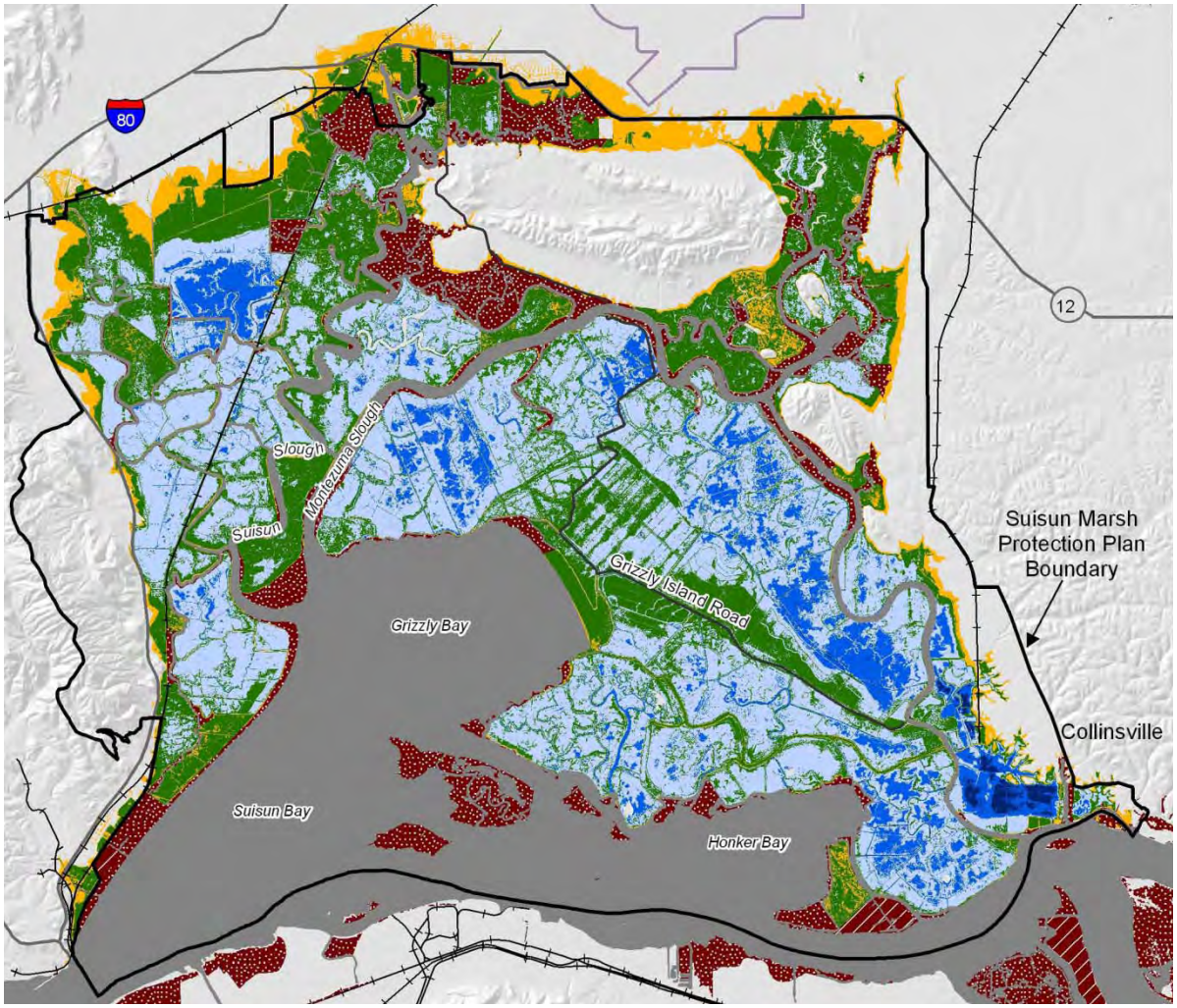
Suisun Marsh Conservation Assessment
Volume I: Characterization Report

September 2011



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WETLANDS AND WATER RESOURCES

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The Nature Conservancy, Delta Program

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Suisun Marsh Conservation Assessment
Volume I: Characterization Report

September 2011

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Suisun Marsh Conservation Assessment
Volume I: Characterization Report

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Suisun Marsh Conservation Assessment
Volume I: Characterization Report

1 Introduction

Suisun Marsh is the largest contiguous brackish water marsh remaining on the west coast of North America. It is a critical part of the San Francisco Bay-Delta estuary ecosystem. Encompassing just over 100,000 acres, the Suisun Marsh includes 52,000 acres of managed wetlands, 25,700 acres of tidal bays and sloughs, 7,700 acres of tidal marshlands, and 16,700 acres of uplands that comprise mostly lowland and hillside grasslands largely grazed, some agriculture, and some developed areas. It is home to public waterfowl hunting areas and 158 private duck clubs. The Marsh encompasses more than 10% of California's remaining natural wetlands and serves as the resting and feeding ground for thousands of waterfowl migrating on the Pacific Flyway. In addition, the Marsh provides essential habitat for more than 221 bird species, 45 animal species, 16 different reptilian and amphibian species, and more than 40 fish species. The Marsh supports 80% of the state's commercial salmon fishery by providing important tidal rearing areas for juvenile fish allowing them to grow twice as fast as those reared in the upper watershed, thus greatly enhancing their survival. The Marsh has two hundred and thirty miles of levees, some of which play an important role in managing saltwater intrusion into the Delta and helping to protect drinking water for 25 million people and agricultural water for 3 million acres south of the Delta. The Marsh's large open space and proximity to vast urban areas makes it ideally suited for wildlife viewing, hiking, canoeing, and other recreation opportunities.

Large-scale tidal restoration has been proposed for Suisun Marsh for many years and is actively being called for in the Suisun Marsh Plan (SMP), the Bay Delta Conservation Plan (BDCP), Delta Vision, and the Delta Plan. The 2000 CALFED Record of Decision identified Suisun restoration in the 5,000 to 7,000 acre range. In 1999, the Baylands Habitat Goals Report recommended 17,000 to 22,000 acres. The SMP is calling for 5,000-7,000 acres (CALFED ROD target) and BDCP and the Delta Plan may call for greater acreage. This Characterization Report is to support The Nature Conservancy in preparing its Conservation Assessment, a necessary step for it to enter into the conservation efforts in Suisun.

This Suisun Marsh Characterization Report provides the foundation information regarding existing conditions, tidal restoration potential, and factors that influence existing conditions and restoration potential over the long term. The conservation context of this report is planning for tidal marsh and tidal aquatic restoration efforts in Suisun Marsh in an ecologically sound

manner that takes into account the range of natural resources important to conserve and the natural and anthropogenic forces acting on Suisun Marsh now and in the future.

The ultimate goals for tidal restoration in Suisun Marsh are to support native resident and migratory species and communities including rare and listed species and to re-establish natural processes that support other wetland ecosystem services such as food web productivity, flood attenuation, water quality enhancement, carbon sequestration, and recreation. Suisun Marsh has particular conservation value for native resident and anadromous fish and migratory and resident waterfowl, shorebirds, and waterbirds.

The very broad concept of tidal restoration in Suisun Marsh is to reconnect former tidelands with the tides through constructing levee breaches. Because much of the former tidal marshlands of Suisun have subsided, restoration sites must rebuild topography through sediment accumulation and plant biomass accretion. Once the levee breaches are established, natural physical and biological processes will guide site evolution from those initial subsided conditions toward higher elevation tidal marsh. It is also possible to initiate subsidence reversal prior to restoring tidal action and promote it after restoration, such as through promoting tall emergent vegetation to maximize biomass accretion and sediment trapping.

This report draws upon information prepared primarily for the Suisun Marsh Plan, including its series of conceptual models and its October 2010 Draft EIR/EIS[1] (USBR et al. 2010).

This report is organized into the following chapters:

Chapter 1: Introduction
Chapter 2: Current Landscape and Waterscape Patterns
Chapter 3: Hydrology
Chapter 4: Geomorphology
Chapter 5: Water Quality
Chapter 6: Future Drivers of Change
Chapter 7: Vegetation
Chapter 8: Fish
Chapter 9: Birds
Chapter 10: Mammals, Amphibians, Reptiles, and Aquatic Invertebrates
Chapter 11: Other Ecosystem Functions
Chapter 12: Levee Integrity and Maintenance

[1] Available at http://www.usbr.gov/mp/nepa/nepa_projdetails.cfm?Project_ID=781

Chapter 13: Contaminants
References

Each of the four biological resources chapters describes distributions and assesses viability, threats, and possible responses to tidal restoration efforts.

Complimentary to this Characterization Report are two other reports: (1) Socio-economic Characterization of Suisun Landowners, to help guide working with landowners for land acquisition, and (2) Suisun Tidal Restoration Strategies, to identify specific restoration strategies to achieve the long-term goals.

2 Current Landscape and Waterscape Patterns

2.1 Setting within the San Francisco Bay-Delta Estuary

Suisun Marsh sits in the center of the San Francisco Bay-Delta Estuary, upstream of San Pablo Bay and downstream of the Sacramento-San-Joaquin River Delta (**Figure 1**). Tides reach Suisun Marsh through Carquinez Straits, an incised river channel drowned during Holocene sea level rise of the past 10,000 years. The southeast border of Suisun Marsh is the confluence of the Sacramento and San Joaquin rivers which drain California's Central Valley, about 40% of the State's land mass. Upstream of this confluence is the Delta, roughly 750,000 acres of diked, subsided lands supporting a broad array of agriculture. In Suisun Marsh and Bay is where the freshwater outflows of the Central Valley meet the tides, resulting in brackish salinity with strong salinity gradients and high seasonal variability, complex patterns of flow interactions, and generally the highest biomass productivity within the entire estuary.

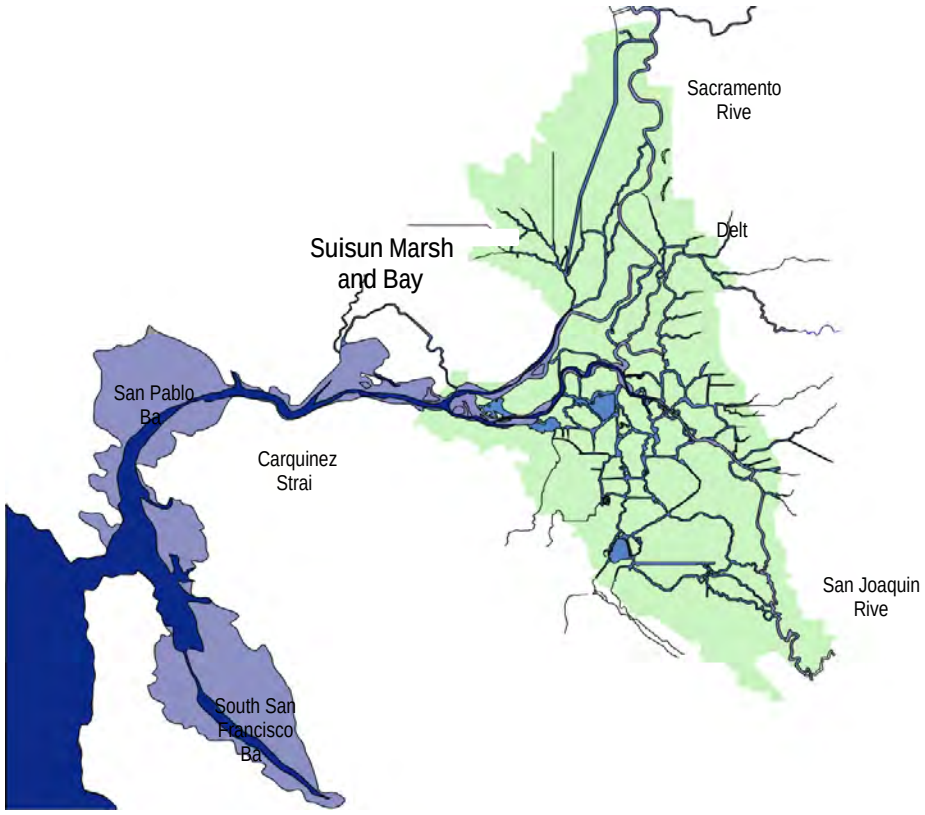


Figure 1. Suisun Marsh Setting within the San Francisco Estuary and Sacramento-San Joaquin River Delta
Source: USGS

Suisun Marsh is generally bounded by the Solano-Contra Costa County line to the south, Highway 680 to the west, Highway 12 to the north, and Shiloh Road to the east (**Figure 2**). The

1976 Suisun Marsh Plan of Protection (BCDC 1977) defines primary (interior lowlands) and secondary (perimeter uplands) management zones. The Suisun Marsh Plan has a fairly similar boundary but excludes the hillsides west of Highway 680 and lands near Collinsville in the Southeast, both of which are included within the BCDC secondary zone.

2.2 Natural Communities

Suisun Marsh consists of four general natural communities: diked baylands, tidal marsh, bays and sloughs, and adjacent upland grasslands on lowland alluvial fans and hillslopes (**Figure 2; Table 1**).

2.2.1 Diked Wetlands

Approximately 55,000 acres in Suisun are diked baylands, most of which are marsh managed primarily for waterfowl. These managed areas are separated from the tidal sloughs by artificial levees and water exchange is controlled by gated culverts and other water control structures. Waterfowl club managers control the timing and duration of flooding to promote growth of waterfowl food plants. The marsh surface is often graded to provide uniform flooding and draining, thus eliminating plant zonation and ditches are dug to increase water circulation throughout the pond. Typical plant species include alkali bulrush (*Bolboschoenus maritimus*), pickleweed (*Sarcocornia pacifica*), brass buttons (*Cotula coronopifolia*), Fat-hen (*Atriplex triangularis*), and watergrass (*Echinocloa crus-galli*). Historically, these waterfowl clubs were tidal marsh, and future tidal marsh restoration will generally occur on portions of these lands. Most of the diked marshes have subsided (see Section 4.2).

2.2.2 Brackish Tidal Marsh

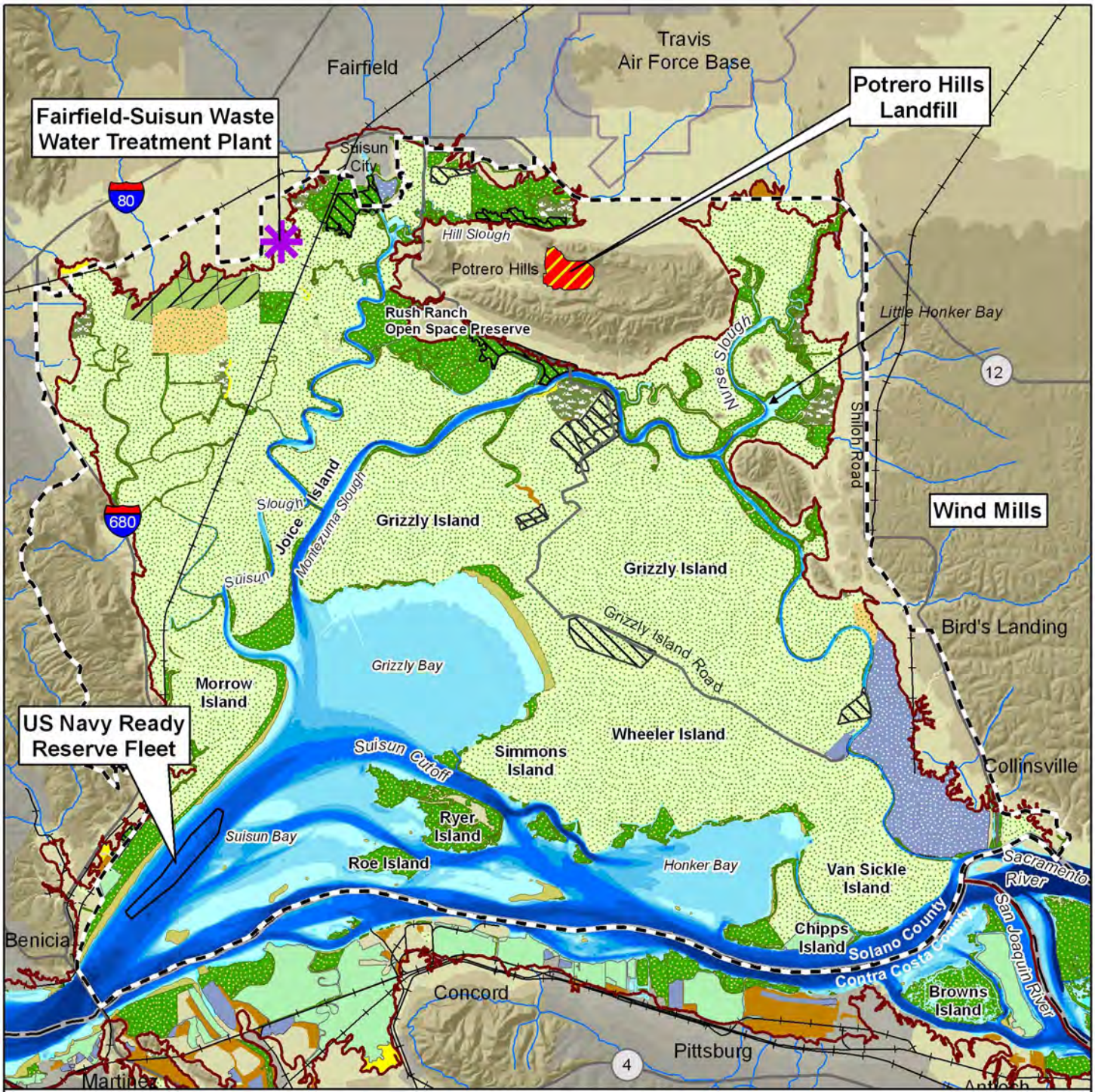
Suisun Marsh supports about 8,100 acres of tidal marshlands (**Figure 3**). Due to its position within the Estuary of the steepest salinity gradient from the freshwater Delta to the saline San Pablo Bay, the tidal marshes of Suisun are the most diverse marshes in terms of flora and providing ecological functions for a great number of fish and wildlife species, supporting species adapted to both fresh and saline conditions.

Below are descriptions of Suisun's tidal marshes in terms of their vertical (topographic) and planform (geomorphic) attributes.

Table 1. Suisun Marsh Acreage by Habitat Type within Suisun Marsh Protection Plan Area

Habitat Type	Subtotal (ac)	TOTAL (ac)
Baylands		**87,790**
Diked baylands[1]		52,741
Managed wetlands and associated uplands [2]	48,230	
Other diked marsh	73	
Farmed	705	
Grazed	916	
Ruderal	39	
Pheasant club	647	
Dredged material basin	2,046	
Storage or Treatment Basin	85	
Tidal marsh		8,714
Tidal bays and sloughs[3]:		25,372
Minor sloughs [4]	1,537	
Suisun Slough	851	
Montezuma Slough	1,416	
Bays (including Little Honker) [5]	21,568	
Filled Baylands[6]		173
Riparian[7]		281
Uplands[8]		**19,335**
Agriculture	1,188	
Alkali Seasonal Wetland Complex	88	
Developed	775	
Grassland[9]	16,424	
Nontidal Freshwater Marsh	3	
Nontidal Open Water	32	
Oak Woodland	492	
Riparian	159	
Undefined	8	
Vernal Pool Complex	166	
TOTAL acres		**106,616**

[1] Diked baylands acres from EcoAtlas (SFEI 1998) as updated by WWR 2011; corresponds to Figure 2.
[2] Includes levees and other "non-wetland" landscape features associated with the diked managed wetlands.
[3] Acreage values from WWR tidal channel digitizing from 2010 NAIP air photo, Jan 2011.
[4] Includes all ungated sloughs except Montezuma and Suisun Sloughs.
[5] Includes Suisun, Grizzly, Honker and Little Honker bays to the SMPP boundary.
[6] Includes developed and ruderal filled baylands.
[7] Determined from 2006 DFG Vegetation data.
[8] Uplands are above tidal inundation (based on modern tidal influence). Includes upland "islands" interior to Suisun (SFEI 1998) and the perimeter of Suisun Marsh. Land use categories follow AECOM (2011) data for Delta Plan.
[9] Includes grasslands with and without disturbed vernal pools (AECOM 2011) and includes natural upland islands within the baylands interior (SFEI 1998).



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Data sources: USGS (2004), TIGER (2000), GAP (1998), Eco Atlas (1998 with updates by WWR: 2009, 2011), CDFG (2006-2007)
Produced by WWR, September 2011
map file: land-use_Suisun_AP_1151_2011-0912mdl.mxd

WETLANDS AND WATER RESOURCES

SUISUN LAND USES

Suisun Marsh
Solano County, California

September 2011 | Project No. 1151 | **Figure 2**

Vertical (Topographic) Attributes

At the most fundamental level, the frequency, magnitude, and duration of tidal inundation exerts the single greatest control on tidal marsh functions and processes. Inundation regimes are controlled through the interaction between relative marsh elevation and tidal action. Constrictions on tidal exchange, such as undersized channels, hydraulic roughness of marsh vegetation, and depressions on the marsh plain mediate the role of marsh elevation (Atwater and Hedel 1976; Hinde 1954; Peinado et al. 1992). This vertical mosaic provides complex habitats for many fish and wildlife species (**Figure 3**).

Habitat diversity is important for plants, which live most of their life cycle fixed in place, with respect to pollinators or in controlling environmental factors such as erosion or drainage. Plant distribution relative to topography is influenced by inundation regime predominantly and salinity secondarily (Adams 1990; Goals Project 2000). In the saline tidal marshes of the lower Estuary, emergent vegetation does not grow very low in the tidal range due to salt stress (Mahall and Park 1976). In the freshwater marshes of the upper Estuary in the Delta, emergent vegetation can grow below low tide due to lack of salt stress. The brackish tidal marshes of Suisun exhibit an intermediate condition (**Figure 4**); how low plants can grow relative to the tides reflects the salt stress environment which itself varies strongly and results in a very diverse marsh flora and a range of elevations down to which emergent vegetation is found.

