, when then the channel area is about halfway developed, and the averaged applied shear stress is likely most representative.

Table 4.2: Results of the Monte Carlo simulation with varying channel bottom widths to determine the number of years required for the breach through the natural marsh berm to reach equilibrium.

Statistical Probability	Bottom Width=22 feet (as-built)	Bottom Width=70 feet	Bottom Width=120 feet (Expected Equilibrium)
95% Exceedance	1.0 years	0.3 years	0.2 years
Median	3.9 years	1.4 years	0.7 years
5% Exceedance	9.6 years	3.5 years	1.8 years

The Sonoma Baylands Marsh Restoration project was a similar project with an initial undersized connection to San Pablo Bay. Figure 4.10 shows the change in channel area over time after construction. The initial points on the figure were published monitoring data from PWA (2003). The final point on the graph was measured from air photos. The Sonoma Baylands project channel was cut through old, consolidated and stiff cohesive clay deposits and did not immediately provide full tidal inundation to the site. The data suggests that the erosion rate increased as the channel area increased. The increase in channel area increased the availability of channel area for erosion, as well as increased tidal flux into the site. The Sonoma Baylands project appears to have taken about 13 years to reach channel equilibrium.

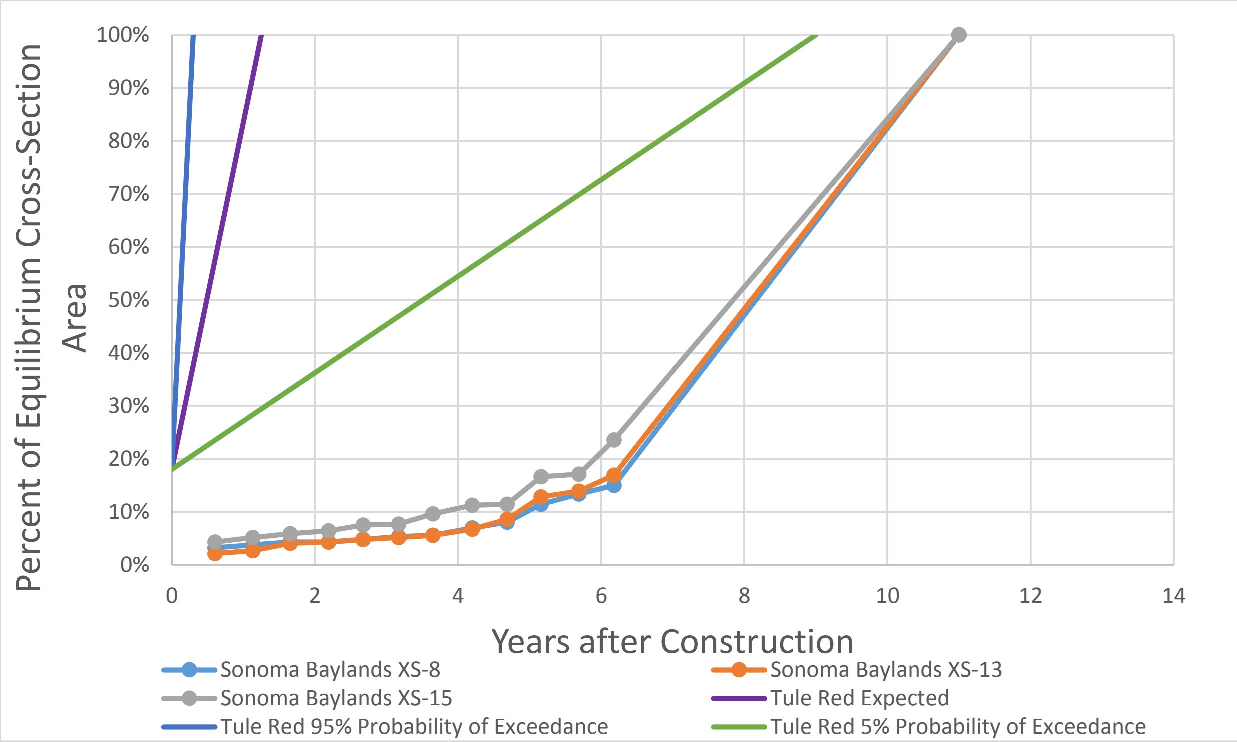


Figure 4.10: Comparison of channel evolution rates to Sonoma Baylands Project.

4.6 Tidal Channel Network Development

ADH models were run to evaluate if the tidal channel network could naturally develop. D'Alpaos et al (2007) showed that results from two-dimensional depth-averaged hydrodynamic models could be used to simulate growth of the low order channels. D'Alpaos et al (2007) used the friction slope, S_f, across the edge of the channel to determine the hydraulic shear stress. The friction slope was computed using the difference in water surface elevations in the marsh plain and channel over a distance of about 20 feet. The depth is the average depth between the marsh plain and channel.

$$\tau = \gamma H S_f$$

The shear stresses were used to compute erosion rates using similar procedures as those described in Section 4.5. Shear stresses are significantly higher than the critical shear strength. However, the duration under which the shear stress occurs is limited to the short duration when the marsh is inundated. The limited duration limits the channel extension lengths to only about 3-10 feet per year. This value also assumes vegetation does not develop at the eroding edge of the channel. Based on the elevations within the marsh, vegetation typical of low marsh habitat is expected to develop around the channel margins. The reed type vegetation (phragmites and tule) can increase the critical shear stress of the marsh plain sediments and inhibit channel growth.