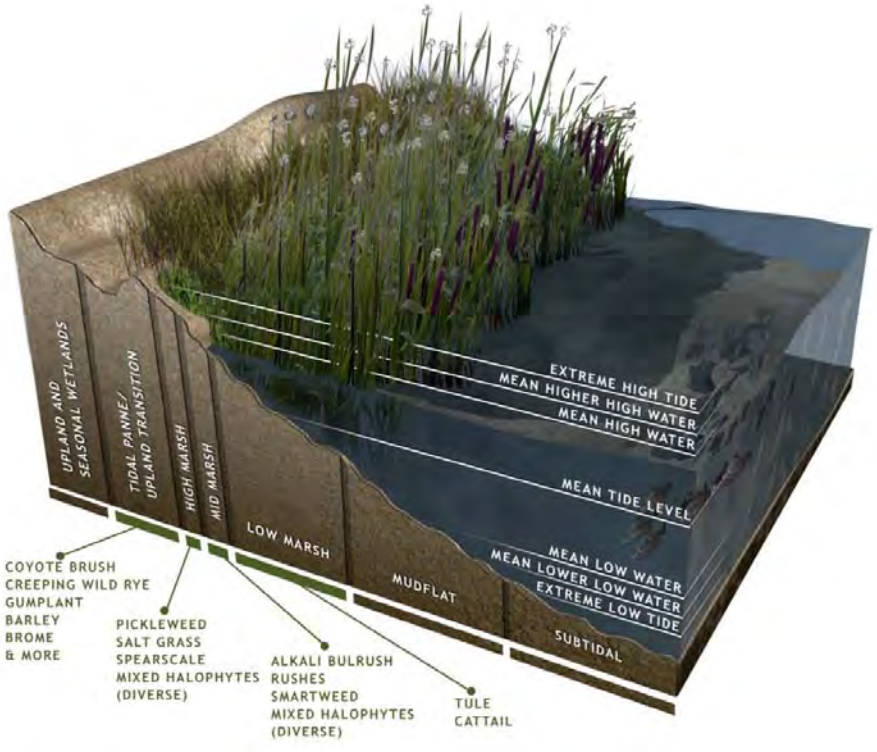


Figure 3. Vertical Zonation Cross Section in Suisun Tidal Marshes
Source: Moffatt and Nichol

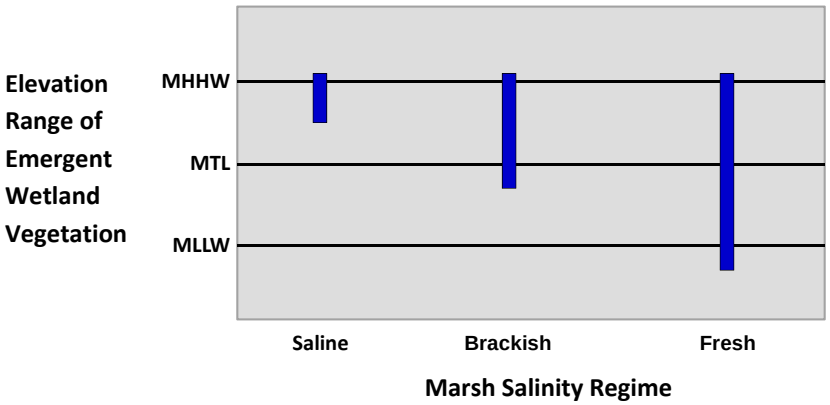


Figure 4. Tidal Marsh Vegetation Vertical Range with Salinity
Source: Wetlands and Water Resources. Ranges are approximations.

Planform Attributes

Suisun Marsh, like much of the San Francisco Estuary, has seen most of its tidal wetlands diked and converted to other land uses (mainly waterfowl clubs in Suisun), with few remnant tidal marshes remaining. Today's Suisun Marsh has three landform types of tidal marsh: Holocene, centennial and fringing marsh (**Figure 5**).

Holocene marshes (pre-European) formed through sea level rise over the past few thousand years and exhibit high geomorphic complexity. Holocene marshes are larger patches, have a high area-to-edge ratio, and typically have high geomorphic complexity. These marshes are found at Rush Ranch Open Space Preserve, Hill Slough, Peytonia Slough, Boynton Slough, Roe Island, Ryer Island, and two small islands in Suisun Bay (**Figure 2**). Holocene marshes typically have large marsh plains, a network of sinuous tidal channels, ponds and pannes on the marsh plain and, when located adjacent to uplands, an upland transition. Rush Ranch (**Figure 5**) illustrates this marsh type.

Centennial marshes formed atop Sierra Nevada hydraulic gold mining sediments deposited over many years beginning in the 19th century and have fairly low geomorphic complexity. Centennial marshes (e.g., the lower tip of Joice Island) can be large in size and with a range of edge:area ratios depending on location. These marshes formed mainly in the later 19th century and early 20th century by emergent vegetation colonizing newly deposited sediment supplied from Sierra Nevada hydraulic gold mining. Their fairly rapid formation has resulted in relatively low geomorphic complexity including much less sinuous tidal channels.

Fringing marsh is long, narrow bands of marsh along slough banks and bay shoreline. In contrast, fringing marsh exists along the outboard side of dikes and generally has formed since diking began and the original sloughs began to shrink in response to the reduced tidal prism. Fringing marsh is found along many of the sloughs in Suisun Marsh and along the bayfront levees around Suisun Bay (**Figure 2**). These marshes vary in size and vegetation composition, are generally far less complex geomorphically, and have a low area-to-edge ratio. In some locations, substantial sediment has deposited along the exterior of the levee allowing vegetation to colonize and expand outward for large distances into the slough. In other areas, fringing marsh is limited to a narrow band along the exterior levee bank. In most cases, channel structure is limited to small, relatively straight segments with comparatively little access provided to the marsh plain. Fringing marshes lack connection with the upland transition, are often found in small, discontinuous segments, and can limit movement of terrestrial marsh species. Nurse Slough (**Figure 5**) illustrates a larger patch of fringing marsh.

Tidal Channels

Tidal channels within tidal marshes perform two fundamental functions. First, tidal channels are the conduits through which water, sediment, nutrients, and aquatic organisms circulate into, around, and out of the marsh, providing a critical connectivity mechanism between marsh plain and open water environments. This distributary function directly controls most of the physical conditions in a tidal marsh to which plants and wildlife are subject. In turn, this distributary function reflects the marsh geomorphology, tidal range, sediment loads, marsh substrate, and marsh vegetation. Consequently, channel morphology is a primary forcing function for ecology (Callaway 2001; French and Reed 2001; Mitsch and Gosselink 2000; Weinstein and Kreeger 2000). Second, channels provide essential habitat for a wide variety of fish and wildlife species. Channel edges provide habitat for species such as the endangered California clapper rail (*Rallus longirostris obsoletus*), a bird that nests and feeds along cordgrass vegetated channel banks (Albertson and Evens 2000). Channels provide shallow water habitat for dabbling and diving ducks (Takekawa et al. 2000). Channels provide forage habitat and ingress/egress routes for a wide variety of fish species, and previous researchers have attributed population size reductions to the tremendous loss of tidal marsh channel habitat in the San Francisco Estuary in the late 19th century (Bennett and Moyle 1996).

Tidal slough networks in Suisun Holocene marshes broadly exhibit the sinuous, dendritic (branching) morphology observed in tidal marshlands around the globe. The brackish Suisun Marsh slough networks differ from those found in saline San Francisco Bay marshes in that they have fewer, larger channels (less total length of channel, wider and deeper channels). Siegel (1993) hypothesized that the saline and brackish marshes convey about the same tidal prism

for a given marsh size and that brackish vegetation growing lower in the tidal range captures the smaller, shallow channels.

Upland Transition

Upland transition occurs from high marsh into upland. This zone provides refuge to wildlife during high tides and habitat for breeding waterfowl and ground nesting birds (Brown 2004). It is generally dominated by a variety of plant species and often supports rare plant species.

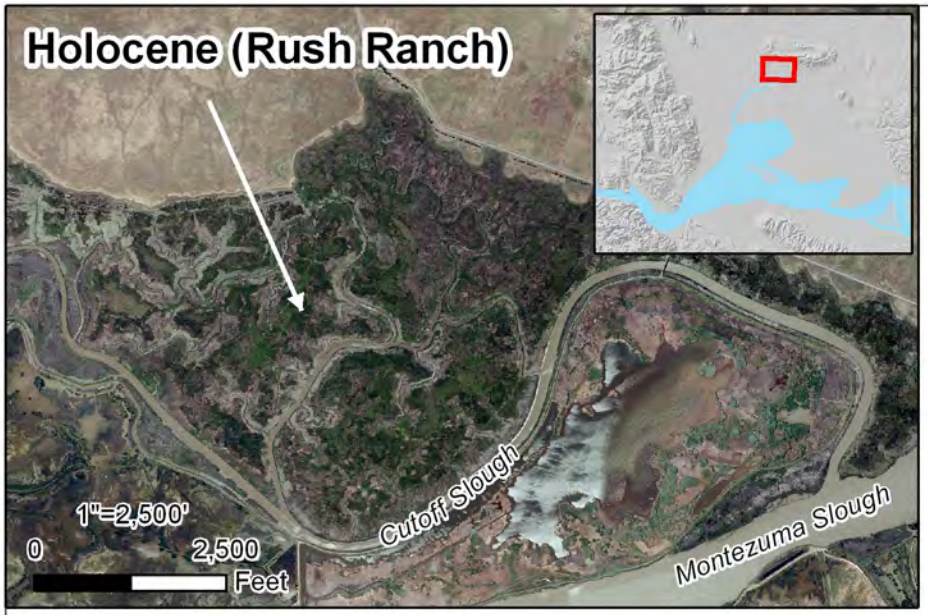
2.2.3 Bays and Sloughs

Suisun Marsh contains a complex of channels, sloughs and water control structures (**Figure 2**). Montezuma Slough spans the Marsh, connecting to Grizzly Bay (a shallow embayment within Suisun Bay) on the west and the lower Sacramento River on the east. The longest slough in the Marsh is Suisun Slough, which meanders from Suisun City in the north towards the south where it connects to western Grizzly Bay. Several smaller slough systems radiate from Montezuma and Suisun sloughs, including the Nurse Slough complex in the northeast Marsh, the Hill Slough complex in the north-central marsh, Peytonia and Boynton Sloughs in the northwest marsh, and Cutoff/Mallard Slough in Rush Ranch in central Suisun Marsh. Most Marsh channels and sloughs are bordered by levees protecting managed wetlands, with fringing tidal marsh often located between the open water of these sloughs and the managed wetland levees.

2.2.4 Upland Grasslands

The terrestrial landscape is currently dominated by non-native grasses with a subdominant component of weedy forbs introduced since the time of European exploration and settlement. These introductions, facilitated by some combination of the competitive advantage of the introduced species, intensive grazing by domestic livestock, effects of introduced pathogens, and other factors (Heady 1988, Malmstrom et al. 2005, Bartolome 2007), resulted in the extensive replacement of the original native grassland species by non-natives throughout the lower elevation coastal and valley regions of California.

The replacement was both rapid and widespread, generally thought to be largely complete by the late 1800s, before any serious scientific characterizations of the original communities had been conducted (Heady et al. 1991, Mensing and Byrne 1998). As a result, there is almost no historical data and virtually no remaining pristine reference sites indicating the distribution and abundance of plant species within the native communities or variations in species and plant community composition across the landscape. Nonetheless, the current grasslands continue to support a high diversity of the original native grassland species, albeit with typically a fairly low cover (Schiffman 2007) except in some areas with thin soils or during years with rainfall patterns that favor annual forbs (WWR et al. 2010a).



Data sources: air photos (Solono County NAIP, 2010)
Produced by WWR, September 2011
Map file:-tidal-marsh-types-suisun_1151_2011-0929mdl.mxd

WETLANDS AND WATER RESOURCES

TIDAL MARSH TYPES IN SUISUN

Suisun Marsh Characterization Report
Solano County, California
The Nature Conservancy

September 2011 | Project No. 1151 | **Figure 5**

The current upland terrestrial plant communities (hillslopes and older alluvial fans) are heavily dominated by introduced annual and/or perennial grasses with a low cover of native grasses and forbs during most years. The hillslopes are dominated by four introduced annual grasses – soft chess, ripgut, wild oats, and Italian ryegrass. These form the dominant matrix of the plant community. These species are widespread throughout the hillslopes with soft chess ubiquitous, ripgut and Italian ryegrass throughout most areas and wild oats the most patchy. Wild oats is most common on deeper soils where grazing appears less intense. Italian ryegrass is densest on more seasonally moist soils such as Altamont and Diablo-Ayar clays and around the bases of the hillslopes with heavier soils. Within this matrix are a limited number of stands of native purple needlegrass and saltgrass. Overall, the upland terrestrial plant communities, in their current condition, may be regarded as having a low to moderate ecological function based on the relatively low cover of native species and the relatively high cover of undesirable invasive weeds. Perhaps the best function of the current grasslands is a foraging and nesting habitat for a host of special-status and other birds (WWR et al. 2010a).

The lower alluvial fan at Spring Branch Creek, Rush Ranch and possibly other drainages with similar features, supports alkali flats with sparse vegetation and relatively unconsolidated sediments, as well as cohesive unvegetated low scarps of intermittently active distributary channels. These features provide specialized sub-habitats for an exceptionally rich, localized and distinctive insect fauna (including possibly endemic species and undescribed species; W. Ericson, pers. comm. 2010). The alkali flats, meadows, seasonal pools, and erosion scars are sub-habitats that support largest populations and diversity of Hymenoptera (wasps) and Cicindelidae (tiger beetles), particularly in bare or sparse sediment areas. Populations of these invertebrate taxa have reportedly been adversely affected by past quarrying (soil removal circa 2001) within the alluvial fan, which was followed by rapid and acute declines or disappearance of Hymenoptera and Cicendelidae in excavated areas (WWR et al. 2010a).

2.2.5 Riparian Scrub

Riparian vegetation is limited within Suisun marsh (**Figure 6**), covering roughly only 26 acres (**Table 1**), and cover varies greatly with land use and habitat characteristics. This vegetation community consists of a few woodland species, including oaks (*Quercus agrifolia/Q. lobata*), willows (*Salix laevigata/L. lasiolepis*), and eucalyptus and scrubs such as blackberry (*Rubus discolor*), coyote brush (*Baccharis pilularis*), and California rose (*Rosa californica*) (Vaghti and Keeler Wolf 2004). As an example of the low riparian density in Suisun Marsh, within Rush Ranch open space there are roughly only a total of 30-40 individual bushes or small stands of coyote brush near the marsh boundary south and southwest of the site. There are no other shrubs or trees within the terrestrial landscape except eucalyptus (*Eucalyptus globulus*) and various horticultural and native plantings around the open space headquarters and a few

planted valley oaks (*Quercus lobata*) along the entry road leading to the headquarters. All other woody vegetation on Rush Ranch is associated with the seasonal creeks (fluvial landscape) or tidal marsh (estuarine landscape) (WWR et al. 2010a). Riparian habitats outside of Rush Ranch are likely localized in isolated areas with suitable water and soil features (USBR et al. 2010).

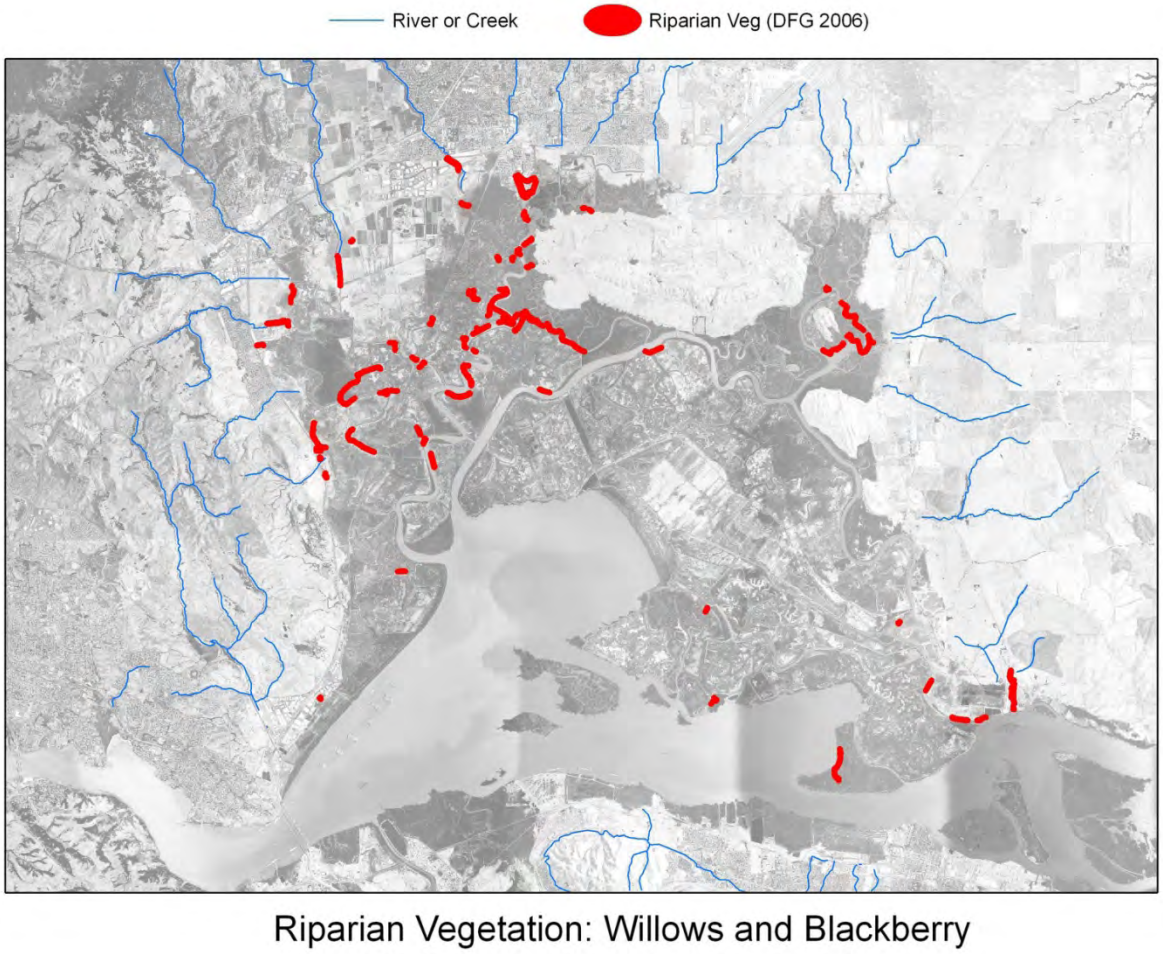


Figure 6. Riparian Scrub Vegetation Distribution
Source: DFG data

2.2.6 Vernal Pools, Natural Seasonal Wetlands, and Associated Grasslands

Historically, complexes of seasonal wetlands and/or vernal pools and associated grassland habitats occurred in upland areas surrounding the Marsh, on low-gradient alluvium which has limited distribution. Seasonal wetlands and vernal pools probably never were widespread in the Suisun area (USBR et al. 2010). However, suitable vernal pool lands are found to the north and especially northeast of Suisun Marsh (**Figure 2**). The nearby Jepson Prairie Reserve is an expansive vernal pool-grassland complex linking Suisun to the Cache Slough region of the northwest Delta. The regional landforms suggest that vernal pools had a broad historical distribution across the northern Suisun border as well as moderate extent along the toe of the Montezuma Hills on the eastern boundary. A small portion of the study area, directly adjacent

to Highway 12, falls in the Solano-Colusa Vernal Pool Region (in the northeastern section of the Marsh), as described by USFWS in their Recovery Plan for Vernal Pool Ecosystems of California and Southern Oregon (December 2005).

Only small areas of seasonal wetland and vernal pool complexes remain, and grazing has degraded much of the habitat. The seasonal wetland and vernal pool complexes remaining in Suisun occur in the northern and eastern portions of the Marsh. These seasonal wetland complexes occur in the Potrero Hills and the southern limits of the Montezuma Hills. Seasonal wetland and vernal pools occur outside the limits of the managed wetlands. Grasslands that occur in this land cover type typically are dominated by annual grasslands and forbs, native perennial grasslands, and agricultural areas. These wetland complexes provide nesting, foraging, and cover habitat for wildlife in Suisun Marsh. The seasonal wetland complexes outside of the Marsh and managed wetlands also provide habitat for special-status species, including California tiger salamander and vernal pool invertebrates and plants.

The USFWS vernal pool recovery plan promotes natural ecosystem processes and functions by protecting and conserving intact vernal pools and vernal pool complexes within the recovery planning area to maintain viable populations of listed species and species of concern and prevent additional threats from emerging over time. Contra Costa goldfields and alkali milk vetch have been identified in Suisun Marsh (U.S. Fish and Wildlife Service 2005).

2.3 Aquatic Food Web-Tidal Marsh Linkages

The aquatic food web in Suisun Marsh is an intricately linked system and has changed along with the changes in the landscape of the marsh. Wetlands play a key role in aquatic food webs through a variety of mechanisms and the conversion of the majority of the tidal wetlands in Suisun Marsh to managed wetlands has undoubtedly altered these food web pathways. The discussion below outlines the way in which tidal wetlands play a role in the aquatic food web of estuarine ecosystems and how wetland conversion may have altered those pathways in Suisun Marsh.

Primary Production

Primary production within tidal wetlands is quite high and is primarily due to the growth of aquatic vegetation (macrophytes) within the low to high-elevation marsh areas. Algae also play a key role in primary production (Mitsch and Gosselink 2000). Algae grow on the surface of submerged plants (epiphytic algae) and on the substrate (edaphic/benthic algae) and occur suspended in the water column as phytoplankton in open water areas such as channels, intertidal mudflats, ponds, and pans. All these types are found in Suisun.