Table 4.3 shows the computed channel growth lengths (increase in channel length) per year relative to other values reported in literature. As the undersized 4th-order channel evolves, the tidal flux and amount of flow passing through the lower order channels increases and increases the erosion rate. Wallace et al. (2005) evaluated channel growth rates in the Tijuana estuary. The site was less vegetated than the Project site. Similarly, D'Alpaos et al (2007) study site was in an Italian estuary with similar tide ranges to the Project site, but in coarser soil with different vegetation. The low order channels are expected to develop across about 1,000 feet of marsh. The rates shown in the Table 4.3 would require about 30 to 100 years for the lower order channel extension to occur and the marsh channel network to fully develop.

Table 4.3: Expected rate of increase in low order channel length

Increase in Channel Length (ft/yr)			
As-Built Geometry	Final Geometry	Wallace et al. (2005)	D'Alpaos et al. (2007)
3	10	4-20	10-54

4.7 Residence Time and Water Balance

The large ponds on the southern edge of the site are intended to increase the overall residence time of the site. The ponds are to be surrounded by a constructed marsh ridge with a top elevation of 5.5 feet. The marsh ridge will disconnect the ponds from the marsh when tidal elevations are less than MHW. The ridge retains water in the ponds during low tides, and limits the volume of water exchanged between the ponds and surrounding marsh during higher tides. A simple reactor based model assuming full mixing in the ponds was used to evaluate the residence times in the ponds, to ensure the ponds did not dry resulting in stranding of fish, and to ensure the pond habitat did not become hyper-saline.

The residence time for effluent leaving the ponds is based on average residence time weighted by volume for the impounded water. The relationship below shows the average residence time of water in the pond, T, at timestep i, as a function of the pond volume at the previous timestep, V_{i-1}, and pond volume at the current timestep, V_i. Pond volume lost to evaporation, E, and infiltration, I, was accounted for using constant rates. The volume of new flow coming into the pond during high tides, ΔV, was computed using a stage-volume curve for the ponds and assuming full tidal exchange on the site. For residence time calculations, negative ΔV values were set to be zero. Figure 4.11 provides water levels in the pond relative to the boundary condition computed with the ADH models.

$$T_i = \frac{(V_{i-1} - E\Delta t - I\Delta t)(T_{i-1} + \Delta t) + \Delta V\left(\frac{\Delta t}{2}\right)}{V_i}$$