It is assumed that approximately 10-40% of above-ground primary production in tidal wetlands is consumed directly by herbivory (Odum 1988). In the wetlands of Suisun Marsh herbivory can be due to sources including mammals (tule elk, muskrats, feral pigs, etc.), waterfowl, and insects. The plant matter consumed by these animals can enter the aquatic food web through their waste, thus becoming part of the detrital food chain (described below). In addition, insects will regularly fall into the water where they are either consumed directly by higher trophic level aquatic organisms (i.e. fish), or by entering the detrital food chain.

Decomposition and Primary Consumption

The remaining 60-90% of the primary production that is not consumed by herbivory is assimilated into the aquatic food web via the detrital food chain. In this process, dead plant and algal material is first broken down primarily by fungi and bacteria and this roughly decomposed organic matter is then ingested and shredded by grazers such as snails and amphipods (Mitsch and Gosselink 2000). The remaining shredded material is then broken down further by bacteria into a detrital mixture that can be consumed by benthic meiofaunal and macrofaunal deposit feeders. Some of this detritus is also suspended into the water column by winds and currents where it mixes with the phytoplankton and is consumed by suspension feeders (bivalve mollusks and oligochaete annelids) and zooplankton (Mitsch and Gosselink 2000). These primary and secondary consumers then become prey for larger aquatic consumers such as fish.

Energy Input from Terrestrial Sources

Terrestrial habitats at the tidal marsh edge and further up the watershed can be a source of inputs to the aquatic food web as well. Primary productivity in the form of terrestrial/aquatic vegetation and algae can enter the marsh through direct leaf fall or by transport in tributary streams where it will enter the aquatic food web as described above. Also, as described in Section 10.1.3, there are several species of terrestrial and aquatic invertebrates that live in habitats bordering wetlands or the streams that feed into the wetlands. These invertebrates can also enter the tidal wetlands in the same method as primary productivity from the surrounding watershed and can either be assimilated into the aquatic food web by direct consumption by higher trophic level organisms (i.e. fish) or by entering the detrital food chain.

Energy Exchange with Adjacent Aquatic Systems

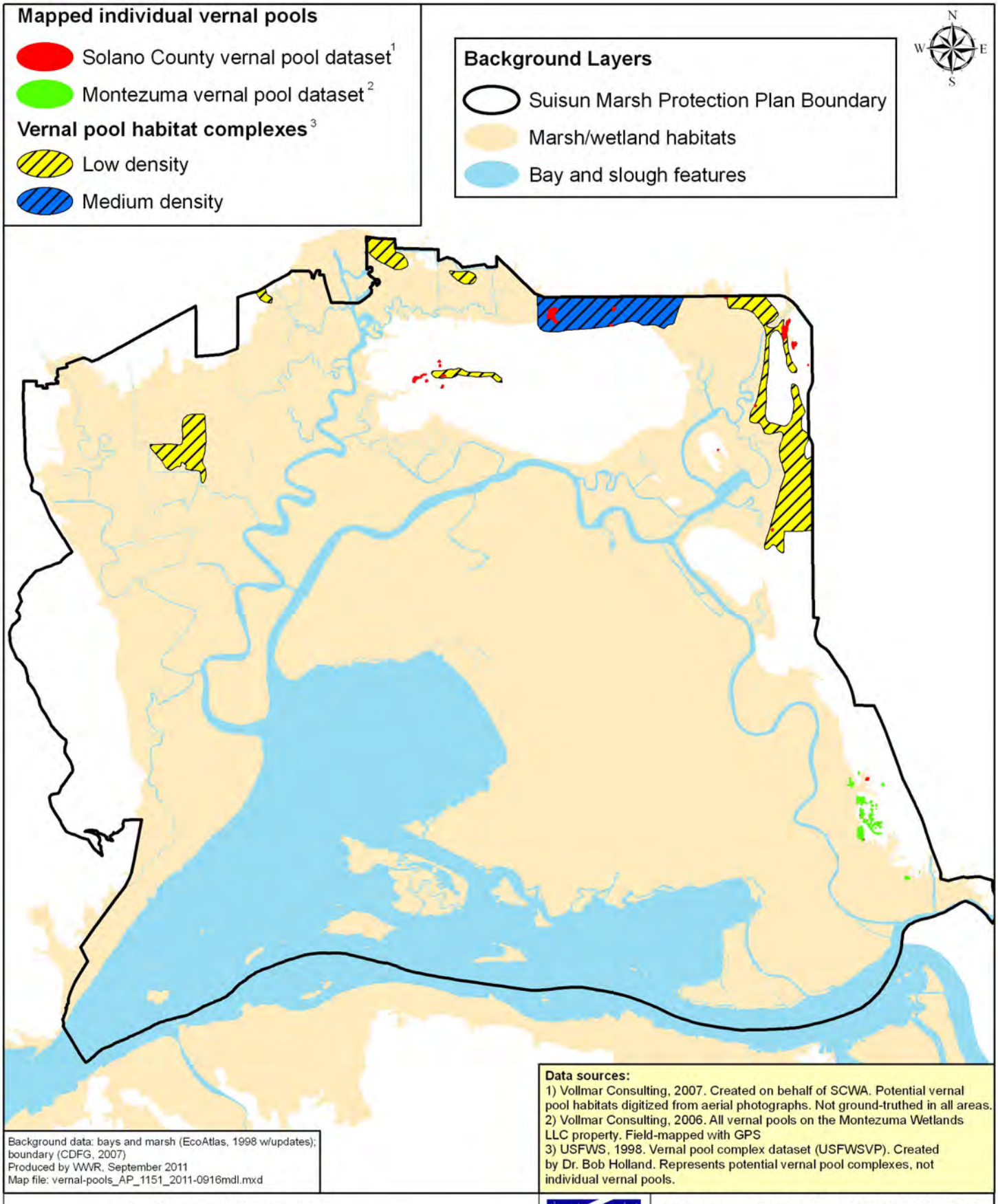
Tidal marshes have regular exchange with adjacent open water areas. The tides move in and out of the wetlands carrying with them organic material, nutrients, and live organisms therefore providing direct connectivity between the food webs in these habitats. Patterns of exchange are linked integrally to the roughly two-week spring-neap tidal cycle. The primary production broken down through the detrital pathways within the wetlands can be re-suspended and transported out into open water areas on ebb tide where it can be either consumed by suspension feeders and zooplankton in the water column, or settle to the bottom

and be consumed by benthic organisms. In addition to this exchange of organic matter, nutrients are also exchanged between tidal marshes and adjacent open water areas, which can have an impact on primary production in both locations. However, whether tidal wetlands serve as a source or sink of nutrients can vary widely based on site-specific conditions (Mitsch and Gosselink 2000). In general, tidal marshes appear to act as nitrogen transformers, taking in dissolved oxidized inorganic forms and exporting dissolved and particulate reduced forms (Nixon 1980). These wetlands are normally sinks for total phosphorus, although there may be some remobilization from sediments and export from certain marshes (Nixon 1980).

The macroinvertebrate primary and secondary consumers found within tidal marshes may also be consumed by higher trophic level organisms (i.e. fish) in adjacent waters either through the prey being transported out of the wetland where it is consumed, or the predator moving into the wetland and consuming the prey *in-situ*.

Historical Alterations in Aquatic Food Web Connectivity

The conversion of much of the tidal marsh in Suisun into managed wetlands has certainly had an impact on the aquatic food web. Since most of the wetlands are not managed to have full tidal exchange with the surrounding system, the exchange of organic matter, nutrients, and predator-prey populations is reduced from historical conditions. The aquatic food webs of the managed wetlands and adjacent waters are still connected, however instead of a hydrologic exchange regime that follows the tidal cycle, managed wetlands often follow discrete flooding and draining cycles in which large volumes of water are exchanged only in one direction, either into (flood) or out of (drain) the wetlands. These events can often be separated by several days or several months, depending on the management objective for a given wetland, resulting in temporally inconsistent exchanges of energy between these systems.



Background data: bays and marsh (EcoAtlas, 1998 w/updates); boundary (CDFG, 2007)
Produced by WWR, September 2011
Map file: vernal-pools_AP_1151_2011-0916mdl.mxd

Data sources:
1) Vollmar Consulting, 2007. Created on behalf of SCWA. Potential vernal pool habitats digitized from aerial photographs. Not ground-truthed in all areas.
2) Vollmar Consulting, 2006. All vernal pools on the Montezuma Wetlands LLC property. Field-mapped with GPS
3) USFWS, 1998. Vernal pool complex dataset (USFWSVP). Created by Dr. Bob Holland. Represents potential vernal pool complexes, not individual vernal pools.

1:144,000 (1" = 12,000' at letter layout)

0 12,000 24,000 Feet

0 3,700 7,400 Meters

WETLANDS AND WATER RESOURCES

VERNAL POOLS IN SUISUN MARSH PLANNING AREA

Suisun Marsh Characterization Report
Solono County, California
The Nature Conservancy

September 2011	Project No. 1151	**Figure 7**

2.4 Connectivity & Fragmentation

Habitat connectivity within Suisun Marsh has been reduced dramatically from historic conditions. The most significant change has been the partitioning of a once almost continuous expanse of tidal marsh and slough habitats into discrete managed wetland bodies. These managed wetlands are separated from adjacent wetland and slough habitats by levees and water control structures which act as hydrologic exchange and organism migration barriers. The tidal marshes that still remain within the Suisun Marsh system are highly fragmented and largely disconnected from each other. The restoration of tidal wetlands throughout Suisun Marsh will help to restore habitat connectivity essential to maintaining a healthy ecosystem.

Under historic conditions, the tidal wetlands experienced unimpeded hydrologic connectivity with adjacent open-water aquatic areas via a network of tidal channels and overbank flow during extreme high water conditions. This connectivity allowed the regular exchange of nutrients and primary/secondary productivity between wetland and bay/slough habitats, promoting a healthy, inter-dependent aquatic food web throughout the marsh (Mitsch and Gosselink 2000). The unimpeded hydrologic connectivity also allowed the free movement of aquatic organisms between marsh and open water habitats. Since many aquatic species, particularly fish, depend on both open water and wetland habitats at various stages in their lives (on both daily and developmental time scales) (Mitsch and Gosselink 2000), the ability to move freely between these habitats is essential. The building of levees to partition Suisun Marsh into discrete wetland areas has drastically diminished the connectivity of the system. Where water once flowed freely through and across the marshes via tidal channels and overbank flow, hydrologic exchange between wetlands and adjacent open water channels and bays is now only provided through water control structures that are operated by wetland managers to achieve the specific management goals of an individual wetland (primarily waterfowl habitat). Managed wetland water control structures typically operate across three modes: flood, drain, or hold water at a specific elevation. It is rare that free, open exchange is allowed between wetlands and adjacent open water areas. This alteration in connectivity has had dramatic consequences for the cycling of nutrients and organic carbon as well as organism movements within the Suisun Marsh ecosystem. The construction of transportation infrastructure in the form of roads and railroads has also contributed to restricted habitat connectivity within Suisun Marsh.

Recent literature suggests there is potential for synergy between otherwise fragmented and noncontiguous habitats, where excess production in one can be transported and utilized in the other. For example, Cloern (2007) presents results of a simple two-box model where one box is a high productivity shallow habitat (something like a slough draining a tidal marsh) and the

other box is a low-productivity deep habitat (like diked portions of Montezuma or Suisun sloughs). Suisun Marsh has high concentrations of suspended sediment from river inputs and wind/wave resuspension, and algal growth rates are limited by low availability of sunlight energy (Cloern 1999). Light limitation is most severe in deeper channels where algal respiration can balance or exceed photosynthesis. Most of the volume in the larger Suisun Marsh sloughs (e.g., Montezuma Slough, Suisun Slough) is below the photic zone and thus exhibits productivity deficits. Simulations show that total system primary and secondary production (the sum of production in both habitats) varies with the hydrologic connectivity rate between habitats. When the connectivity rate is optimized, productivity exports from shallow donor habitats subsidize production in resource deficit habitats like deeper sloughs. In general, the optimal connectivity rate occurs when the percentage of water mass exchanged per day is roughly equal to the percentage of excess primary production. For example, when a shallow water habitat produces 10% more phytoplankton than it consumes and a nearby heterotrophic habitat is exposed to about 10% of the shallow habitat water volume, then overall primary and secondary biomass is roughly maximized.

The model also explains why consumers like amphipods and copepods have a limit to the amount of food they can take in daily. If the food supply (e.g. phytoplankton biomass) exceeds consumption capacity, then secondary production is limited by feeding constraints of the consumers and reaches a plateau. If some of the excess food supply is exported to low productivity habitats (like Montezuma Slough), then it can support additional secondary production. At the same time, low productivity habitats regenerate nutrients through excess respiration that can in turn be transported to autotrophic habitats, thereby stimulating higher total system primary productivity.

2.5 Other Land Uses and Infrastructure In and Adjacent to Suisun Marsh

A number of other land uses takes place within and surrounding Suisun marsh, discussed below and shown in **Figure 2**.

DWR Salinity Management Infrastructure

DWR has constructed several facilities in Suisun Marsh for the purpose of mitigating adverse impacts on Suisun salinity from the State Water Project and Central Valley Project. These facilities are described more fully in Section 5.2 and include the Suisun Marsh Salinity Control Gate at the southeast end of Montezuma Slough, the Roaring River distribution facility on Grizzly Island, the Morrow Island Distribution System, and the Goodyear Slough Outfall.

Agriculture within Suisun Marsh

Agricultural uses are still present in Suisun Marsh in comparatively small amounts. Uses include cattle grazing in the northwest, on Grizzly Island, and in northeast; sheep grazing in the east, and some row crops in the northwest.

Potrero Hills Landfill

The Potrero Hills Landfill is located within the north-central region of the Marsh. The Landfill has been pursuing approvals for expansion to four times its existing capacity.

Roads within Suisun Marsh

Grizzly Island Road is the primary paved road within Suisun Marsh, extending from Fairfield south to the DFG and SRCD headquarters on Grizzly Island, crossing Montezuma Slough at Beldon's Landing. Grizzly Island Road continues as a maintained gravel road from the headquarters area southeast to the Roaring River distribution facility. Numerous smaller gravel and dirt roads are located throughout Suisun Marsh, providing access to the many ducks clubs.

Petroleum Pipelines and Natural Gas Production

Petroleum pipelines traverse the marsh in the west, north, and east. Suisun Marsh has natural gas fields and exploration and production are built into the Plan of Protection. Natural gas wells both active and closed and associated pipelines are located at various locations in the Marsh. Presence of any such facilities must be investigated on a site-by-site basis when considering restoration or other work. None of these facilities are included on maps in this report.

Roads and Rails Surrounding Suisun Marsh

Freeways and highways bound the west and north sides of Suisun Marsh, I-680 on the west, I-80 on the northwest, and 12 on the north. A small county road, Shiloh Road, bounds the east side of the Marsh. The railroad crosses through, not around, Suisun Marsh on its western side from Benicia to Suisun City. This railroad is actively used for freight and passenger service.

Surrounding Cities, Towns and Agriculture

Several cities and small communities are spread around Suisun Marsh and Bay. Fairfield (population of 105,955[2]) and Suisun City (28,962) border to the north-central, Cordelia at the northwest corner, and Benicia (28,086) at the southwest corner. South across Suisun Bay on the Contra Costa County shoreline are Martinez (36,663[3]), Concord (125,864), Pittsburg (64,967), and Antioch (102,330). Two very small communities are in the southeast corner: Birds Landing and Collinsville (population a few dozen each). To the north and east of Suisun Marsh are

[2] Populations for Fairfield, Suisun City, and Benicia as of January 2010, were derived from published data from Solano County website, http://www.co.solano.ca.us/about/county_facts_n_figures.asp.

[3] Populations for Contra Costa County were taken from California Department of Finance, http://www.dof.ca.gov/research/demographic/reports/estimates/e-1/2009-10/view.php.

roughly 21,000 acres of lands within the watershed that are in agriculture uses. Irrigated and non-irrigated crops are most of that acreage, each at about 8,500 acres. Cattle graze on some of the remaining lands. These operations will affect stream water quality through nutrient and pesticide loadings, with the details depending on specific operations.

Military Facilities

Travis Air Force Base borders to the immediate northeast and its runoff reaches Suisun Marsh primarily through Union Creek. Roe and Ryer Islands in Suisun Marsh are U.S. Navy property. The U.S. Navy "Mothball" or Ready Reserve Fleet is a group of World War II navy vessels anchored for decades in the southwest portion of Suisun Bay. These ships are the source of contaminants into sediments of Suisun Bay and the subject of removal which after many years of planning is just getting underway. Concord Naval Weapons Station is on the southern shore of Suisun Bay.

Wastewater Treatment Plant

The Fairfield/Suisun City Wastewater Treatment Plant is located in the northwest corner of Suisun Marsh. The treatment plant handles the sanitary waste flows only; storm flows do not pass through the plant but drain directly into Suisun Marsh. Details of plant discharges and water quality are discussed under the sections on the Wastewater Treatment Plant (Section 3.5) and Other Water Quality (Chapter 5).

Wind Power Generation

The Montezuma Hills to the east of Suisun Marsh support extensive wind power generation facilities, utilizing hundreds of wind turbines to generate several hundred megawatts of power. Leased lands continue in sheep grazing and oat hay production.

2.6 Land Ownership

There are nearly 160 privately-owned waterfowl clubs in Suisun Marsh along with the more than 15,000 acres that comprise the Department of Fish and Game Grizzly Island and Hill Slough complexes. Other public agency and non-profit owners in the Marsh include the Suisun Resource Conservation District, Department of Water Resources, U.S. Navy, Fairfield-Suisun Sewer District, and the Solano Land Trust (**Figure 8**).

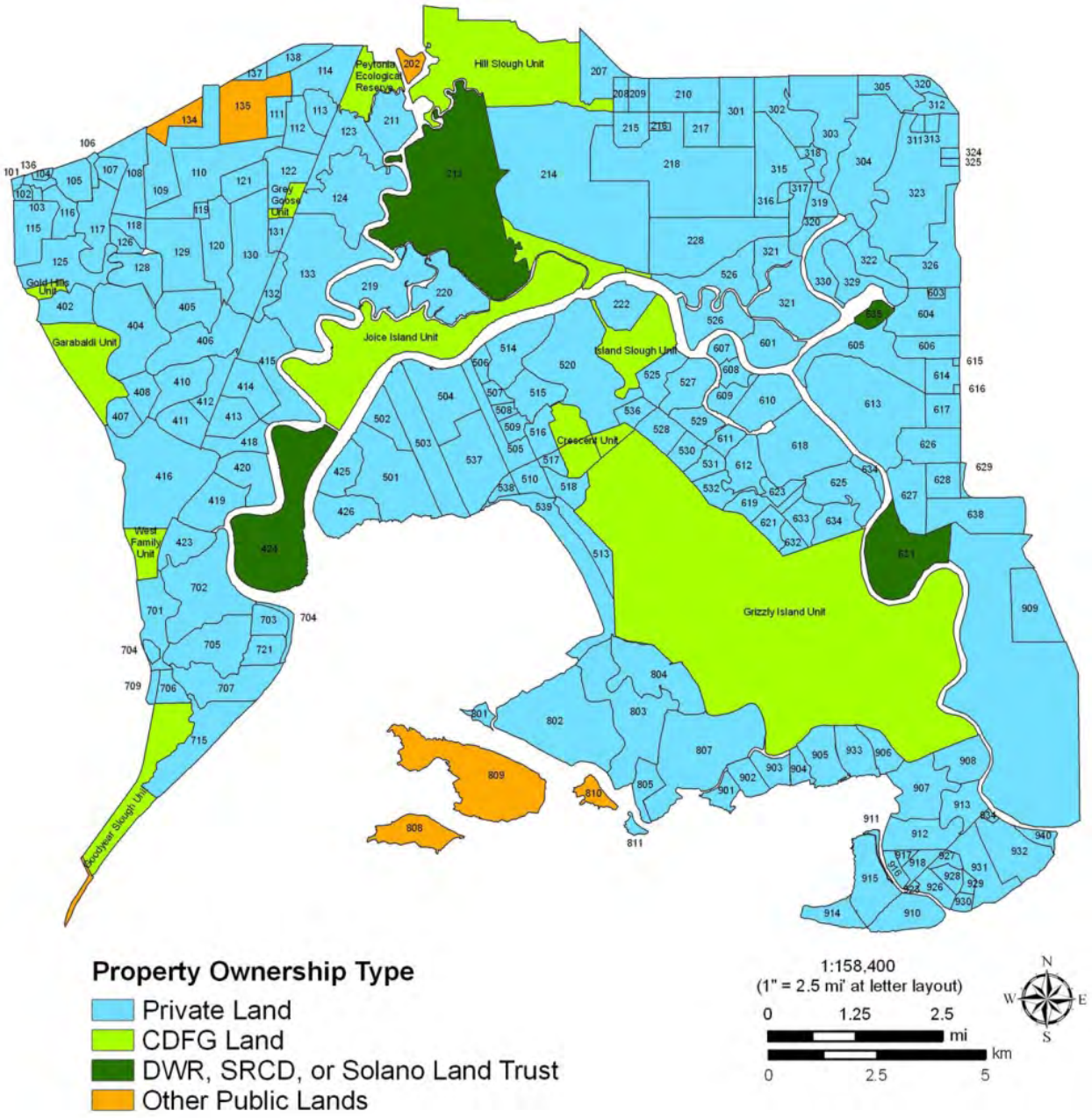


Figure 8. Suisun Marsh Land Ownership
Source: Suisun Resource Conservation District

2.7 Historical Conditions

Historically, Suisun Marsh was a vast series of tidal marshes and pannes that were directly connected to the estuary and bordered by grasslands on hillslopes and alluvial fans and probably some riparian corridors along the creeks (**Figure 9**). The nature of the wetland-upland

transitions likely varied quite a bit throughout the Marsh, in relation to steepness of the edge, local freshwater flows, and presence of pannes at the marsh edge.