$$V_i = V_{i-1} - E\Delta t - I\Delta t + \Delta V$$

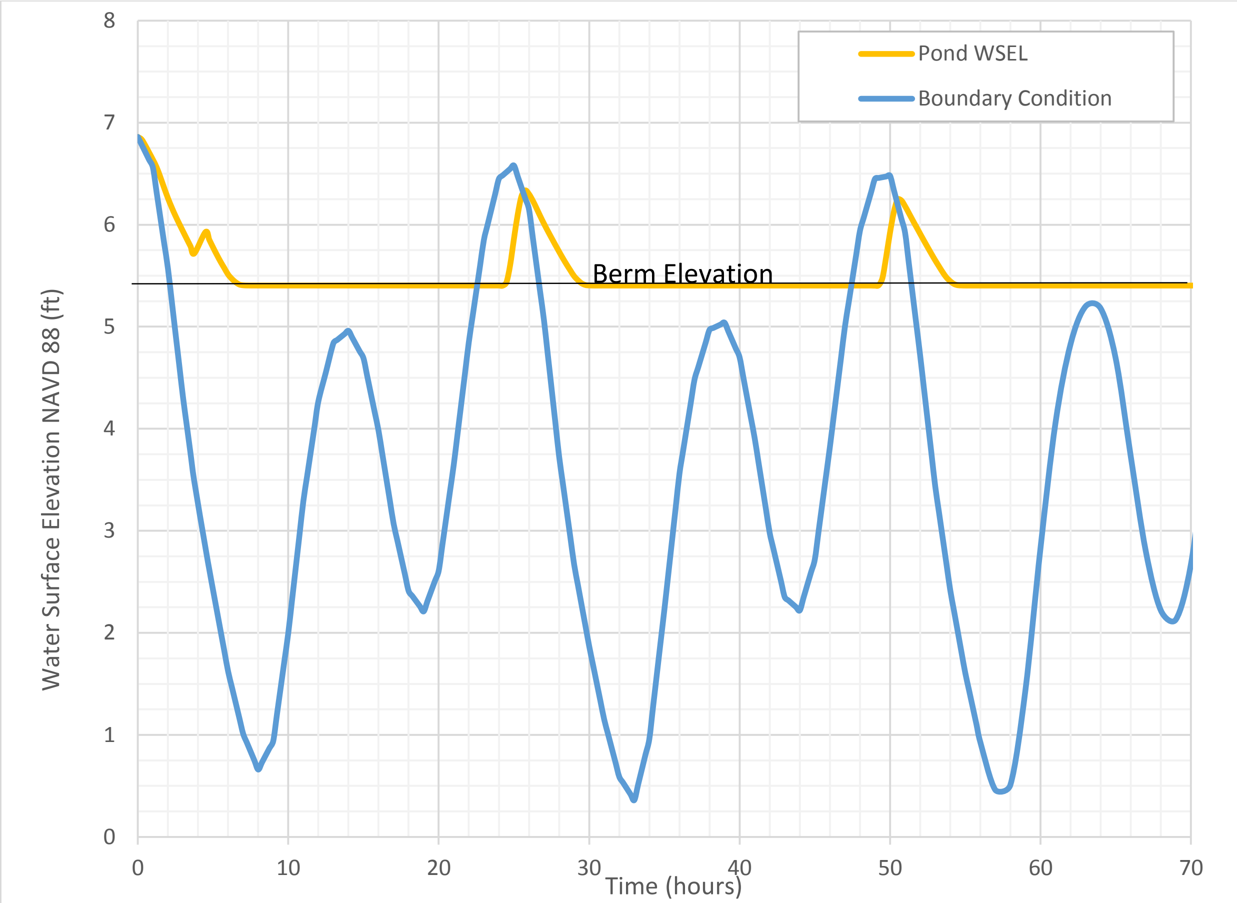


Figure 4.11: ADH computed water surface elevation within the ponds during spring tide simulation with as-built geometry.

Evaporation was accounted for assuming a constant value of 0.0008 ft/hr. This value was the peak seasonal value from Lionberger et al (2004). Lionberger (2004) also noted that infiltration becomes negligible in mature marsh ponds as the pore spaces in the pond bottom becomes clogged with microbial slimes and colloidal soil materials. This is expected to occur within the first few months after final construction is complete. Infiltration was accounted for using Darcy's law assuming a hydraulic conductivity value of 1.1 ft/hour, and by computing the head difference between the pond and the nearby marsh. The hydraulic conductivity value is indicative of clean silts.

Figure 4.12 shows the average residence time for the ponds over a simulation period from January 1, 2013 to December 31, 2014. The residence times were computed using observed hourly water surface elevations from the NOAA Port Chicago gage. The residence time of zooplankton growing in the ponds is assumed to be equivalent to the residence time of water in the ponds. Since zooplankton doesn't evaporate, nor is it expected to be lost due to infiltration, Figure 4.12 also shows residence time for simulations which don't account for evaporation or infiltration.