The tidal marshes of Suisun formed over the past 3,000-4,000 years as Holocene sea level rise slowed enough to allow marsh establishment (Atwater 1980). Suisun is thus a drowned river valley, buried in peat formed with mineral sediment during that period of ~400-foot sea level rise. Peat thicknesses are deeper in the marsh interior and thin toward the edges of the most recently submerged alluvial plains. Tidal marsh soils atop the recently buried alluvium have a very thin organic horizon. These entirely different substrate characteristics between the marshes at the upland edge of Suisun and the marshes within the Suisun interior will drive significantly different functions; vegetation communities would be quite different, invertebrate communities would be expected to differ also as would associated large fauna. Put another way, high elevation marsh at the upland edge will exhibit different characteristics and functions than high elevation marsh within the interior of Suisun Marsh.

2.8 Restoration Efforts to Date

Very little restoration has taken place to date (**Figure 10**). The only constructed restorations are Blacklock (70 acres, 2006, Department of Water Resources) and one mitigation site (68 acres, recent, Caltrans). Another 1,500 acres have self-restored through unrepaired levee failures over the past 30 years with another few hundred acres potentially following that path anew today. Two projects are currently being planned – Hill Slough (865 acres, Department of Fish and Game) and Rush Ranch (80 acres, Solano Land Trust). The Montezuma Wetlands Project, a 2,100-acre dredged material reuse tidal wetland restoration effort, has been under construction for several years and has not yet opened any areas to the tides. DWR purchased the 660-acre Mein's Landing property for tidal restoration but may opt to retain it as diked wetlands due to three underground petroleum transmission pipelines crossing the property.

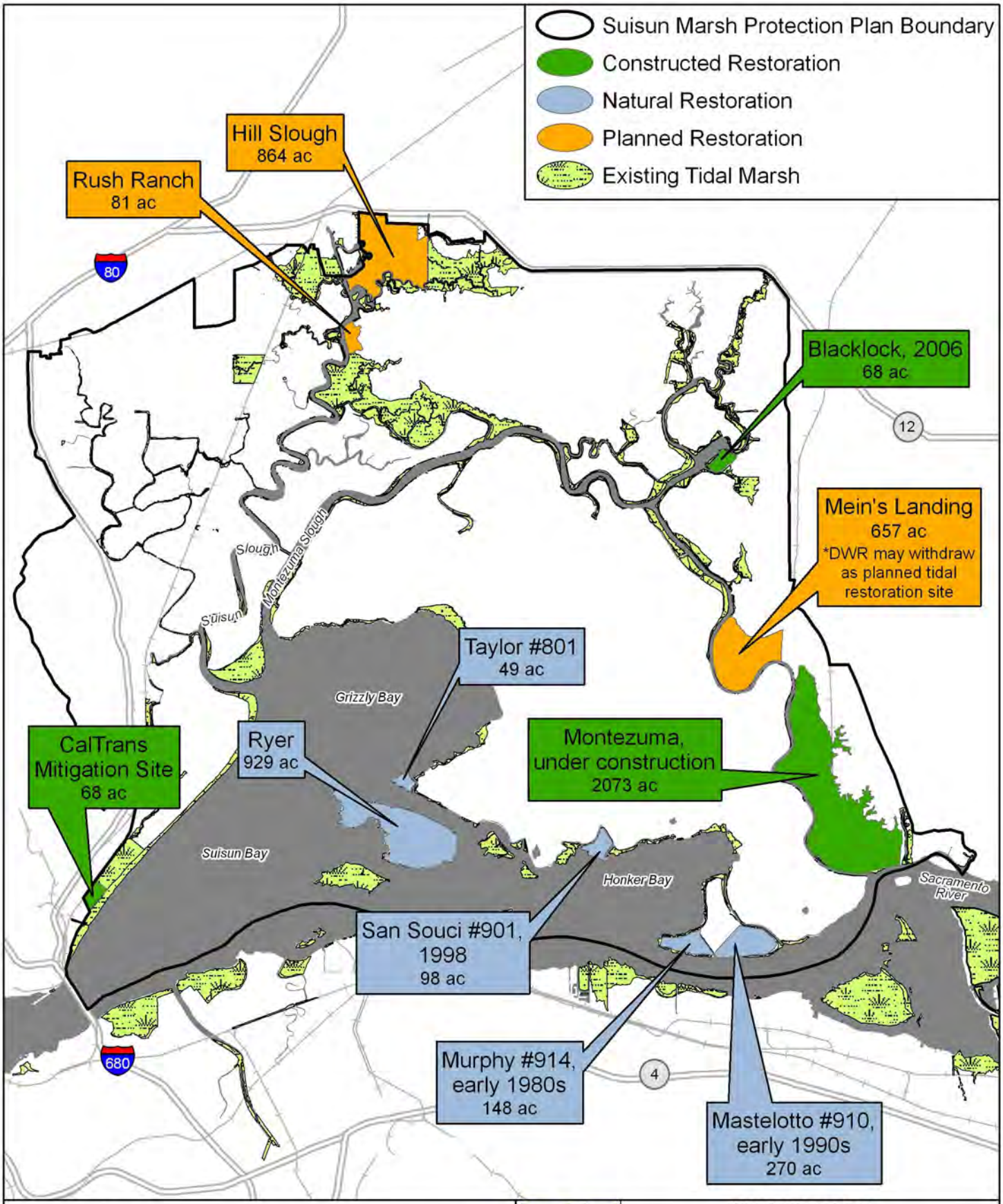
2.9 Pipelines

Several pipelines (gas and oil) traverse through Suisun Marsh (**Figure 11**). Of these, the three pipelines which traverse the west and east perimeters of Suisun Marsh may potentially be subject to impacts from restoration and managed wetland activities. These pipelines transport natural gas and other usable products. Many traverse open water over some portion of their alignment and were constructed over 50 years ago (USBR et al. 2010).

HISTORIC SUISUN MARSH HABITATS

Suisun Marsh Characterization Report
Solano County, California
The Nature Conservancy

January 2011	Project No. 1151	**Figure 9**



N
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0 1 2 mi

0 2 4 km

Data sources: tidal marsh (EcoAtlas 1998), restoration sites (WWR 2010)
Produced by WWR, January 2011
map file: tidal-restoration-sites_Suisun_AP_1151_2011-0919mdl

WETLANDS AND WATER RESOURCES

SUISUN TIDAL RESTORATION SITES

Suisun Marsh Characterization Report
Solano County, California
The Nature Conservancy

September 2011	Project No. 1151	**Figure 10**

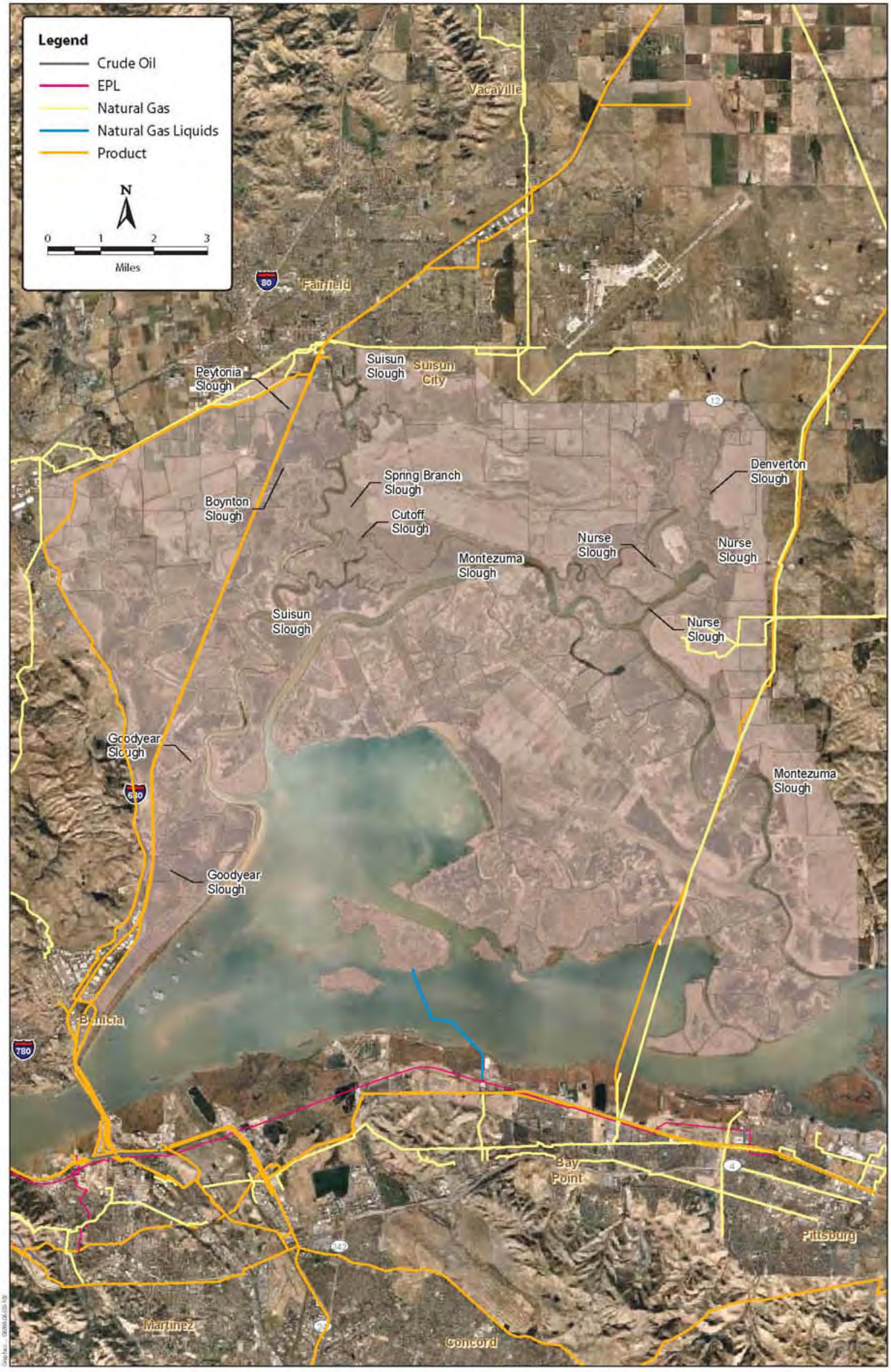


Figure 11
Pipeline Locations in Suisun Marsh

3 Hydrology

This section summarizes the alterations to Suisun Marsh hydrology (Section 3.1) and describes the full range of hydrologic drivers that influence the ecology of Suisun tidal marshes and tidal aquatic habitats: tides (Section 3.2), delta outflow (Section 3.3), the local watershed (Section 3.4), wastewater treatment plant (Section 3.5), managed wetlands (Section 3.6), and meteorology (Section 3.7). See Section 5.2for a discussion of DWR Suisun Marsh facilities.

3.1 Summary of Alterations to Hydrology

The key hydrologic alterations that have influenced Suisun Marsh ecology are:

1) Delta outflow reductions, resulting from: diversions upstream, in-Delta use, withdrawals from higher in the watershed (e.g., Hetch-Hetchy to San Francisco), construction and operation of the State Water Project and the federal Central Valley Project. The net effects are reduced winter-spring Delta outflows (for water supply export) and increases in summer-fall Delta outflows (for maintaining fresh water salinity within the Delta and its export facilities) (Section 3.3)
2) Construction and operation of the Montezuma Slough Salinity Control Gates at the southeastern corner of Suisun Marsh, for the purpose of tidally pumping freshwater Delta outflow through Suisun Marsh via Montezuma Slough during the winter and spring months in order to help mitigate for CVP and SWP operations (Section 5.2)
3) Diking of most of the tidal marshes of Suisun and the associated significant reduction in tidal prism of Suisun (the primary local land use change)
4) Diversions and returns for the diked managed marshes, ranging from hundreds of small diversions and returns to large features like the Roaring River Distribution facility, and operating on seasonal time frames associated with diked marsh management (Section 3.6)
5) Recent sea level rise (about 0.7 ft at the Golden Gate during the 20th century) and projected upcoming increasing rates of sea level rise (Section 3.2)
6) Local watershed stream flow changes by watershed development (Section 3.4)
7) Input of up to 16 million gallons per day into the northwest Suisun Marsh from the Fairfield-Suisun Wastewater Treatment Plant (Section 3.5)

3.2 Tides and Recent Sea Level Rise

Semidiurnal Tides

The San Francisco Estuary experiences a mixed, semi-diurnal tidal regime with a 24.8-hour cycle in which two daily tides of unequal height occur (**Figure 12**). During each tidal cycle there is a

higher high, high, low, and lower low tide. Three main periodic variables control tide stage patterns: (1) spring-neap tide cycle (~ 2 weeks) tied to moon phase, (2) solstice-equinox cycle (3 months) tied to the seasons, and (3) complex astronomical controls that comprise the 18.6-year tidal epoch.

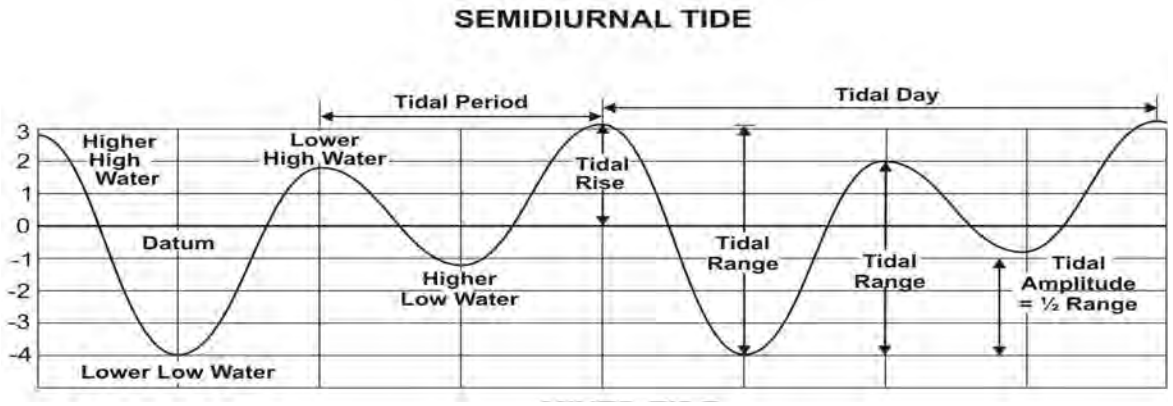


Figure 12. Diagram of Mixed, Semi-Diurnal Tides of the San Francisco Estuary
Source: National Ocean Service

Tide Range Variation in the Northern Estuary

Spring tide range (mean lower low water to mean higher high water) is 1.78 m (5.84 ft) at the Golden Gate Bridge (NOS 2003a). Tide range varies throughout the Estuary. South Bay experiences a standing wave that amplifies tides about 50% (2.74 m or 8.99 ft at Coyote Creek [NOS 2003b]). North Bay, Suisun and Delta experience a progressive wave that when combined with Delta outflow dampens tides (1.50 m or 4.92 ft at Port Chicago [NOS 2003c]; 1.24 m or 4.07 ft at Rio Vista [NOS 2003d]) (**Figure 13**). This tidal exchange is a fundamental determinant of water surface levels, direction, and volume of flow and salinity and thereby exerts a fundamental influence on the biological, chemical, and physical conditions of the Estuary.

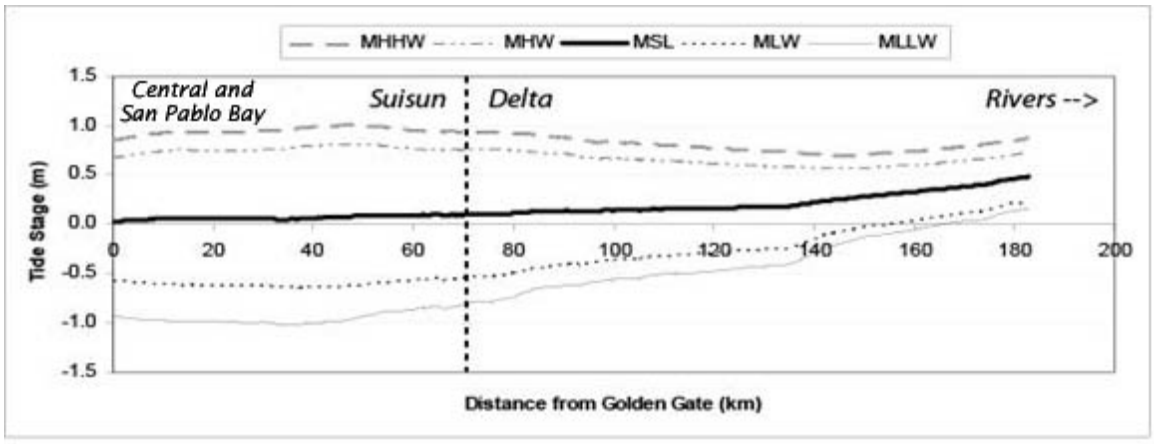


Figure 13. San Francisco Estuary-Delta Tidal Datum Profile (modeled)
Source: DWR 2004

Tidal Flows

Tidal exchange volumes at Carquinez Strait on the west side of Suisun Bay (i.e., tidal linkage downstream to the lower estuary) are ±600,000 cfs and at Collinsville on the east side of Suisun Bay (i.e., tidal linkage upstream to the Delta) are ±300,000 cfs (**Figure 14**). For perspective, the flood of record on the Sacramento River (1986) at Freeport is approximately 600,000 cfs (J. Burau, pers. comm.). The Sacramento River average summer/fall flow into the Delta ranges between roughly 10,000 to 20,000 cfs (DWR 2008).

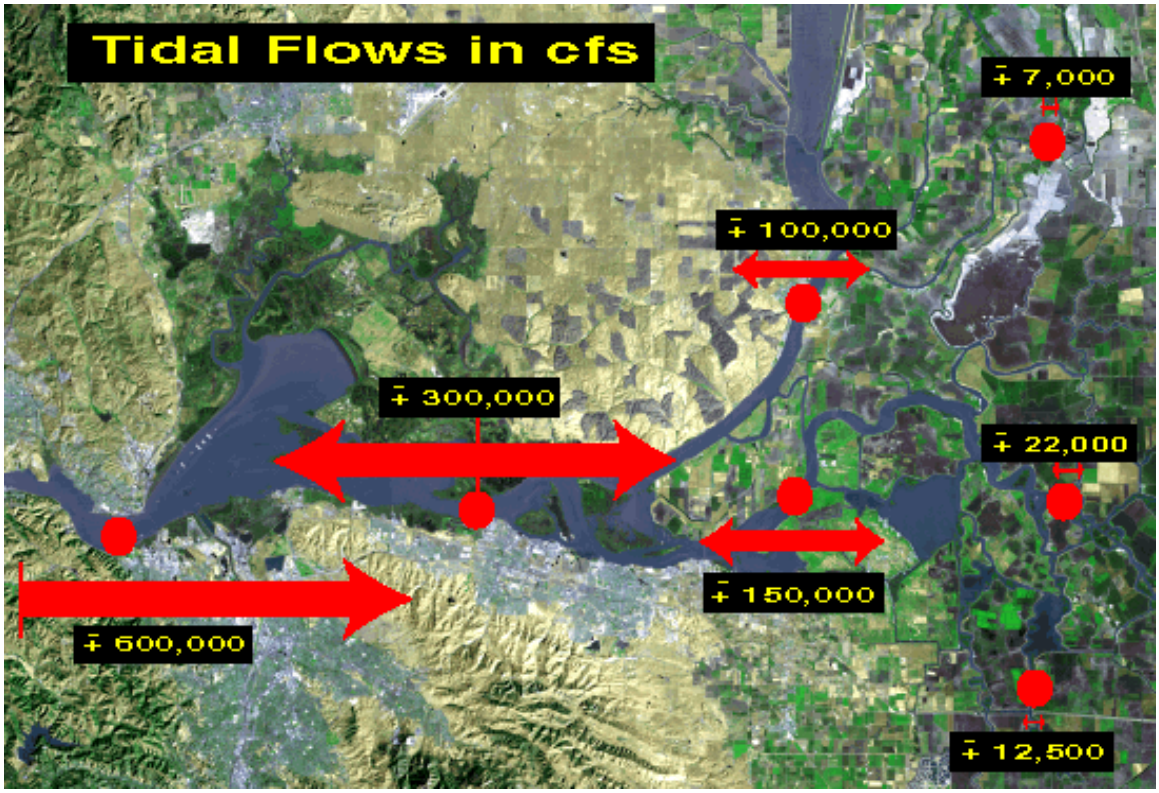


Figure 14. Tidal Flows Between Carquinez, Suisun, and the Delta
Source: USGS

Tides and Inundation Regime

The inundation regime is defined as the frequency, duration, and depth of flooding. Inundation regime is one of the most significant drivers of marsh ecology (Mitsch and Gosselink 2000) as it influences substrate character, vegetation composition, and hydrologic connectivity. Tidal marshes are distinguished from many other wetland systems in that their inundation regimes are driven by tidal cycles as well as seasonal precipitation cycles. River flows, both local tributaries (e.g., local Suisun streams) and main-stem rivers (e.g., Delta outflow) can add additional depth and duration to the tidal inundation regime, though the frequency of such contributions is much lower, less predictable, and occurs predominantly during the winter and spring months only.

3.3 Delta Outflow

According to Kimmerer (2004), the biota of the San Francisco Estuary may have one of the strongest and most consistent responses to flow among large estuaries. Delta outflow is considered to be one of the most significant driving forces on Suisun Bay and its environs. Delta outflow represents total inflow from the Sacramento River (the primary source), San Joaquin River, east side tributaries, northwest tributaries (primarily via Yolo Bypass), and southwest tributaries less in-Delta diversions and less exports from the Delta by the State Water Project, Central Valley Project, and Contra Costa Water District. The Export-Inflow Ratio (E-I Ratio) is a commonly used metric to describe how much water is being used within and exported from the Delta. This ratio often ranges from above 50% in summer to an average of 1% in the spring (Kimmerer 2004). **Figure 15** shows Delta outflow conditions across seasons and the interannual variability reflecting a range of wet to dry water year types.

Summer and fall Delta outflow is maintained by releases from the federal Central Valley Project and State Water Project dams on the tributaries to the Delta as well as by hydroelectric facilities operated by other entities. The State and federal water projects are required through their water rights permits to maintain Delta outflow and salinity standards for the Delta and Suisun Marsh at varying levels according to season and water year type. Winter and spring Delta outflows are controlled by a combination of storm patterns, snow melt, and ability of reservoirs to store water to balance flood protection, water supply, power production, and recreation.

Interannual variability of delta outflow is due primarily to variability in precipitation followed by exports, with year-to-year carry-over effects during successive dry years (Harrell 2008). Cloern et al. (1983) notes that outflow can vary from a low of about 4,700 cfs (130 cms) at the end of the drought to more than 320,000 cfs (9,000 cms) during the El Niño outflow event in January and February of 1998 (**Figure 15**). This variation typifies the overriding influence of Delta outflow in Suisun. These events, though extreme, exemplify the seasonal and interannual changes the Bay and Marsh experience. In addition, winter storm Delta outflows can bring sediment into Suisun Bay (though amount and interannual variability are not well understood; see Section 4.3). Each season's first storms carry a bulk of that sediment load, known as the "first flush" (Schoellhamer and Wright 2003).

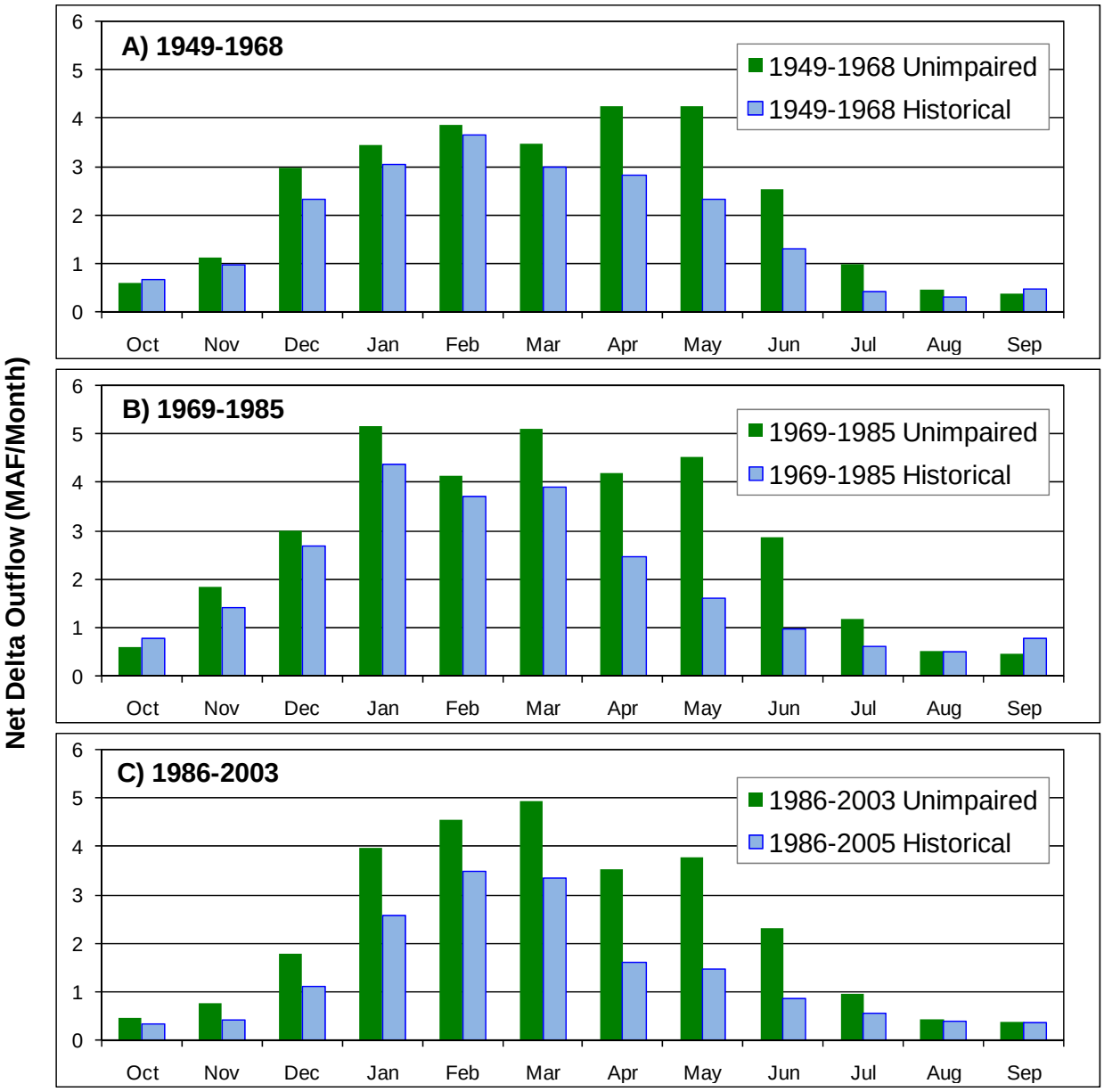


Figure 15. Delta Outflow Seasonal and Interannual Variability

Source: UC Davis Watershed Science Center, based on DWR Dayflow Data

Delta outflow can have significant effects on tide stage in Suisun Marsh. **Figure 16** illustrates the roughly 2 feet of stage increase associated with the major El Niño outflow events of early February 1998.

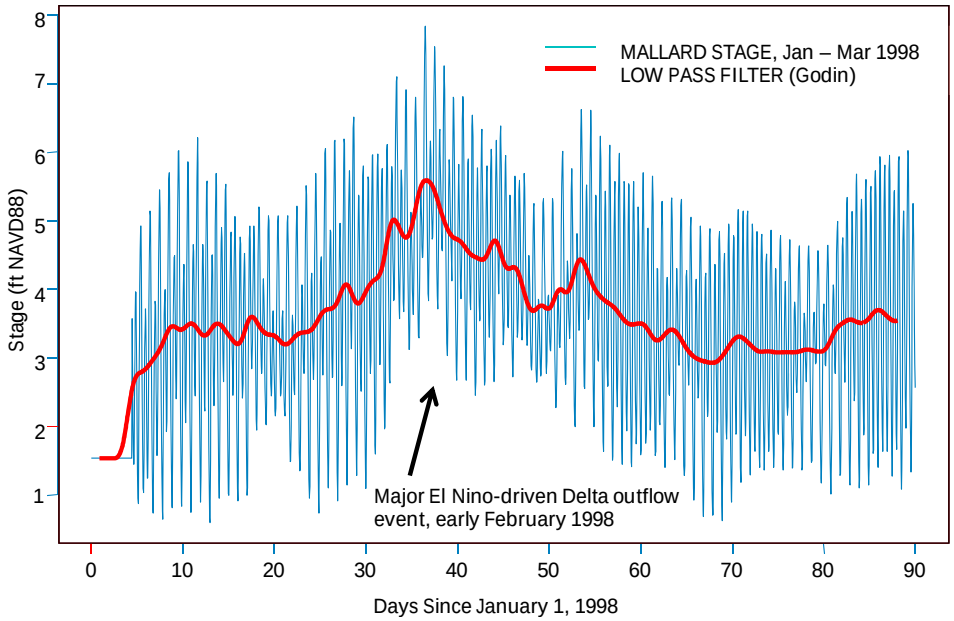


Figure 16. Effects of Delta Outflow on Suisun Tide Stage: the 1998 El Niño.
Source: DWR

3.4 Local Watershed

Several creeks enter Suisun Marsh from the west, north and east (**Figure 9**). The small drainages on the east and west are generally ephemeral. The larger northern watersheds are generally perennial; for much of the dry season, base flow in these creeks is derived from urban runoff. These larger creeks are Suisun, Green Valley, Ledgewood, Laurel, McCoy, and Union. The largest and only gauged creek inflows enter from Suisun and Green Valley creeks in the northwest Marsh. Storm runoff from ~30-50 square mile watersheds are usually short duration (1-5 days) with peak flows near 6,400 cfs (180 cms). Base flow is year round on the order of 4 cfs (0.1 cms). Suisun Creek flow is maintained year round by a water supply reservoir close to its terminus point in the Vaca Mountains above Suisun Marsh. However, this reservoir is not designed or used for flood control purposes.

Local creeks provide valuable riparian corridors and steelhead spawning habitat, but also deliver contaminants from land runoff to subtidal areas. Chapter 1 explores these contaminant concerns. In addition, residential and commercial developments immediately adjacent to the Suisun Marsh area continue to expand, causing upland habitat loss and increased runoff and water quality impacts.

Although these creeks still yield sediment from the local watershed, the sediments are difficult to capture beneficially for tidal marsh restoration because they no longer enter the marsh

system in a manner that the marsh can distribute and handle. Farming and urban development have encroached on the riparian zones of these creeks, leaving them open to scour and high sediment loads. Creeks have been channelized, causing bank erosion and flooding since the natural ecosystem no longer functions to slow and control discharge of water from the watershed into the marsh. Impaired creeks are characterized by virtually bare, undercut, and eroding banks, and movement of the creek out of its natural channel. Sediments are deposited high in the marsh, near the northern border. These areas have low energy flows from tides, wind, and currents. Consequently, sediments are left in place with suspension and minor positive movement into the central marsh.

3.5 Wastewater Treatment Plant

The Fairfield-Suisun Wastewater Treatment Plant is located in northwest Suisun Marsh and serves more than 130,000 residential, commercial, and industrial customers in central Solano County. The Fairfield-Suisun Sewage District treats an average of 16 million gallons (60.5 million L) per day, with about 90% of its waste stream being discharged into Boynton Slough (**Figure 2**). This effluent introduces a freshwater source, nutrients, biological oxygen demand (BOD) that influences water column oxygen levels for aquatic organisms, trace metals, and other pollutants to Suisun Marsh. The organic contaminant load contribution of the wastewater treatment plant to Suisun Marsh is at or below ambient levels (Yee et al. 2001). The treatment plant does, however, discharges elevated nutrient levels (Richard Looker, pers. comm.). The San Francisco Bay Regional Water Quality Control Board regulates discharge water quality via its National Pollutant Discharge Elimination System (NPDES) permit for the treatment plant. Storm water does not enter the wastewater treatment plant; it is discharged untreated into Suisun Marsh via the area's creeks.

3.6 Managed Wetlands

The diked managed wetlands of Suisun flood and drain from the tidal sloughs and bays of Suisun and they receive direct rainfall. Three wetlands also receive direct inputs from the Fairfield-Suisun City Treatment Plant. The general wetland management cycle includes fall flood up after summer periods when wetlands are relatively dry for annual maintenance activities. Fall flood up can result in net upstream flows in the smaller sloughs around the margins of Suisun Marsh, due to the large volume of water diverted from the sloughs to flood these lands. This phenomenon, observed as part of the Suisun Low Dissolved Oxygen/Methyl Mercury Study (**Figure 17**), reduces tidal exchange which can lead to reduced DO levels and increased concentrations of constituents such as methyl mercury entering these waters. During the Suisun Low DO study, these events occurred for periods of roughly one month in early fall.

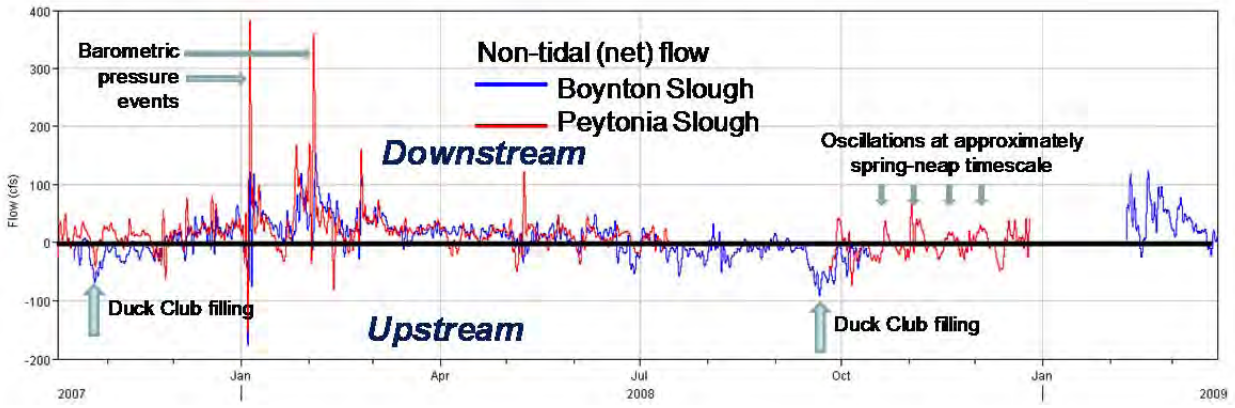


Figure 17. Net Upstream Flows in Peytonia and Boynton Sloughs During Fall Flood Up
Source: DWR

3.7 Meteorological Drivers

Along with river inputs and tides, flows are also driven by meteorological forcings including wind, evaporation, and barometric pressure change. These forces are generally co-varying, but we present them one at a time and discuss interactions.

Wind forcing

The prevailing wind in Suisun Marsh is from the west and southwest direction. During low barometric pressure conditions, wind is generally southerly. Approximately 10% of the time, more often in winter during fair weather, the wind is out of the north. Since most Marsh channels meander, reaches that are oriented along the wind direction can experience high surface water shear that generates wind waves and high turbidity during wind events. Around the bend where the channel orientation approaches orthogonality with the wind, turbidity is lower and the water surface far more quiescent. If wind direction, magnitude, and duration are long enough, the water surface shear can “set-up” the water surface and affect water levels.

Evaporation

Suisun Marsh contains a mosaic of emergent aquatic vegetation that is highly efficient at evapotranspiring water. Tule, bulrush, cattail, and rush species (including within the genera *Schoenoplectus*, *Bolboschoenus, Typha*, and *Juncus*) can evaporate 2 to 9 feet of water per year depending on temperature, wind, and humidity (USGS 2008). During late spring and summer, net flows in terminal sloughs are slightly negative owing to vegetation evaporation losses along the slough or in adjacent marsh plains. During the warm months, sloughs within tidal marshes begin to accumulate water volume. In particular First Mallard Branch accumulates water rapidly during spring tides when channel water overflows the bank and occupies the marsh plane

where it is easily evaporated. This mechanism is an important advective transport process within small sloughs during the warm months.

Barometric pressure

Barometric pressure co-varies strongly with wind direction and evaporation. When it changes rapidly, it can generate barotropic flows and change tidal heights. Over 95% of the variance in peak northern reach sea level is controlled by storm induced coastal sea level variations and wind set-up (Walters and Gartner 1985). Delta outflow generates a second, lower, peak in Suisun Bay non-tidal sea level that lags a few days.

4 Geomorphology

4.1 Summary of Alterations to Natural Geomorphology

There have been several alterations to the physical environment in Suisun Marsh over the years. As described in Section 2.7, prior to 1860 Suisun Marsh was a vast series of tidal marshes and pannes that were directly connected to the estuary and bordered by grasslands on hillslopes and alluvial fans and probably some riparian corridors along the creeks. Beginning in the 1860s, levees were constructed that diked off most of Suisun's tidal marshes, converting them into cropland and pastures (USBR 2010). Several existing large slough channels were blocked or redirected and new interior channels (e.g., Roaring River) were constructed to allow diverted water to be transported to diked agricultural lands not immediately adjacent to the natural marsh sloughs.

During this time, Suisun Marsh was also experiencing elevated rates of sedimentation. The hydraulic gold mining that took place in the Sierra Nevada in the latter half of the 19th century lead to an enormous amount of silt being washed down into the estuary, where it deposited, leading to the shallowing of bays and channels, the formation of extensive intertidal mudflats, and the conversions of some existing open water areas to tidal marsh (BDSC 2004). By the late 20th century, however, much of this material had been eroded from the open water areas of Suisun due to a ban on hydraulic mining and a reduction in sediment supply from the Delta and other upstream sources from increased diversions (Capiella et al. 2001).

By the early 1900s, livestock grazing was being replaced by other agricultural activities, but increasing soil salinities and land subsidence, due to oxidation of peat soils on diked lands, caused agriculture to fail and be replaced by managed wetlands for duck hunting (USBR 2010). Conversion to managed wetlands brought its own suite of geomorphological alterations to the landscape. Additional water control structures were installed in the perimeter levees around the clubs and internal marsh channels were constructed to better move water within the managed wetlands. In addition, many of these managed wetlands were graded to provide appropriate topographic variations for waterfowl habitat and to establish preferential water flow paths (Suisun RCD personal communication). The construction of transportation infrastructure in the form of roads and railroads throughout the 19th and 20th centuries has also disrupted the natural geomorphology of the marsh and affected the connectivity of habitats in this area.

Finally, the remaining large tidal sloughs and smaller sloughs at the northern Suisun margins had some geomorphic adjustments. For navigation purposes, Suisun Slough was straightened in

its northern reach and Hunter's Cut was built to link lower Suisun Slough with the western end of Montezuma Slough to avoid the need to navigate Grizzly Bay. For stormwater drainage purposes, many of the creeks and upper reaches of smaller tidal sloughs were modified considerably.

4.2 Topography and Bathymetry

Topography

Suisun Marsh has undergone varying levels of subsidence on lands that have been diked from the tides. To restore diked lands to tidal marsh, the primary restoration opportunity in Suisun, this subsidence has to be reversed through mineral and/or biological accretion. The time scale over which restoration sites evolve is largely a function of starting elevation and suspended sediment concentrations. Higher starting elevations are inherently closer to the "mature" marsh such as Rush Ranch, yet their time scale for maturing is driven by sediment deposition and plant matter accumulation. Consequently, the geography and interactions of subsidence and sediment supply are key drivers in tidal restoration efforts.

LiDAR topographic data has inherent accuracy limitations in wetlands because of vegetation interference. Suisun Marsh vegetation varies from plants less than 1ft tall to 5-10ft tall bulrush and tules. DWR evaluated several methods to account for this variable interference and settled upon a uniform 1.5ft lowering within the wetlands. No simple method will be accurate and no complex approach has been tried. This adjustment likely works well in some areas yet is too large or too small elsewhere. Consequently, the data presented here must be considered approximate and are best used for more regional patterns than providing a definitive land surface elevation of any given parcel of land.

Figure 18 maps the geographic distribution of diked lands topography within Suisun Marsh and the immediately surrounding upland areas, and **Figure 19** shows the histogram of acreage by depth intervals.

Geographic Patterns of Subsidence in Suisun Marsh

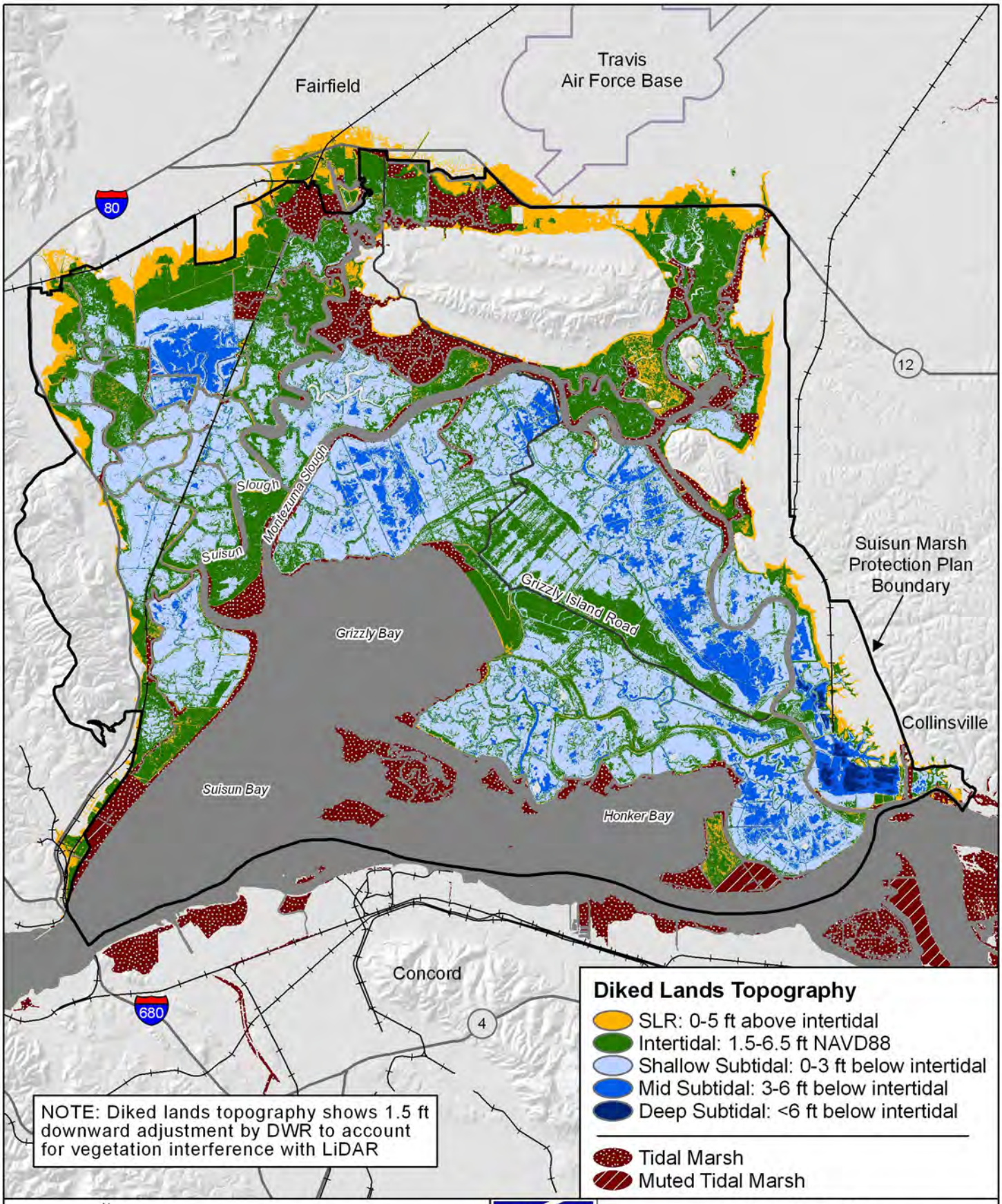
Diked lands in the northern part of Suisun Marsh are mostly within intertidal elevations and exhibit the least amount of subsidence. These lands generally also have fairly broad, gently-sloping upland edges. This combination sets an important restoration stage – wetland-transition-upland ecosystem complexes and space to accommodate lateral migration of tidal marshes with sea level rise (see lands denoted as "SLR 0-5ft" in **Figure 18**). Other intertidal elevation diked lands are found in the southwest around Goodyear Slough, the southern portion of Joice Island, and a central ridge through southern Grizzly Island. All these areas have

levees or rail lines as their upland edge, offering little if any opportunity for transitional habitats or sea level rise accommodation. Southern Grizzly Island may have some potential.