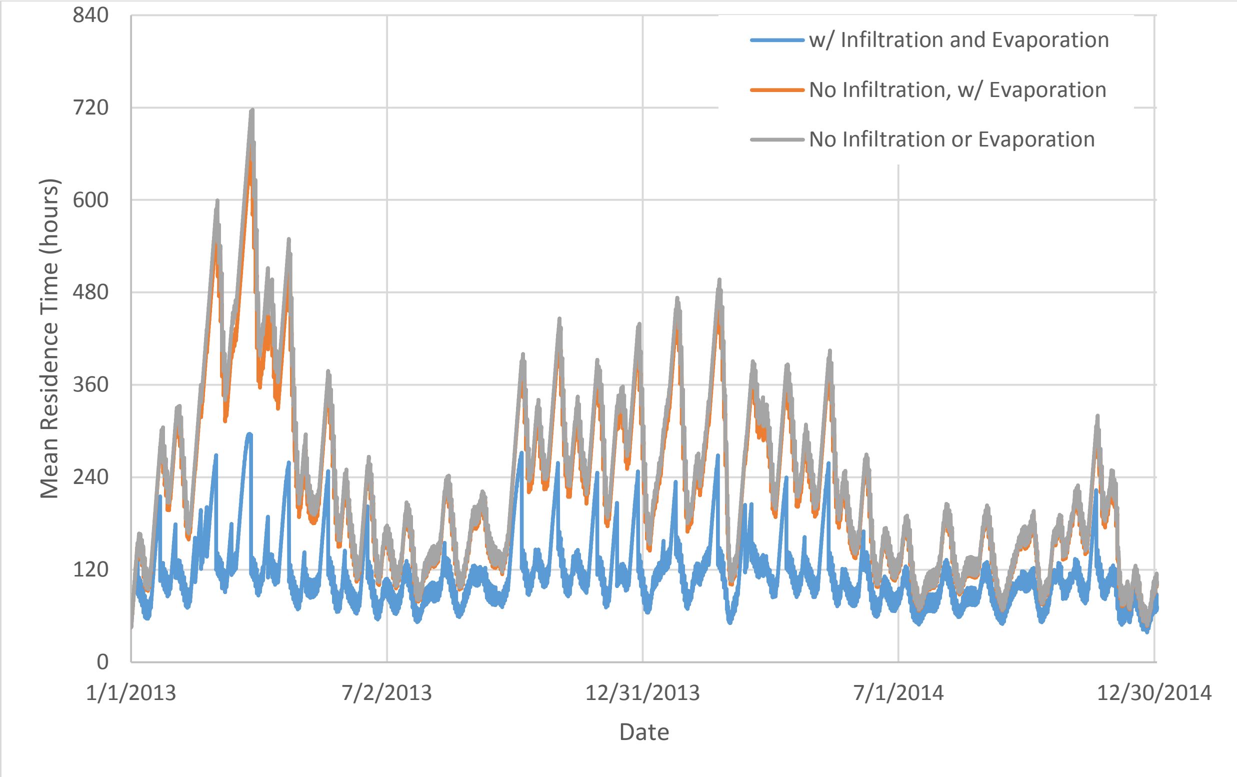


Figure 4.12: Mean residence time in ponds surrounded by marsh ridge

Table 4.4 compares the results of the three lines above. When infiltration is included, the median residence time is only about 4 days. The median residence time will almost double as the ponds age and infiltration (seepage losses) becomes negligible. The median residence time of zooplankton (excluding evaporation and infiltration) is about 9.5 days. Residence time in the ponds will generally be between 4 and 20 days.

Table 4.4: Distribution of residence times in ponds

Residence Time	Including Evaporation and Infiltration	No Infiltration	No Evaporation or Infiltration
Minimum	38 hours	45 hours	45 hours
5 Percentile	63 hours	91 hours	93 hours
Median	105 hours	202 hours	211 hours
95 Percentile	210 hours	430 hours	466 hours
Max	297 hours	677 hours	717 hours

The model assumed full mixing within the pond (i.e. no stratification). The ponds will be about 3.5 feet deep, with isolated areas up to 5.5 feet deep as measured from the surrounding marsh ridge. The windy conditions and daily temperature variation is expected to keep the relatively shallow pond well-mixed. Analysis of a two-year period from January 1, 2013 to December 31, 2014 showed the minimum depth in the ponds reached was 0.6 feet above the raised sections of pond, and 2.6 feet over the deep sections of pond. The median depth over the simulation period was 3.2 feet, with 5% and 95% exceedance values of 4 feet and 1.5 feet, respectively.

Salinity was evaluated in the ponds using results of the residence time analysis. The concentration of salinity in the pond, *C*, was computed as a volumetric weighted average. Loss of volume in the ponds due to evaporation and infiltration were accounted for as discussed above. Infiltration was assumed to have no impact on salinity, as salt would stay in solution during the infiltration process. However, evaporation was assumed to increase the salinity of the ponds. A constant concentration for salinity was assumed for Grizzly Bay, C_0. Figure 4.13 shows the salinity in the pond relative to this reference concentration.