Subtidal elevation diked lands are distributed throughout much of Suisun. Considerable subtidal acreage is west of Suisun Slough with some lands being moderately subtidal (3 to 6 ft <MLLW). The northern portion of Joice Island is shallow subtidal (0 to 3 ft <MLLW). Much of Grizzly, Wheeler, and Van Sickle islands and Mein's Landing are subtidal, with a reasonable portion being moderately subtidal. The southern portion of the Montezuma Wetlands Project is the most subsided portion of Suisun, being more than 6 ft <MLLW.

Degree of Subsidence in Suisun Marsh

A vast majority of the diked lands in Suisun have undergone subsidence (**Figure 19**). Today, half the 52,000 acres of diked baylands in Suisun are above MLLW (intertidal) and half are below MLLW (subtidal). Lands subsided to shallow subtidal depths (0 to 3 ft <MLLW) make up 43% of the total diked acreage and 85% of all lands subsided below MLLW. The most subsided lands, up to 9 ft < MLLW, make up 8% of the total diked lands area.



N
W E
S

1:150,000 (1" = 12,500' at letter layout)

0 1 2 mi

0 2 4 km

Elevation Data Source: DWR 2005 LiDAR
DEM with diked wetlands lowered 1.5ft to account for vegetation interference
Produced by WWR, April 2011
map file: diked-topo-05LiDAR_Suisun_AP_1151_2011-0912mdl.mxd

WETLANDS AND WATER RESOURCES

DIKED LANDS
2005 LiDAR TOPOGRAPHY

Suisun Marsh
Solano County, California

September 2011	Project No. 1151	**Figure 18**

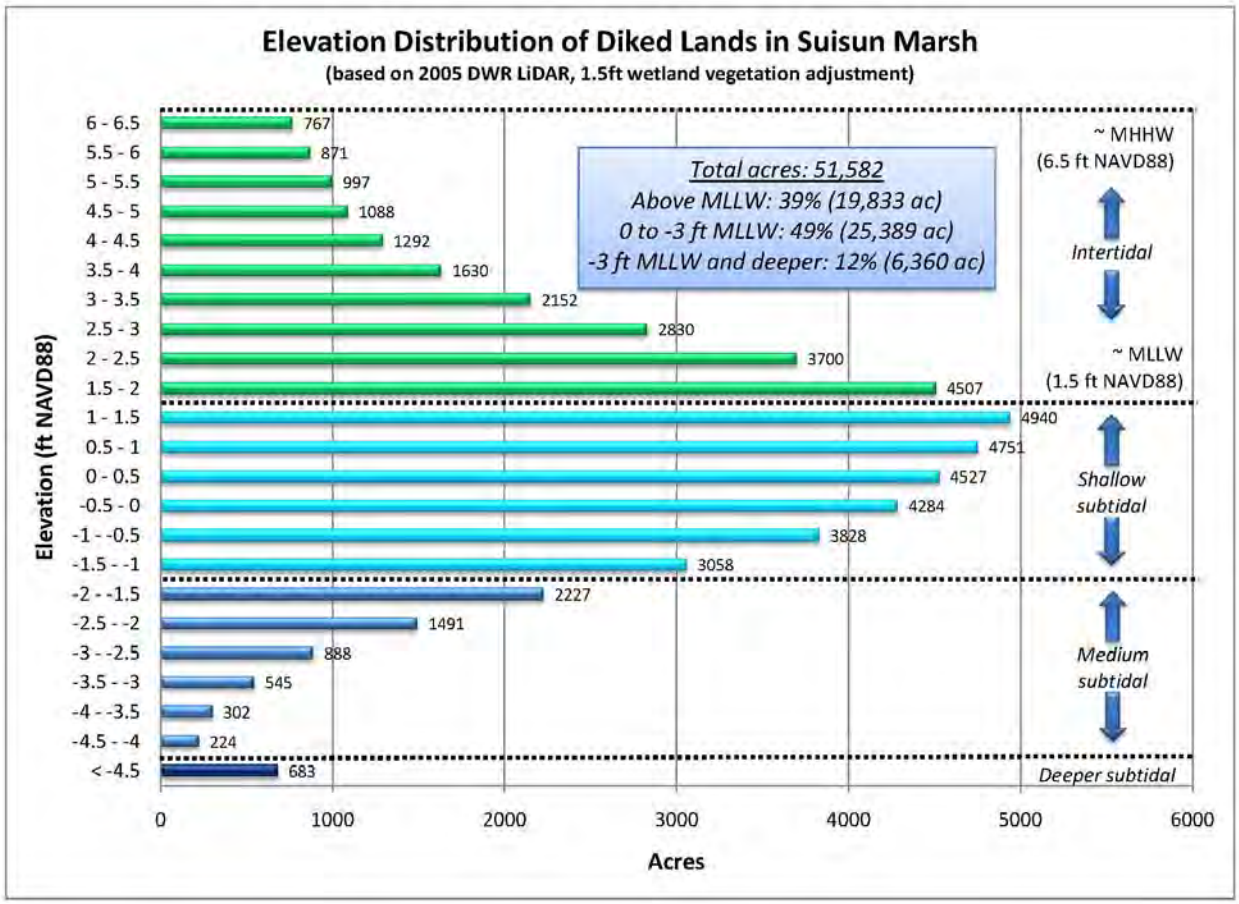


Figure 19. Histogram of Diked Lands Topography

Bathymetry

The most extensive current bathymetric data set for Suisun Marsh was compiled by the United States Geological Survey (USGS) (Foxgrover et al. 2003). USGS created a 10-m grid of depth based on data collected from several agencies, including NOAA, DWR, USGS, USBR, and USACE. Approximately 350,000 soundings were used for the Suisun Bay portion of the grid. The grid does not cover sloughs within Suisun narrower than 10 m wide; data from the SFEI EcoAtlas (SFEI 1998) fills that gap here.

Subtidal water depths in Suisun range from 1 foot (0.3 m) to nearly 90 feet (27 m) (**Figure 19**). The deepest areas are in the Suisun Bay deepwater ship channel traversing the southern boundary of Suisun Marsh. Depths through the Carquinez Straits to the west extend to well over 100 ft. Depths in larger sloughs, such as Montezuma and Suisun, generally range from 10 to 30 feet (3 to 9.1 m) with maximum depths of about 60 feet (18 m), while depths in smaller sloughs, such as Cutoff Slough, are shallower, ranging from 1 to 18 feet (0.3 to 5.5 m).

A significant fraction of the aquatic environment in Suisun, about 43% (~11,000 ac), is very shallow subtidal, within 6 ft below MLLW. Another 29% (~7,500 ac) is the remaining depths that SFEI classifies as "shallow subtidal," to -18ft MLLW. Deep subtidal accounts for 24% (~6,000 ac). Intertidal mudflats have limited extent within Suisun Marsh, covering only about 4% (<1,000 ac). **Figure 20** shows the acreage distribution by depth within Suisun Bay.

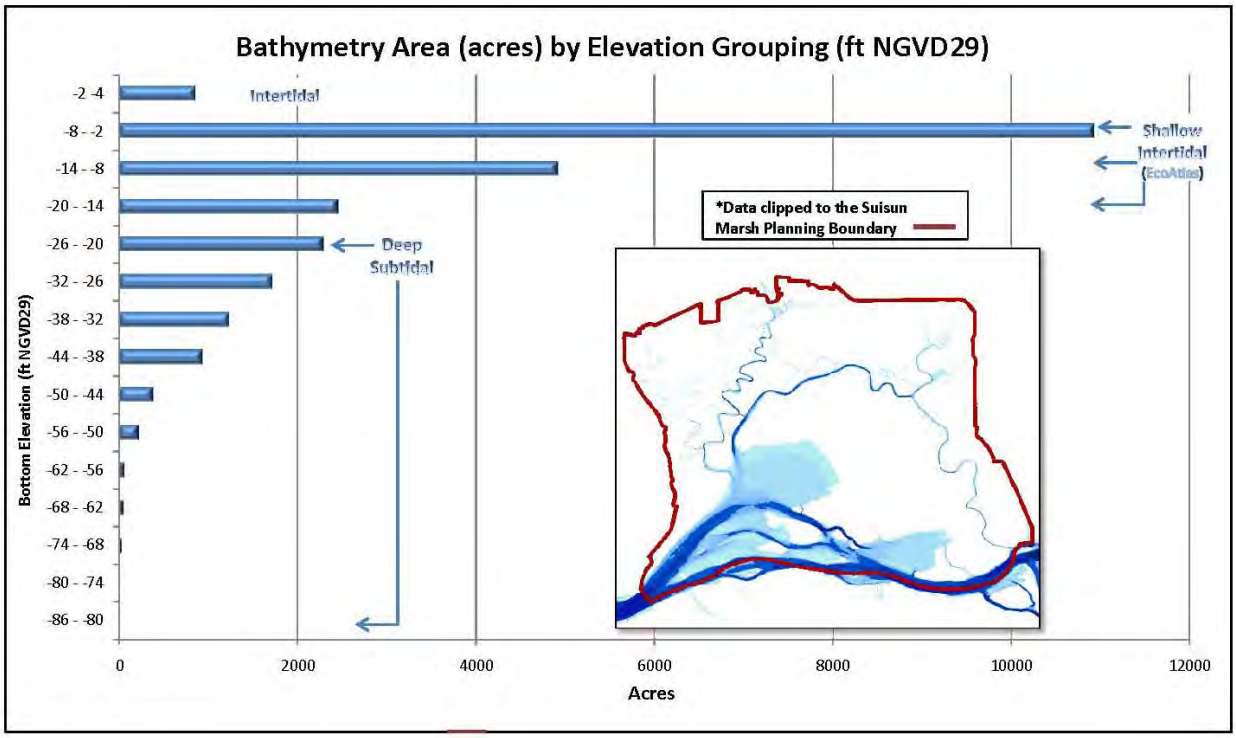


Figure 20. Histogram of Suisun Bay and Large Slough Bathymetry
Data derived from the USGS 2003 10-meter grid data set and SFEI 1998 EcoAtlas. Source: Wetlands and Water Resources.

Volume and area values for Suisun Bay (**Figure 21**) were calculated based on bathymetry grid data (Foxgrover et al. 2003). Resource Management Associates recently calculated the volume of the larger sloughs in the interior marsh to be approximately 46,000 acre-feet (56.7 m^3) at Mean High Water (MHW) and 34,000 acre-feet (41.9 m^3) at Mean Low Water (MLW).

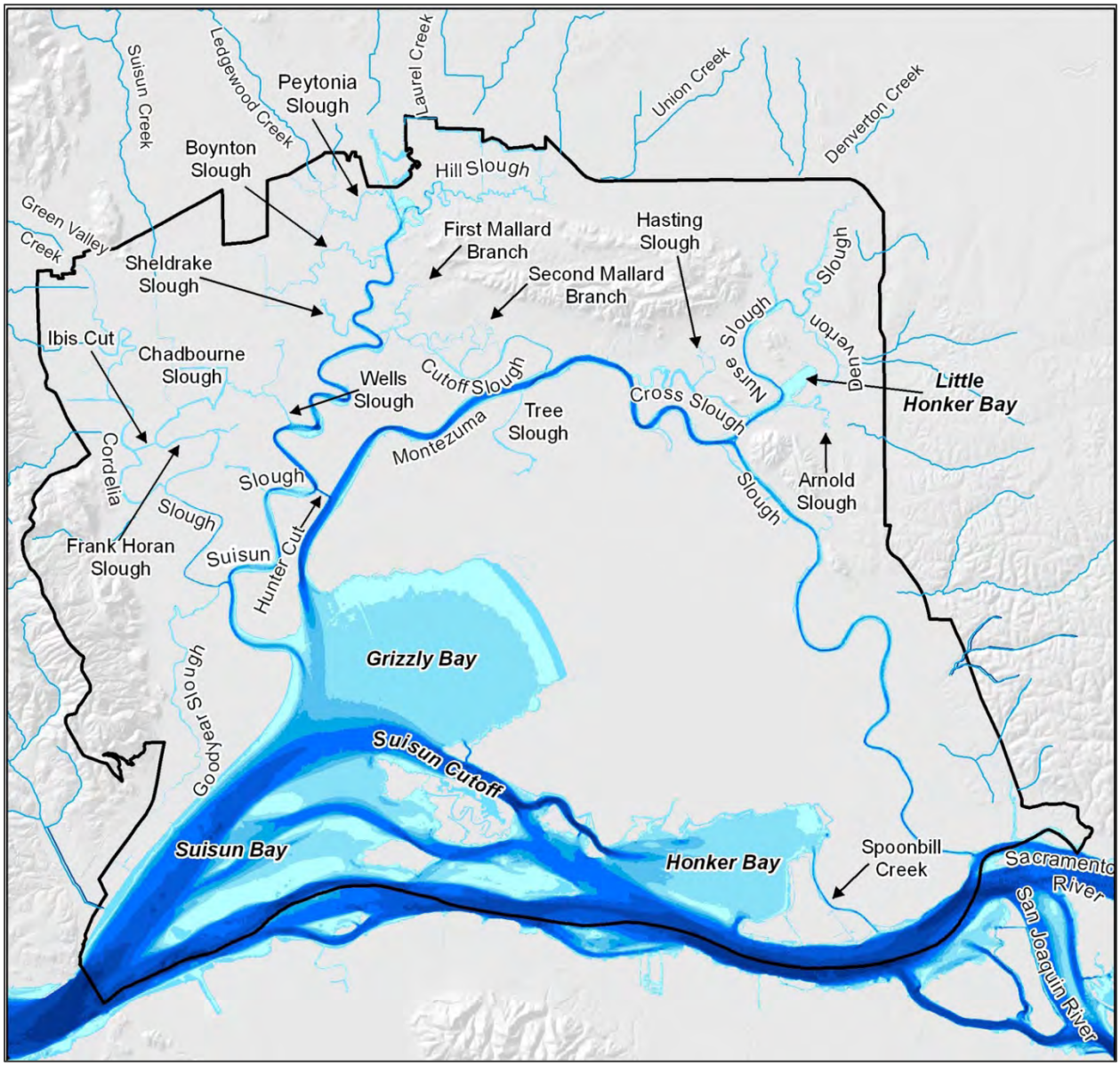


Figure 21. Suisun Bays, Tidal Sloughs, and Creeks Names

4.3 Sediments and Sediment Supply

Understanding the availability of sediment for rebuilding subsided landscapes is an important element for restoration planning. Tidal marsh accretion rates are a function primarily of sediment supply and its grain size characteristics (mass for deposition and settling velocities), time period of inundation (opportunity for deposition), and sufficiently low water velocities to avoid resuspension (keeping deposition in place). Regional-scale processes control available sediment supply and grain size characteristics; restoration planning can at most control for this variable through site selection. Site elevations, tide ranges, and extent of tidal connections

control time period of inundation; restoration planning can control for this variable mainly through levee breach designs and pre-restoration subsidence reversal efforts.

4.3.1 General Patterns of Sediment Supply in Suisun

Figure 22 illustrates the very broad pattern of sediment supply and key controlling factors in Suisun that are explained later in this section. Taking the broad view, the generalized suspended sediment gradient is lower in the north at the margins of Suisun Marsh and higher in the south in Suisun Bay. Little Honker Bay in the northeast locally has higher SSC levels from wind and tidal resuspension from the shallow bay bottom. Tidal transport from the large shallow bays in the south and some within-slough resuspension can make locally higher SSC concentrations in many sloughs. The main Suisun Bay channel SSC levels are driven by Delta inputs, some tidal inputs from San Pablo Bay, and resuspension from the shallows of Grizzly, Honker and Suisun bays.

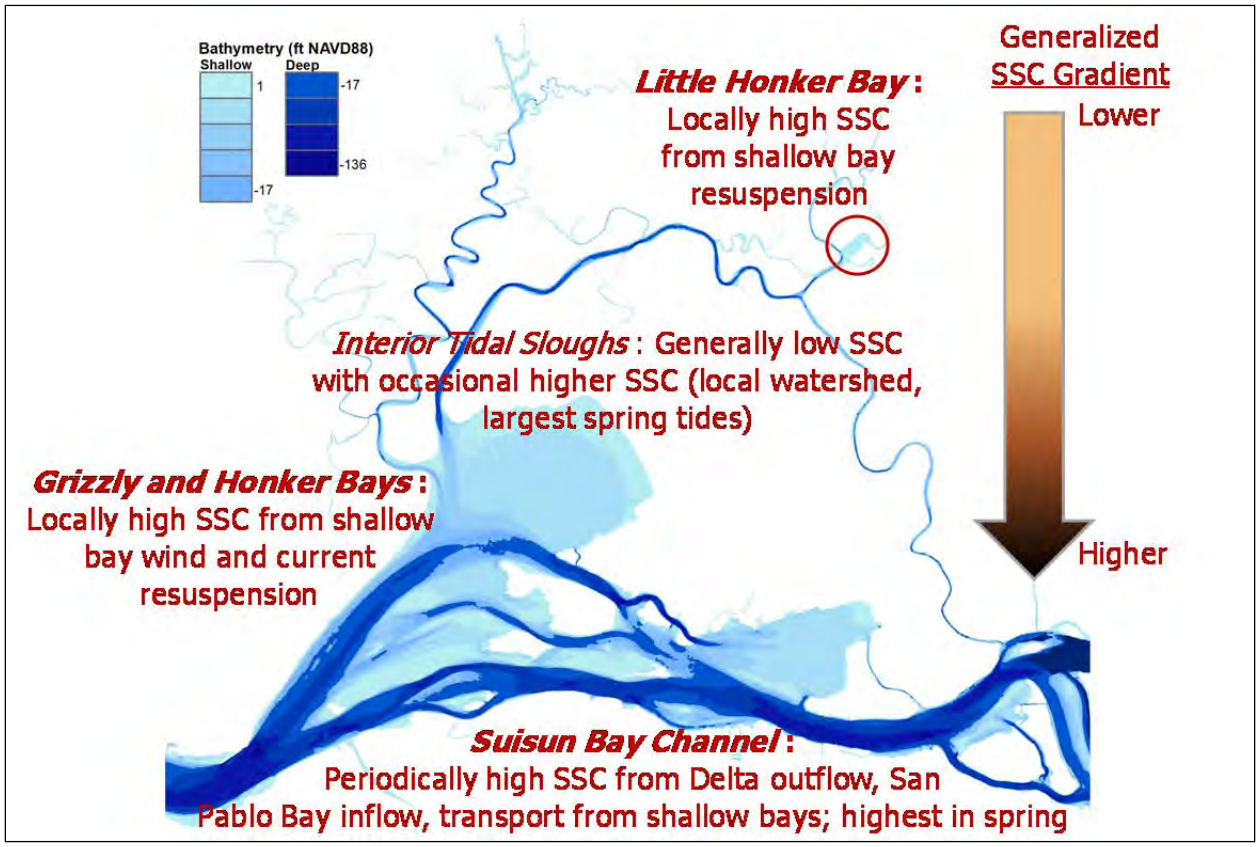


Figure 22. Conceptual Model of Suspended Sediment Concentration Gradients in Suisun Marsh

Source: Developed from Schoellhamer pers. comm.

Recent work by the USGS (Schoellhamer 2011) hypothesizes that the San Francisco Estuary cross a threshold in 1999 wherein the erodible sediment pool on the estuary's bottom is depleted. These pools are resupplied by watershed contributions, both local and from Delta outflow. The decline in those sources along with prior resuspension, transport, and deposition in areas that do not readily erode (e.g., tidal marsh restoration sites) translates into the crossing of this threshold. The ramification of this recent hypothesis is that the estuary will have reduced suspended sediment concentrations, which translates into lower rates of marsh accretion and increased potential for wind-wave resuspension to keep restoration sites from accreting at all or accreting far more slowly.

4.3.2 Conceptual Model of Local Sediment Transport in Suisun

Figure 23 illustrates the mechanisms that tidally transport and deposit from the shallow bays into the large sloughs and thus become available for marsh accretion; the primary consideration is that SSC concentrations decrease with distance upstream of the shallow embayments, meaning that restoration sites near these bays have a comparatively high sediment load and sites far from these bays have a comparatively small sediment load.

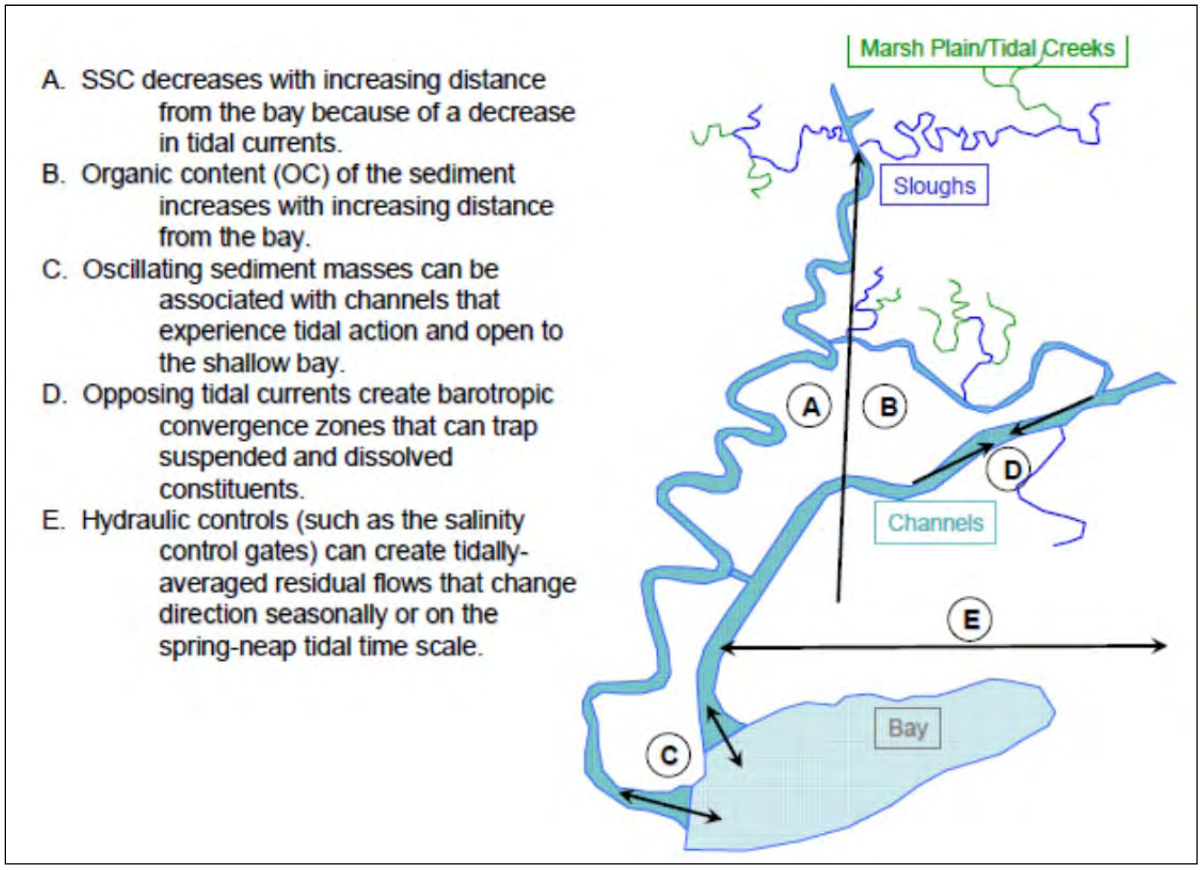


Figure 23. Conceptual Model of Tidal Transport of Suspended Sediment
Source: Chris Enright, DWR

Features that reduce water velocity within restoration site "settling basins" are vegetation, wind shelter structures, and geomorphic complexity; restoration sites have the greatest ability to manage for these variables through active site intervention. One strategy, used at Blacklock, is pre-restoration management for tall emergent vegetation; Friedrichs and Perry (2001) found that the presence of vegetation can slow flow velocity significantly allowing sedimentation throughout the inundation period, with net deposition at vegetated sites at similar elevations up to five times greater than at adjacent unvegetated sites. Another strategy is construction of non-uniformly placed higher points throughout the site to break up wind waves, as designed into the Sears Point Restoration Project (http://www.sonomalandtrust.org/publications/plans_reports.html). A third strategy is constructing large internal berms to break wind fetch (e.g., Sonoma Baylands, http://ceres.ca.gov/wetlands/projects/sonoma.html).

The suspended sediment concentration is positively influenced by (1) the position of the site in the estuary, or how close the site is to sources of sediments (rivers, creeks, bays, mudflats), (2) wind-generated waves which re-suspend sediments off the bottom, and (3) tide and storm flows, which bring sediment loads to the site from the various sources. Tide and storm flows are influenced primarily by (1) eustatic sea level rise, which increases the amount of water exchanged during the tidal cycle and (2) climate change, which acts to alter tide stage by changing storm flows, the frequency of El Nino events, and barometric pressure conditions, all of which contribute to changing surface water elevations.

Sediment grain size has a positive correlation with deposition because settling velocity generally increases with grain size. Bottom sediments in Suisun Bay typically range from silts and clays in shallow waters to silts and sands in deeper areas (Conomos and Peterson 1977). As with suspended sediment concentration, grain size is positively influenced by proximity to sediment sources and tide and storm flows. The increase in water velocities due to tidal action and storm flows allows greater suspension of larger particles than during slack-water conditions (Friedrichs and Perry 2001).

Finally, increases in salinity can increase sedimentation by promoting flocculation. This process increases sediment grain size, leading to higher rates of deposition.

4.3.3 Delta Sediment Supply to Suisun

Sediment discharge from the Delta into Suisun is the primary source of external sediment inputs into Suisun Marsh and Bay (Schoellhamer 2001). Schoellhamer et al. (2008) developed a conceptual model of sediment supply for the Delta that described supply discharged into the lower estuary (**Figure 24**). That work found that Delta sediment supply is limited and decreasing

due to trapping behind dams and diminishment of the hydraulic mining sediment supply. It also found SSC to be in the range of 10-50 mg/L except during river floods when SSC can exceed 200 mg/L.

Roughly 40% of the sediment that enters the Delta is transported into Suisun Bay, representing an average annual sediment flux of 0.56±0.18 million metric tons (Mt) during water years 1999-2002 (**Figure 24**). That sediment comes mainly from the Sacramento River (66% of total Delta sediment influx) with the Yolo Bypass, San Joaquin River, and east side tributary rivers contributing 19%, 13%, and 2%, respectively. Mallard Island in eastern Suisun Bay is a primary reporting station for Suisun water quality. Annual suspended-sediment loads from 1995-2003 at Mallard Island (see **Figure 31**) averaged 1.2 ±0.4 Mt, varying from 0.26 ±0.08 Mt in WY 2001 to 2.6 ±0.8 Mt in WY 1995. Given that the average water discharge for 1995-2003 was greater than the average discharge for the previous decade, it seems likely that the average suspended-sediment load at Mallard Island may be less than 1.2 ±0.4 Mt. Annual sediment loads at Mallard Island for WY 2002 and WY 2003 were 0.31±0.09 and 0.55±0.18 Mt, respectively, which were less than half the long-term annual average load (Leatherbarrow et al. 2005). The largest controls on interannual variability and long-term trends of sediment discharge from the Delta are amount of runoff (climate and reservoir management), whether or not Yolo Bypass is inundated which occurs in wetter years only, and sediment capture behind dams (Schoellhamer et al. 2008).

Tidally-averaged sediment transport is usually from the Delta into Suisun Bay. For water years 1999-2002, Mallard Island suspended sediment flux was seaward and 51% of the Freeport sediment discharge (Wright and Schoellhamer 2005). On a daily time scale, which is roughly tidally-averaged, McKee et al. (2006) found that sediment transport was landward 9 of 198 days for which data were available. Small river flows, gravitational circulation, and tidal asymmetries such as higher concentrations in Suisun Bay due to wind wave resuspension (Ruhl and Schoellhamer 2004) or a turbidity maximum (Schoellhamer 2001) and greater bottom shear stress during flood tide (Brennan et al. 2002), account for occasional net sediment transport from Suisun Bay into the Delta (Tobin et al. 1995). Landward sediment transport is approximately 11% of the seaward sediment transport during high flows and 52% during low flows (McKee et al. 2006). On a tidal time scale, flood tides transport sediment from Suisun Bay into the Delta and ebb tides reverse sediment transport. Tides thus exchange and mix suspended sediment between Suisun Bay and the Delta.

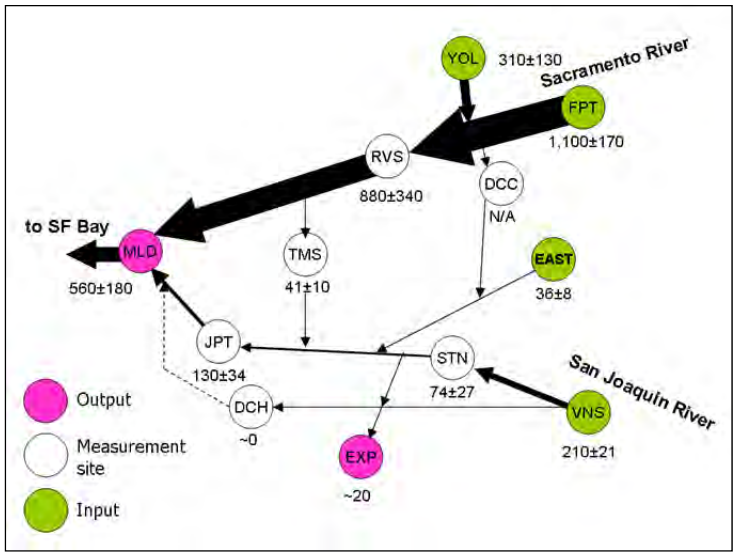


Figure 24. Average Annual Delta Sediment Budget

Data based on water years 1999 – 2002, except for Three Mile Slough (TMS) which is based on water years 2001 and 2002 only (Wright and Schoellhamer 2005). Numbers are the annual suspended-sediment flux and the estimated error in ***thousand metric tons****. Arrow thickness indicates relative magnitude of the suspended-sediment flux. Sediment deposition accounts for the decreased sediment fluxes from east to west. Additional sites are Sacramento River at Freeport (FPT), Yolo Bypass (YOL), Delta Cross Channel (DCC), Sacramento River at Rio Vista (RVS), Mallard Island (MAL), Eastside tributaries (EAST), San Joaquin River at Vernalis (VNS), San Joaquin River at Stockton (STN), exports from the State and Federal water projects (EXP), Dutch Slough (DCH), and San Joaquin River at Jersey Point (JPT). Source: Schoellhamer et al (2008)*

Taking a longer historical perspective on the role of Delta sediment exports, long-term patterns of sedimentation in Suisun were altered by the input of hydraulic mining debris from the Sierra Nevada from 1850 to the late 1800s. Capiella et al. (2001) used historical bathymetric data to determine sediment and bathymetry changes in Suisun Bay (including Grizzly and Honker bays) from 1867-1990. From 1867 to 1887 approximately 115 million m^3 of sediment, much of it hydraulic mining debris, was deposited in Suisun Bay. From 1887 to 1990, Suisun Bay eroded due to a decrease in sediment supply, a result of the ban on hydraulic mining and an increase in water diversions and flood control projects upstream of the Bay. As a result of this erosion, Suisun Bay has lost over 100 million m^3 of sediment and 40 km^2 of tidal flat area since 1887 (Capiella et al. 2001).

4.3.4 The Suisun Estuarine Turbidity Maximum

One of two significant physical processes that generate water column turbidity and thus suspended sediment that can be tidally transported throughout Suisun Bay and Marsh is the Estuarine Turbidity Maximum. The San Francisco Estuary is somewhat unique in how its ETM functions. In many estuaries around the world, the mixing of riverine freshwater and ocean salt water is driven largely by the density differences of the fresher (lighter) and saltier (heavier)

waters and the rising and falling of the tides (**Figure 25**). Those processes do operate in this estuary.

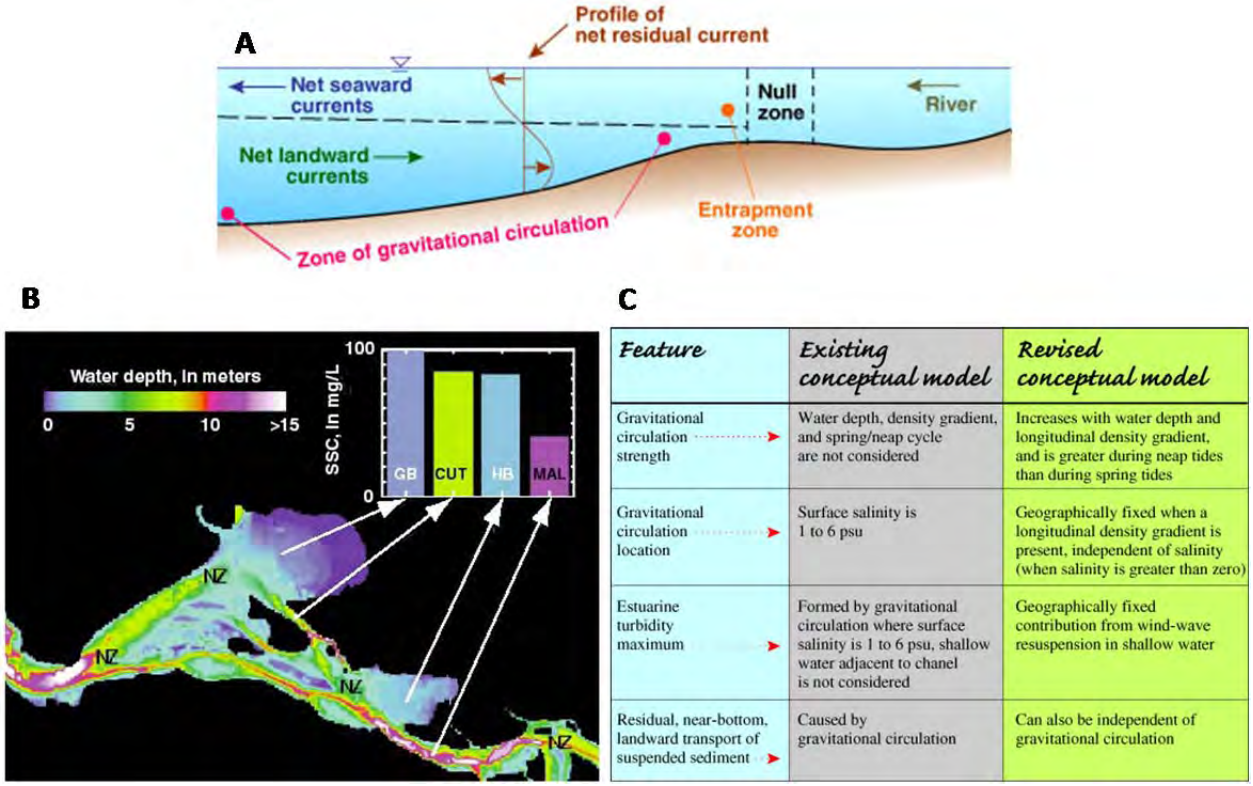


Figure 25. Existing (Classic) Model of Estuarine Mixing and New Model for Suisun Bay
(A) Existing (classic) modeling of estuarine mixing and estuarine turbidity maximum; (B) Location of three bathymetric sills in Suisun Bay that generate added gravitational circulation component; (C) Comparison of key features of existing and revised model for Suisun Bay. Source: USGS (http://sfbay.wr.usgs.gov/sediment/circulation/index.html)

The very important additional process at play in Suisun Bay are three large bathymetric sills, one a short distance east of the Benicia Bridge and two more associated with Suisun Cutoff (**Figure 26**). These abrupt bathymetric sills cause strong vertical mixing in the water column the action of which resuspends mobile sediments. These processes operate more strongly on spring tides.

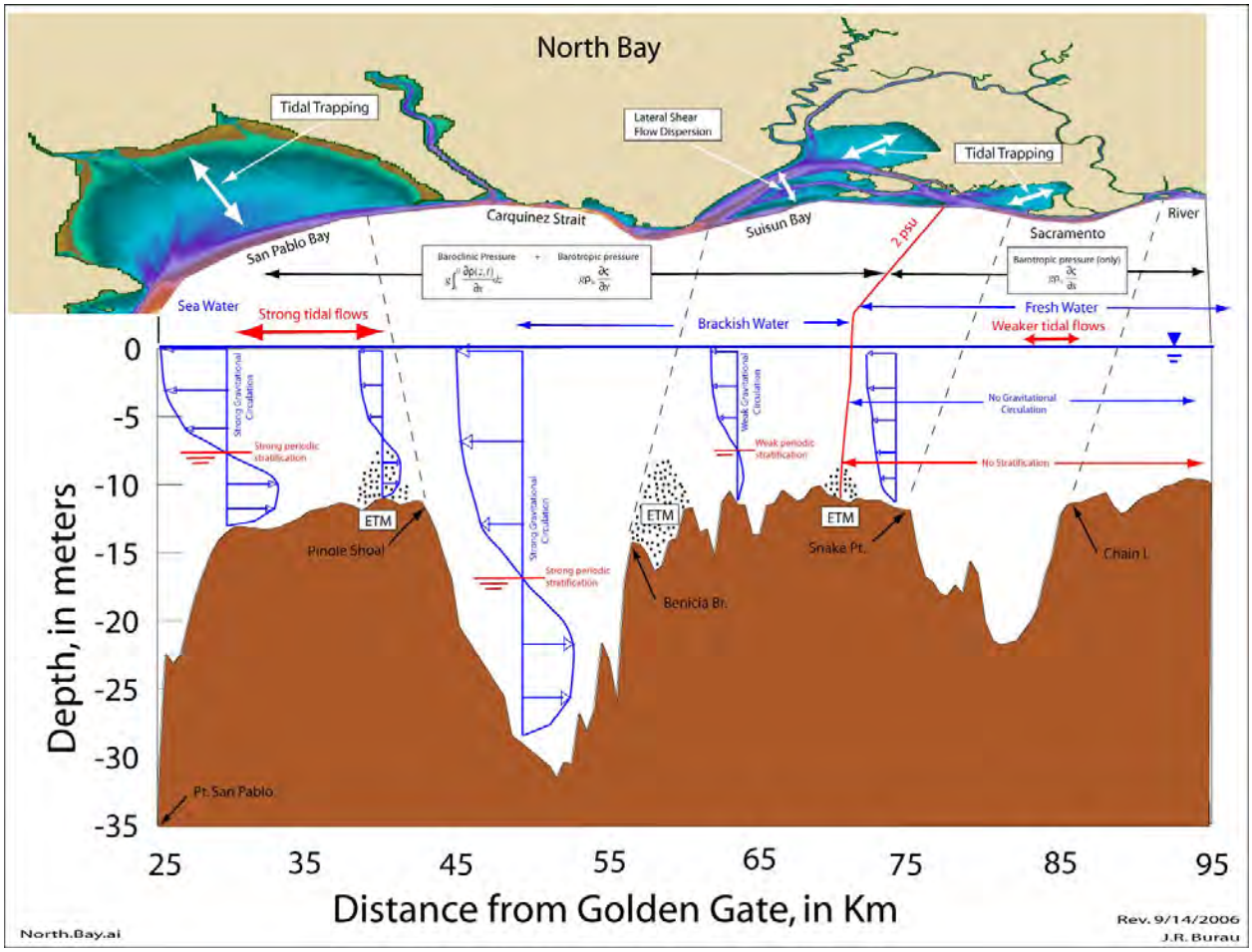


Figure 26. Current Model of Suisun Bay Mixing
Source: Jon Burau, USGS

During the summer months when wind-wave action resuspends sediments in San Pablo Bay to the west, this mechanism can transport those sediments into Suisun Bay where they can become actively mixed in the water column.

Movement of sediment is affected by sediment characteristics such as grain size and cohesiveness and flow characteristics such as turbulence and shear stress across submerged surfaces (Kimmerer 2004). Processes within the Bay strongly influence suspended sediment transport into and out of the marsh sloughs. Three factors have a potentially major influence on the distribution of suspended sediment within the Marsh: 1) barotropic convergence zones, 2) hydraulic controls, and 3) tidal channels that open to shallow water regions of the Bay. Barotropic convergence zones, where tidal flows are in opposition, can trap dissolved and suspended components on a tidal time scale (Swanson et al. 2003, Warner et al. 2003). Entrance controls, such as the salinity gates on Montezuma Slough (**Figure 31**), can affect the transport of materials by altering flow across the marsh (Warner et al. 2003). In tidally

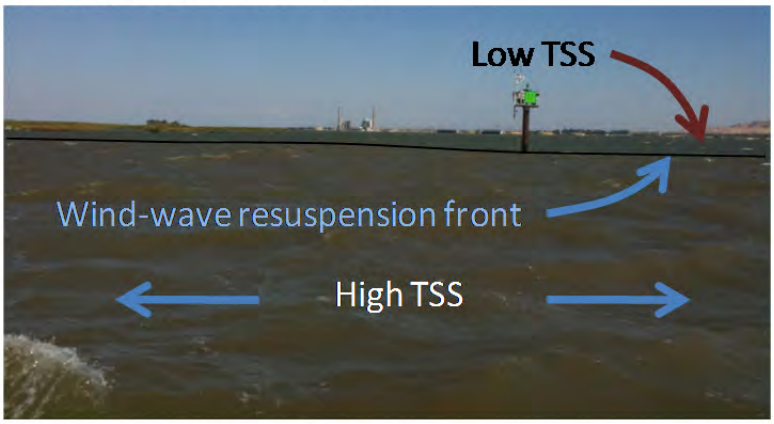
influenced channels that open to the shallow Bay, physical processes operating on a tidal time scale can result in the oscillation of sediment between channels and the Bay. Flood tide currents can resuspend sediments outside the mouth of a channel and transport them up into the channel. As the tide goes slack, sediment becomes deposited in the channel. When the tide reverses, local currents increase and the sediment mass is resuspended. The mass is transported out of the channel and can be redeposited outside the channel mouth (Ganju et al. 2004). This phenomenon was observed by Brennan et al. (2000), who found that sediments in Cutoff Slough eroded more readily during the first two hours of a spring ebb tide and that strong stratification developed during neap ebb tide conditions. They calculated the average landward flux of sediment on an 8 day interval to be 14 g/s/m2.