$$C_i = \frac{(C_{i-1}V_{i-1}) + (C_0 \Delta V)}{V_i}$$

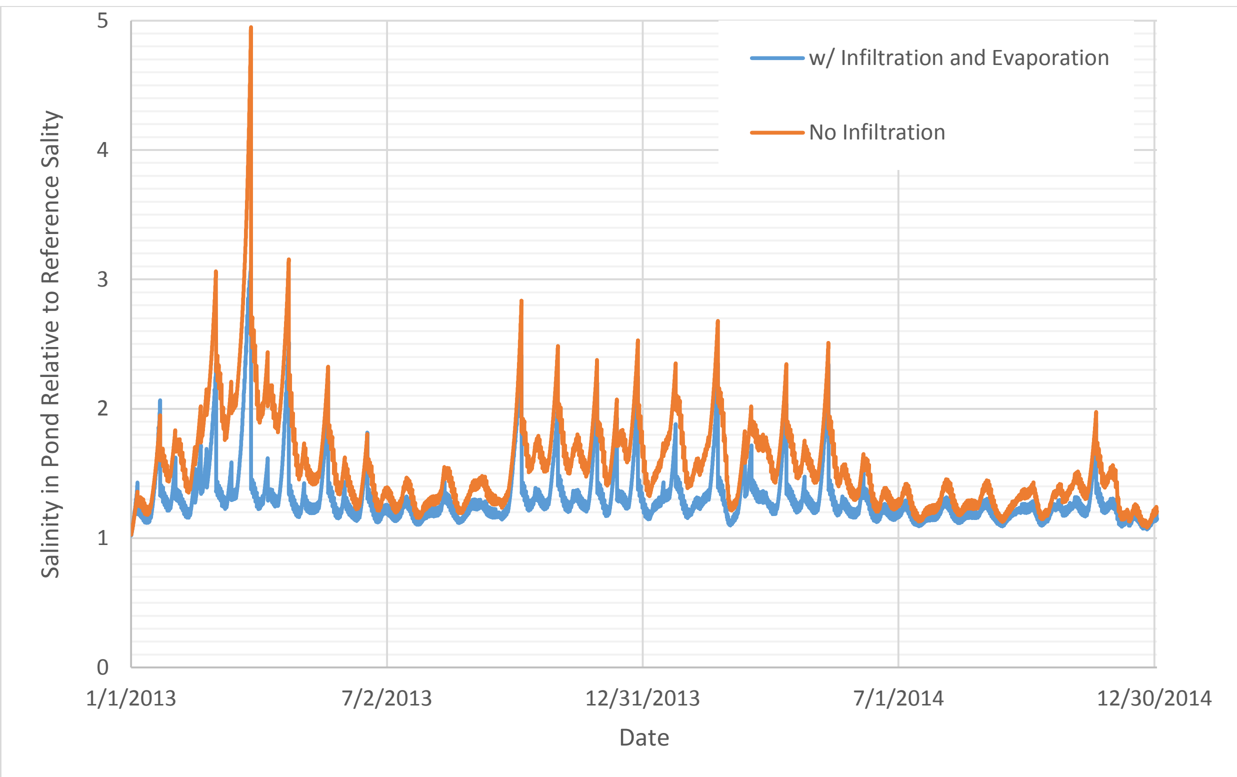


Figure 4.13: Salinity in ponds

Figure 4.13 shows salinity in the ponds is expected to be higher than that of the rest of the marsh and Grizzly Bay. The increase in salinity will be about 1.5 to 2 times that of Grizzly Bay, with occasional short durations above 3 times the Grizzly Bay salinity. The mixing of new tide water on high tides lowers the salinity in the ponds. The ponds are not expected to become hyper-saline due to this mixing.

5.0 PROJECT IMPLEMENTATION

5.1 Overview

The project will be implemented in two construction phases. The first construction phase is planned to be completed in the summer of 2016. The first phase will include excavation of the lower order channels, the habitat berm, the marsh ridge, ponds, and most of the 4th-order channel. The final 300 feet of the 4th-order channel connecting the project site to Grizzly Bay will not be excavated. Connection to the existing tide gates will be maintained to allow management of water on the site. After construction, disturbed areas of the site will be revegetated.

The second and final phase of the construction is planned to be completed in the summer of 2018 once the vegetation onsite has established. The second phase of the construction will remove both of the existing tide gates. The habitat berm in these areas will be filled to disconnect the drainage through these existing channels. The final 300 feet of the 4th-order channel will be constructed to connect the Project site to Grizzly Bay. The existing club house will be removed from the property, and the restored tidal processes will allow the site to continue to evolve naturally over time.

The project will require the excavation of about 345,000 cubic yards of soil. Of this, 315,000 cubic yards will be placed as fill to form the habitat berms and marsh ridge. The rest of the excavated soil will be side cast across the site. The project will permanently impact (through either excavation of fill placement) about 145 acres of the approximately 420 acre site.

5.2 Phase 1 Construction

The phase 1 construction will initiate early in the summer of 2016. The site will be managed to begin drying the site early in the spring. Dewatering with existing tide gates, then grubbing and stripping will be completed as the site becomes dry enough to support these activities. Earthwork activities will commence as grubbing and stripping is completed. Excavated material from the 4th-order channels and ponds will be used to construct the habitat berm and new marsh ridges. Excavated material from the lower order channels will be sidecast and shaped to help create topographic diversity on the marsh plain surface, and reduce impacts from dirt hauling across the marsh plain. As excavation is completed, impacted areas will be revegetated with appropriate native marsh species.

The fourth-order channel and ponds are expected to be excavated using wheeled tractors pulling wheeled scrapers. The scrapers will place the excavated material in 3-foot lifts within the footprint of the proposed habitat berm and marsh ridge. The 3-foot lifts were recommended in the Project geotechnical investigation (Hultgren-Tillis Engineers, 2014). Finishing work on the channels and excavation of the lower order channels will be completed with tracked excavators. Habitat berms and marsh ridges will be placed assuming 0.25 feet of settlement for every vertical foot of fill placed based on recommendations in the geotechnical recommendation (Hultgrin-Tullis, 2014).

The test pits in the geotechnical investigation found groundwater at approximately elevation zero NAVD88 near the northern edge of the site, and did not find groundwater in the 9 foot deep test pits along the proposed 4th-order channel alignment in the center of the site. Excavation will be kept at -2 feet and above to reduce wet excavation. The excavation will likely occur in sections to allow control of ground water within the excavated areas. Wet excavated material will be disked and dried in the footprint of the proposed habitat berm as necessary during placement. If excavated areas require draining or dewatering, the areas will be drained using pumps to direct the water onto the existing marsh plain to allow for natural infiltration away from Grizzly Bay.

The existing tide gates will be kept through the Phase 1 construction to allow drainage of potential high tides from the site. After earthwork activities are complete, the tide gates will be used to manage inundation on the site to assist with the establishment of vegetation. The on-site caretaker will continue to manage the site and maintain conditions to help promote the desired vegetation growth and establishment.

5.3 Phase 2 Construction

Phase 2 of the construction is planned to occur in the summer of 2018. Phase 2 construction will include limited earthwork onsite to account for differential settlement issues. Excavators will be used to close the connections to the existing tide gates, and the tidal gates will be removed. Large specialty marsh excavators will be required to excavate the connection of the 4^{th}-order channel to Grizzly Bay. The wet material will be side cast over the existing vegetation. The final connection will be constructed over a final low tide from the marsh out to the Grizzly Bay, with the final connection at low tide to prevent excavation in flowing water. The low tide condition will allow loose material left from the excavation to be pushed onsite during the flood tide.

5.4 Tidal Marsh Sustainability

Sustainability of tidal marshes relies on marsh accretion processes (both mineral and organic) keeping balance with sea level rise. Mineral accretion on the marsh plain requires a sustainable source of sediment and a process to bring the sediment to mash site. Warner et al (2004) provides a discussion of the processes which bring sediment into Grizzly Bay and sources of sediment. The asymmetric tidal forcing is a function of the shallow embayment being located next to the deep Suisun Bay, and the tidal regime. The floodtide pulses push sediment suspended in San Pablo and Suisun Bay back into Grizzly Bay and the Project site. The results of this process are evident in the historic ongoing shoreline accretion at this site.

The source of sediment in Suisun and San Pablo Bay is the Sacramento River Delta. Shvidchenko et al (2004) showed over 80% of the sediment inflow into the Sacramento River Delta comes for the Sacramento River watershed. Sediment yield in the Sacramento River watershed has significantly declined over the past 150 years due to the end of hydraulic mining, and due to installation of large dams throughout the watershed. NHC (2012) showed that over the past 30 years, the sediment yield out of the Sacramento River watershed has been relatively consistent, showing the watershed has adapted to these previous changes. The sediment delivery and ongoing processes currently depositing sediment along the Project shoreline are likely to continue until another large scale adjustment occurs within the Sacramento River watershed.

About 25% of the total sediment transported from the Delta through Carquinez Straights deposits in San Pablo Bay (Wegen and Jaffe, 2013). Estimated sediment loads from the Delta vary from 1 million to 2 million tons per year (Shvidchenko et al., 2004; Wright and Schoelhammer, 2004). The total mass of sediment required for mineral sediment accretion rates to match expected sea level rise rates over the next 100 years is about 2.25 million tons (3 feet of sediment overlaying a 400 acre site with 80 pcf dry bulk density). This value is less than 2.5% of the total sediment delivered to the San Francisco Bay through the delta, and less than 10% of the total sediment expected to deposit in San Pablo Bay. This conservative estimate neglects the additional bio-accretion processes that will occur on the Project site.

Krone (1987) identified the physical processes that control marsh plain accretion are dynamic, and the accretion rate is a function of the marsh plain elevation and inflowing sediment concentration. Sediment accretion occurs as suspended sediment is carried on-site during flood tides. As flows inundate the marsh plain, the sediment falls out of the water column accumulating on the marsh plain. Higher marsh elevations are inundated for shorter durations, reducing the duration over which accretion may occur relative to accretion rates on lower marsh elevations. In addition to these mineral sediment accretion process, bio accretion of decaying marsh vegetation is an important marsh accretion process, as demonstrated by Deverel et al. (2014) that greatly supplements the accretion rate, especially for higher marsh plain elevations where vegetation productivity is higher.

Marsh accretion rates from suspended sediment can be computed using a simple mass balance between sediment deposition and marsh accretion. The mass balance requires an approximate known sediment concentration, C_*, of the inflowing flood tides, a sediment concentration on the marsh plain, C, a fall velocity representative of the suspended sediment, w_s, as well as the elevation of the marsh plan, Y_m, the elevation of the tide, Y, and time, t. Warner et al (2004) showed suspended sediment concentrations in Grizzly Bay between 50 to 400 ppm and reported a fall velocity of 0.00015 ft/s. Time averaged suspended sediment concentrations were on the order of 100 to 125 ppm.

$$(Y - Y_m)\frac{dC}{dt} = -w_s C + (C_* - C)$$

Table 5.1 shows accretion rates from suspended sediment deposition for marsh elevations relative to MSL for a range of sediment concentrations. The National Resource Council (NRC, 2012) provided updated sea level rise estimates for San Francisco Bay for the years 2030, 2050, and 2100 relative to the year 2000. Assuming average rates of sea level rise between these increments provides a bench mark for comparing marsh accretion rates. If marsh accretion is greater than the sea level rise rate, the marsh elevation will increase relative to MSL. If marsh accretion is less than sea level rise rate, the marsh elevation will decrease relative to MSL. However, lower marsh plain elevations have correspondingly higher mineral sediment accretion rates, providing opportunity for marsh plain surfaces to "catch up" with the sea level rise rate. The accretion rates shown in the Table 5.1 do not account for bio accretion components of tidal marsh accretion. Deverel et al (2014) indicated that bio accretion rates can be significant for supplementing mineral accretion rates in the Delta and Suisun Bay region.

Table 5.1: Marsh accretion rates from mineral sediments (neglects bio-accretion)

	Average Accretion Rate (in/yr)						**Average Rate of Sea Level Rise (inches/yr)**		
Marsh Elevation (feet above MSL)	**C*=50**	**C*=75**	**C*=100**	**C*=125**	**C*=200**	**C*=400**	**2000-2030**	**2030-2050**	**2050-2100**
0	0.54	0.81	1.08	1.35	2.16	4.31	0.19	0.27	0.50
0.5	0.42	0.63	0.84	1.05	1.68	3.35			
1	0.29	0.44	0.59	0.73	1.17	2.34			
1.5	0.17	0.26	0.34	0.43	0.69	1.37			
(MWH) 2	0.08	0.12	0.16	0.20	0.33	0.65			
(MHHW) 2.5	0.03	0.04	0.05	0.06	0.10	0.21			
3	0.00	0.01	0.01	0.01	0.02	0.04			

Comparison of the accretion rates to sea level rise in Table 5.1 show the rates are comparable. Generally, accretion rates exceed sea level rise at elevations between MSL and MHW. These marsh elevations may increase relative to MSL until the accretion rate matches the sea level rise. Marsh elevations above MHW may fall relative to the rising MSL until the marsh accretion rate matches the rate of sea level rise. The accretion rates and sea level rise rates are of similar magnitude indicating that changes in marsh habitat will occur relatively slowly (over a period of 100s of years). The marsh accretion values also do not include bio-accretion which is expected to be significant, especially at the higher marsh elevations where vegetation growth and productivity is higher. The addition of bio accretion to the calculations for mineral accretions described above indicates that marsh accretion from both mineral and biological processes in the Tule Red region would be expected to keep pace with sea level rise rates in the region.

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APPENDIX A: HISTORIC MAPS OF THE PROJECT SITE

WESTERVELT ECOLOGICAL SERVICES

nhc northwest hydraulic consultants

Legend

Project Area

DATA SOURCES:
California State Geological Survey Map, 1873.
Esri StreetMap, 2012.

SCALE - 1:36,000

0 1,000 2,000 3,000 *Feet*

N

Coordinate System:
NAD 1983 California State Plane Zone 2
Units: feet

Job: 5001024

Date: NOVEMBER 2015

FIGURE A1

Tule Red Tidal Restoration Project

Project Site
Located on 1890 Map

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WESTERVELT ECOLOGICAL SERVICES

nhc northwest hydraulic consultants

Legend

Project Area

DATA SOURCES:
USGS Topographic Map, Antioch, 1908.
NAIP Color Orthoimagery, 5/20/2012-5/22/2012.
Esri StreetMap, 2012.

SCALE - 1:36,000

0 1,000 2,000 3,000 Feet

N

Coordinate System:
NAD 1983 California State Plane Zone 2
Units: feet

Job: 5001024

Date: NOVEMBER 2015

FIGURE A2

Tule Red Tidal Restoration Project

Project Site Located on 1908 Map

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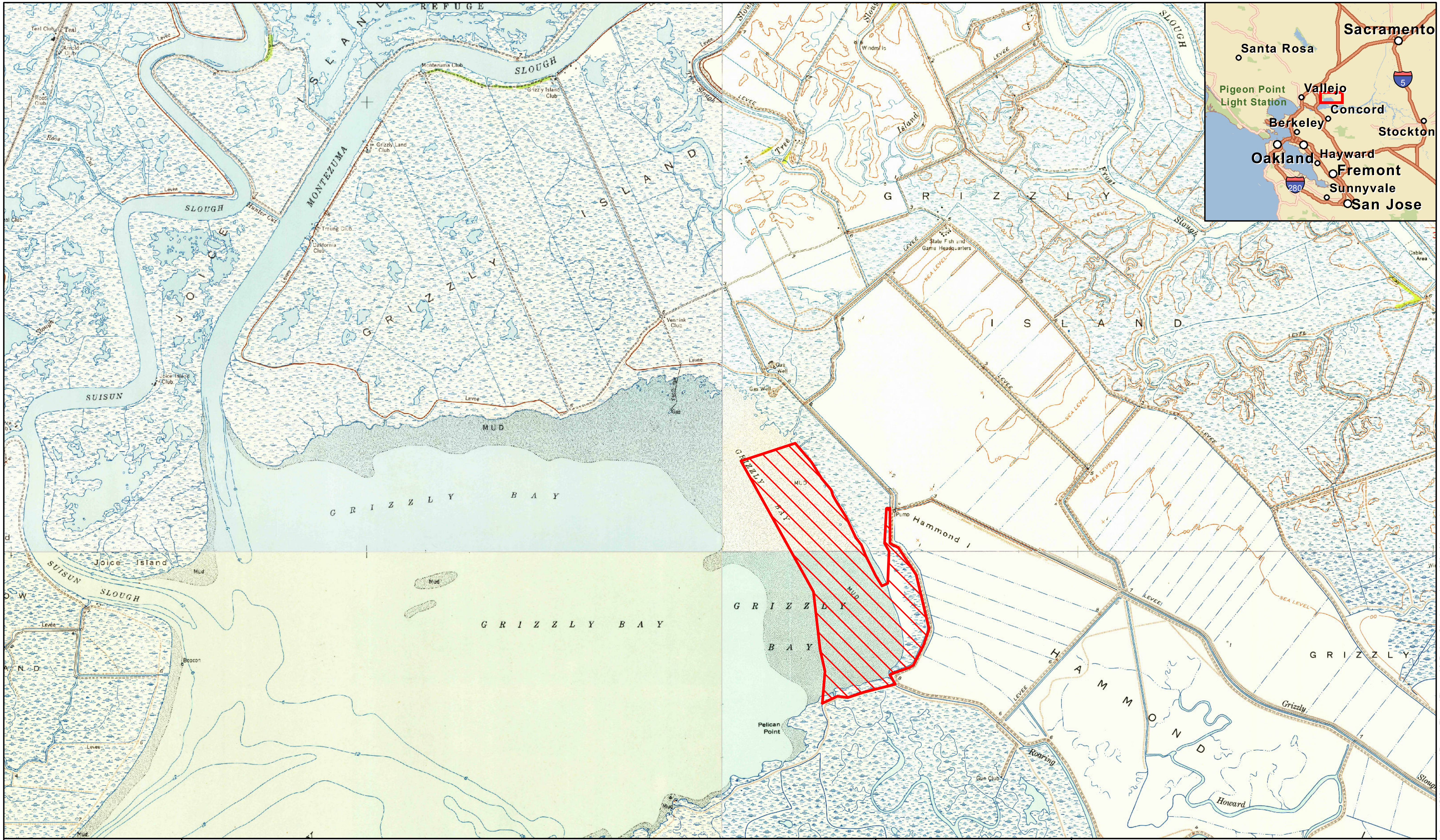

WESTERVELT ECOLOGICAL SERVICES

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Legend

Project Area

DATA SOURCES:
Esri StreetMap, 2012.
USGS 7.5 MinuteTopographic Maps:
Denverton, 1953; Fairfield South, 1949; Honker Bay, 1953; Port Chicago, 1951.

SCALE - 1:36,000

0 1,000 2,000 3,000 Feet

N

Coordinate System:
NAD 1983 California State Plane Zone 2
Units: feet

Job: 5001024

Date: NOVEMBER 2015

FIGURE A3

Tule Red Tidal Restoration Project

Project Site Located on 1949-1953 Maps

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APPENDIX B: COMPARISON OF ODELL ET AL (2008)

A site in Honker Bay, located to the south east of the Tule Red site, was chosen as a reasonable analog for comparing tidal channel characteristics proposed by Odell et al 2008 with tidal channels in the Suisun Bay and Marsh region. The site's proximity to the Tule Red site is shown in Figure B-1. The Honker Bay site is characterized by a single primary tidal channel that flows on the easterly edge of the marsh site. The shoreline of the Honker Bay site is also oriented to the in a north westerly to south easterly direction, and thus would be subject to similar wind and wind driven wave patterns as those seen at Tule Red. The Honker Bay site is also similar to the Tule Red site given the site is surrounded by human made berms for the adjacent managed marsh systems.

Figure B-1. Tule Red and Honker Bay site locations.

The Honker Bay tidal channels were digitized and their channel lengths, top of bank channel widths, and channel order were measured from digital orthophotos. The aerial photography was taken in 2014. The digitized channels, and a subset of their assigned channel order, are shown on Figure B-2.

Figure B-2. Digitized Honker Bay tidal channels and subset of channel ordering.

The digitized Honker Bay channel dimensions are compared with the channel dimensional guidance from Odell et al (2008) in Table B-1. In general, the dimensional characteristics of channel length and width between the Honker Bay site and the values obtained from relationships presented by Odell et al are reasonably consistent. The primary difference between Honker Bay characteristic and Odell et al guidance is in the bifurcation ratio, which is a measure of channel density on marsh plain surfaces. Odell et al's data was derived primarily from salt water marsh conditions, whereas Honker Bay is a brackish marsh. Channel density in brackish marsh systems is generally observed to be lower than the channel density of salt water marsh systems in the San Francisco Bay region so this difference is to be expected.

Table B-1. Comparison of tidal channel characteristics from those determined from Odell et al (2008) relationships to measured tidal channels at Honker Bay.

Parameter	Odell et al (2008)	Honker Bay Analog
Channel Order	4	4
Bifurcation Ratio	1st order – 3 - 5 2nd order – 3 - 6 3rd order – 2 - 10 4th order – 2 - 4	1st order – 1 - 3 2nd order – 2 - 3 3rd order – 2 - 4 4th order – 10
Channel Length	1st order – 3ft – 180 ft 2nd order – 60ft – 350 ft 3rd order – 150ft – 1,000ft 4th order – 300ft – 2,000ft	1st – 30ft – 120ft 2nd – 200ft – 380ft 3rd – 250ft – 430ft 4th order – 2,250ft
Main Channel Top width	40 ft	35 – 40 ft
Sinuosity	1 to 2	1.04
Channel Pattern	All	All