Total suspended solids concentrations affect the depth to which light can penetrate the water column. This penetration depth in turn affects primary productivity and the production of chlorophyll-a and dissolved oxygen (DO). If secondary consumption is greater than primary production, oxygen saturation decreases to less than 100%. If primary producers outproduce consumption rates, the water column can become supersaturated with regards to DO. DO is discussed more in-depth in Section 5.3 below.

4.3.5 Wind-Wave Resuspension and Tidal Transport

Wind-wave resuspension combined with tidal transport provides a suspended sediment source. The Suisun Marsh region is renowned for persistence, strong winds; so renowned in fact that much of the lands extending from the east side of the Marsh to Rio Vista now support extensive wind mills generating large quantities of electricity. These winds generally originate from the west. The large shallow embayments of Suisun Bay, Grizzly Bay, and Honker Bay in the south and the smaller Little Honker Bay in the northeast can produce high suspended sediment loads. Their physical orientation relative to prevailing winds (**Figure 2**) often optimizes wind-wave resuspension. These processes are readily visible in the water as shown in the photographs taken near Chipps Island (**Figure 27**).

A) Honker Bay wind-wave resuspension on flood tide; front of higher TSS waters tidally transporting east



B) Plume of Honker Bay wind-wave resuspended sediments transporting on flood tide through Spoonbill Slough (between Chipps and Van Sickle Island) into deepwater channel

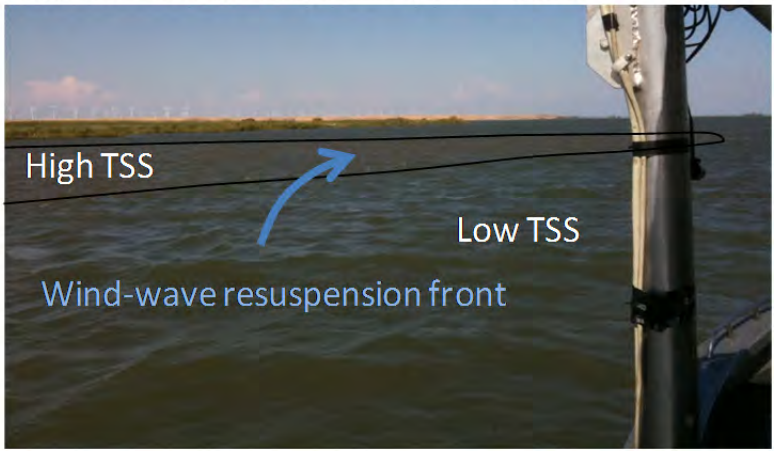


Figure 27. Wind-Wave Resuspension and Tidal Transport, Honker Bay and Deep Water Channel

Photos taken 7-29-2009 within first two hours of flood tide with moderately strong wind-wave energy resuspending sediment from Honker Bay. Photos by Stuart Siegel

4.4 Geology and Soils

Suisun Bay occupies a topographic depression in the easternmost portion of the Coast Ranges. This low area is defined on its west side by uplift along the active Green Valley and Concord fault trends (Wagner and Bortugno 1982; Wagner et al. 1990; Hart and Bryant 1997; Graymer et al. 2002) and on the east by the Pittsburg–Kirby Hills fault zone, which is likely allied to the Mt. Diablo thrust system to the south and may also be active, as discussed in more detail below (Unruh and Hector 1999). West of Suisun Bay the Coast Ranges rise steeply; east of Suisun Bay are the rolling Montezuma Hills, which consist of uplifted sedimentary strata of early

Pleistocene age, with active (Holocene) alluvium in stream drainages that dissect the uplift. Low-lying flat areas of current and former marshland that border the Bay proper are underlain by Bay Mud deposits of Holocene age. To the north of Suisun Bay, the Potrero Hills, which form the topographically higher central portion of Grizzly Island, consist primarily of tightly folded and faulted marine sedimentary rocks of Eocene age, flanked by an apron of late Pleistocene alluvial fan deposits (Graymer et al. 2002) (**Figure 28**).

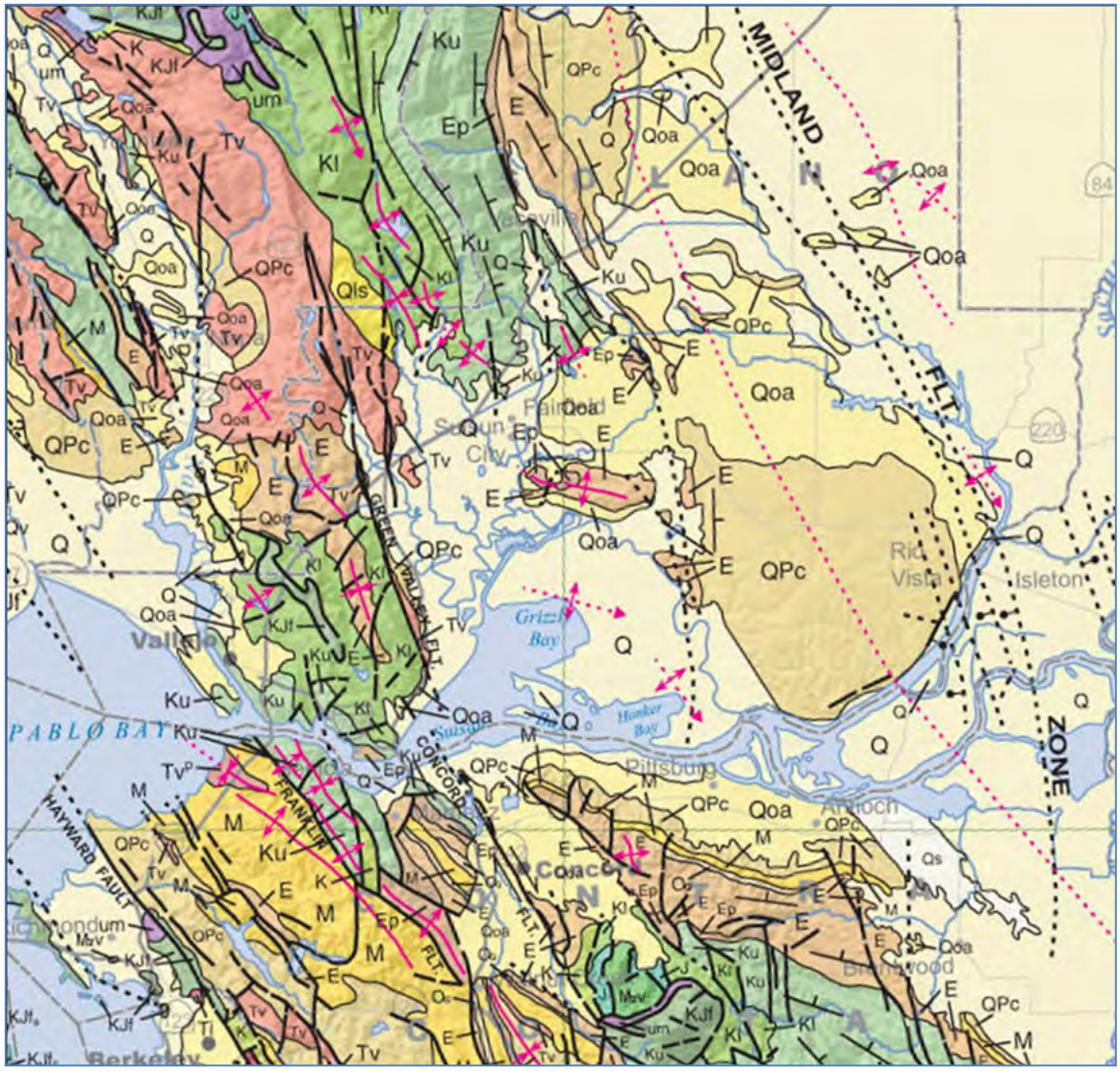


Figure 28. Geologic Map of Suisun and Surroundings
Source: California Geologic Society

Suisun Marsh soils are mixtures of deposited mineral sediments and plant detritus (SEW 2001). As the Marsh formed, plant detritus slowly accumulated, compressing the saturated underlying

material while mineral sediments were continually added to the organic material by tidal action and during floods (SEW 2001).

All Suisun Marsh soils that were historically inundated by the brackish tides are saline. Salts are present throughout the soil profile and maintained by saline groundwater and by periodic flooding with brackish surface water (SEW 2001). As with channel water, there is an increasing soil water salinity gradient in Suisun Marsh from east to west and from north to south (SEW 2001).

Soils of Suisun Bay's bayland and marsh areas include the Joice muck, Tamba mucky clay, and Suisun peaty muck, with small enclaves of remaining active tidal marsh substrate. Areas of Reyes silty clay, and Valdez loams (Valdez silty clay loam, clay substratum; Valdez silt loam, drained) are also present (Bates 1977) (**Figure 29**).

The Joice and Suisun series occur in nearly level areas of salt marsh or former salt marsh and are very poorly drained organic soils that formed from the accumulation of hydrophytic plant remains with an input of fine-grained mineral sediment (Bates 1977). A typical profile of the Joice muck consists of black, saline clayey muck to depths of more than 60 inches. Permeability is limited; surface water tends to pond, and erosion hazard is slight (Bates 1977). The Suisun peaty muck consists of more than 60 inches of dark-colored muck that contains dark reddish-brown plant fibers. Permeability is rapid, but under natural conditions the water table is shallow (10–20 inches below ground surface), so surface water tends to pond. Erosion is not a hazard in the Suisun peaty muck (Bates 1977).

The Tamba series also occurs in nearly level areas of current and former salt marsh and consists of very poorly drained organic-rich soils. Tamba series soils formed in alluvium derived from mixed sources and in hydrophytic plant remains. In a typical profile, the Tamba mucky clay consists of about 10 inches of light brownish-gray, grayish-brown, and yellowish-brown mottled mucky clay overlying about 30 inches of mottled gray and black mucky clay, which in turn overlies a substratum consisting of more than 30 inches of gray mucky clay. Permeability of the subsoil is moderate, and under natural conditions the water table (12–36 inches below ground surface) so surface water tends to pond. Erosion hazard is slight (Bates 1977). Active tidal marsh is a very poorly drained, strongly saline land type restricted to areas between constructed levees and bodies of water. Tidal marsh substrate ranges from mud flats to a mixture of hydrophytic plant remains and alluvial sediment (Bates 1977).

The Reyes series occurs in nearly level areas of current and former salt marsh and consists of poorly drained soils that are very strongly acid and saline. Reyes soils formed in alluvium

derived from mixed sources. A typical Reyes profile, like that of the Reyes silty clay, consists of about 7 inches of light gray, yellowish-red, and grayish-brown mottled silty clay overlying about 35 inches of mottled gray silty clay, which in turn overlies a substratum of gray silty clay. The substratum is moderately alkaline *in situ* but becomes strongly acid when exposed to the air and allowed to dry. The water table is 24–48 inches below ground surface under natural conditions. Permeability is slow, and surface water ponds on Reyes soils. Erosion is a slight hazard (Bates 1977).

The Valdez series consists of poorly drained soils that formed in nearly level areas on alluvial fans. Valdez soils are also present in some areas where dredge spoils have been disposed of. A typical Valdez profile includes about 12 inches of light-colored mottled silty clay loam, overlying about 20 inches of light-colored mottled and stratified silty clay loam and very fine sandy loam, which in turn overlies subsoil consisting of more than 40 inches of slightly darker colored mottled and stratified silty clay loam, silt loam, and very fine sandy loam. The Valdez silty loam, drained, has a profile similar to this, except that the texture is silt loam throughout, and salinity is lower. Artificial drainage maintains the fluctuating water table at depths of more than 4 feet below ground surface. Permeability is moderately slow, runoff is slow, and erosion hazard is slight in the Valdez silt loam, drained. The Valdez silty clay loam, clay substratum is also similar to the typical Valdez profile but is underlain by a buried clay soil at a depth of 35–50 inches below ground surface. It is a moderately to strongly saline soil. Permeability is slow, runoff is slow, and erosion hazard is slight in the Valdez silty clay loam, clay substratum. The water table is 3–5 feet below ground surface in this unit (Bates 1977).

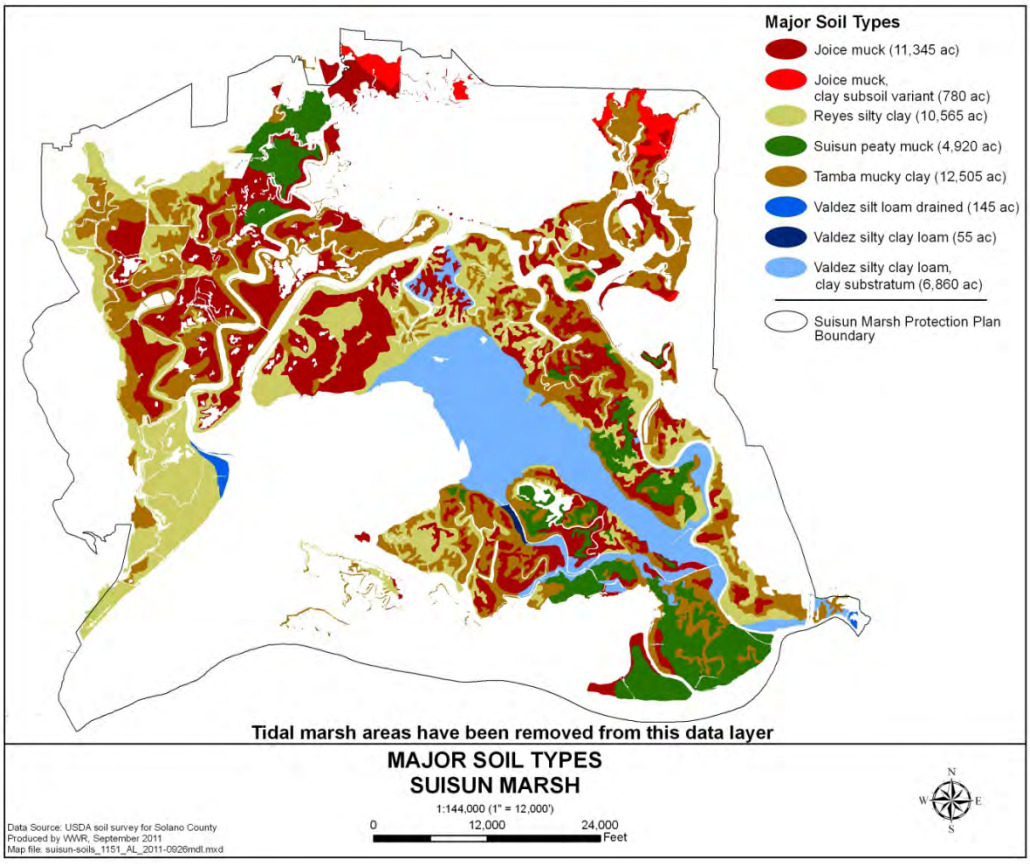


Figure 29. Major Soil Types of Suisun Marsh Diked Wetlands
Source: NRCS Soils Data

5 Water Quality

5.1 Summary of Alterations to Water Quality

There have been many changes in Suisun Marsh and its surrounding watershed since the time of European colonization that have had an impact on water quality within the marsh. Agricultural and urban development began in the Suisun Marsh watershed in the late 1700s – early 1800s (Goals Project 1999), likely leading to an increase in the loading of nutrients, sediments, bacteria, and other pollutants. Suisun City, founded in the 1850s along the northwest edge of the marsh, was an important port for shipping agricultural goods from the surrounding areas to markets in San Francisco and a bustling center of commerce in the area (Suisun City website 2009), which undoubtedly contributed pollutants via untreated wastewater and stormwater directly to Suisun Slough. Development within the watershed continued throughout the 19th and 20th centuries increasing the level of pollution input to Suisun Marsh. The enactment of water quality protection laws in the 20th century eventually lead to the construction of wastewater treatment plants, which have helped to reduce the amount of organic, bacterial, and nutrient pollution in receiving waters. The modern Fairfield-Suisun Sewer District treatment plant in the northeast corner of the marsh discharges water directly to Boynton Slough and several managed wetlands in the vicinity.

The management of diked wetlands for waterfowl habitat usually involves a series of discrete flooding and draining events spaced out over a time period of a week to several months, which is significantly different from the daily flooding and draining of a tidal marsh. Researchers have found that water held for long periods of time within these marshes typically has low dissolved oxygen (DO), and elevated dissolved organic carbon (DOC) and methylmercury (MeHg) due to biological processes occurring within the wetlands (WWR et al. 2010b). When this water is released into the adjacent sloughs, it can impact regional water quality as evidenced by DO sags measured within the receiving water bodies at the time of release (O'Rear et.al 2010, Schroeter and Moyle 2004, WWR et al. 2010b).

Construction of the Central Valley Project (CVP) and the State Water Project (SWP) in the 20th Century led to increased water exports from the Delta for agriculture and municipal uses, resulting in decreased flows into Suisun Marsh at certain times of the year. The decrease in flows into Suisun Marsh led to salt water intrusion from San Francisco Bay to the west and an alteration in the salinity regime of the marsh (SEW 2001). As a result, several salinity management structures were constructed throughout the marsh beginning in the 1970s to combat these changes to the salinity regime.

5.2 Salinity

Salinity within the Suisun Marsh-Bay system is an important habitat characteristic that exerts a major control on both physical and ecological processes. As a result, salinity control has been the focus of water management activities in the Marsh since the 1970s. Salinity influences chemical processes such as sorption-desorption and flocculation, physical processes such as density stratification and vertical mixing, directly influencing the distribution and form of many trace substances (Cloern et al. 1983), and the ecological suitability for organisms as a function of physiological tolerances. For example, the Suisun Ecological Workgroup concluded that fish species native to Suisun Marsh require low salinities during the spawning and rearing periods, stating that salinities exceeding 8 parts per thousand (ppt) could be limiting to spawning and rearing of native fish (SEW 2001). Meng et al. (1994) found that overall fish abundance and species diversity declined in Suisun Marsh over a 14-year period due to decreases in freshwater outflow and increases in salinity.

Salinity Regime

The Suisun Bay-Marsh system contains both the maximum estuarine salinity gradient and low salinity zone within the San Francisco Bay Estuary. The position of the low-salinity zone is often described using a parameter called X2. This parameter is measured as the distance from the Golden Gate upstream to the 2 ppt bottom isohaline. X2 has been used since 1995 as an index of estuarine productivity within the Bay/Delta system that integrates several physical, chemical, and biological parameters (Jassby et al. 1995). High productivity in upper trophic levels often occurs within in the region of X2 and just downstream along the maximum estuarine salinity gradient. The system's overall estuarine salinity gradient trends from west to east, with higher salinities in the west and lower salinities in the east. The west-east salinity gradient across Suisun Marsh (via Montezuma Slough) generally is consistent with the Suisun Bay salinity gradient. Exceptions to this dominant regime are encountered when the Suisun Marsh Salinity Control Gate (SMSCG; discussed below) operates in the fall and winter. The salinity gate tends to compress the Montezuma Slough salinity gradient. Despite salinity gradient compression, tidal salinity variability is reduced because the flood tide is arrested by the closure of the gate (Enright 2008). Suisun Marsh also exhibits a persistent north-south salinity gradient because several creeks generally emerge from the coast range in the north. Despite low and seasonal flows, the surrounding creeks have a significant water freshening effect due to long residence times in upper sloughs. Wastewater discharges into Boynton Slough from the Fairfield-Suisun Treatment Plant also contribute to locally reduced salinity.

Long-Term Salinity and Control Structures

The State and federal water projects built several salinity control structures in the Marsh between 1970 and 1990, including the Roaring River Distribution System, Morrow Island

Distribution System, Goodyear Slough Outfall, Lower Joice Island Unit, Cygnus Unit, and the Suisun Marsh Salinity Control Gate (SMSCG). The SMSCG (**Figure 30**) is the largest and most effective salinity control structure within Suisun. Located at the east end of Montezuma Slough (**Figure 31**), when operational the salinity gate is opened on ebb tide to allow low salinity Sacramento River water into the Marsh and closed on flood tide, thereby tidally pumping freshwater from the Delta northwest into Suisun Marsh. The SMSCG usually begins operating in early October and, depending on salinity conditions, may continue operating through the end of the control season in May[4]. When the gate is operating, the tidally averaged flow in Montezuma Slough is more than 70 cms (2,500 cfs) (east to west) compared to nearly zero when not operating. By comparison, the discharge in the Sacramento River measured at Freeport (near Sacramento) during the typical period of gate operation is on the order of 200-500 cms (7,000-18,000 cfs). When not operational, the gate is left in the fully open position, allowing full tidal exchange between Montezuma Slough and the lower Sacramento River.

Figure 30. Suisun Marsh Salinity Control Gate
Source: DWR, http://www.iep.ca.gov/suisun/facts/physicalFacilities.html#smscg

Gate operations are effective at controlling salinity levels at most locations in the Marsh. The magnitude, timing, and duration of salinity reduction in response to the SMSCG operation vary with proximity (**Figure 32**). Water quality stations are located throughout Suisun Marsh (**Figure 30**). A drop in salinity due to gate operations is seen immediately at monitoring station S-64 (National Steel) and about one day or so later at S-49 (Montezuma Slough at Beldon's Landing) because both are located close to the gates (**Figure 31**), it takes about two to three days before a salinity drop can be observed at S-42 (Suisun Slough and Volanti) and S-21 (Chadbourne

[4] http://www.iep.ca.gov/suisun/facts/physicalFacilities.html#smscg

Slough at Sunrise Club), because both are located in the north-central part of the marsh. Salinity levels at C-2 (Sacramento River at Collinsville) tend to increase slightly from gate operations because of interactions between tidal exchange, outflow, and gate operations. At S-35 (Goodyear Slough), gate operations are effective in controlling salinity, but to a lesser magnitude and with a longer time lag due to the distance of the station from the gates. At S-97 (Ibis), gate operations are not effective in controlling salinity because of its location in the far western portion of the marsh.

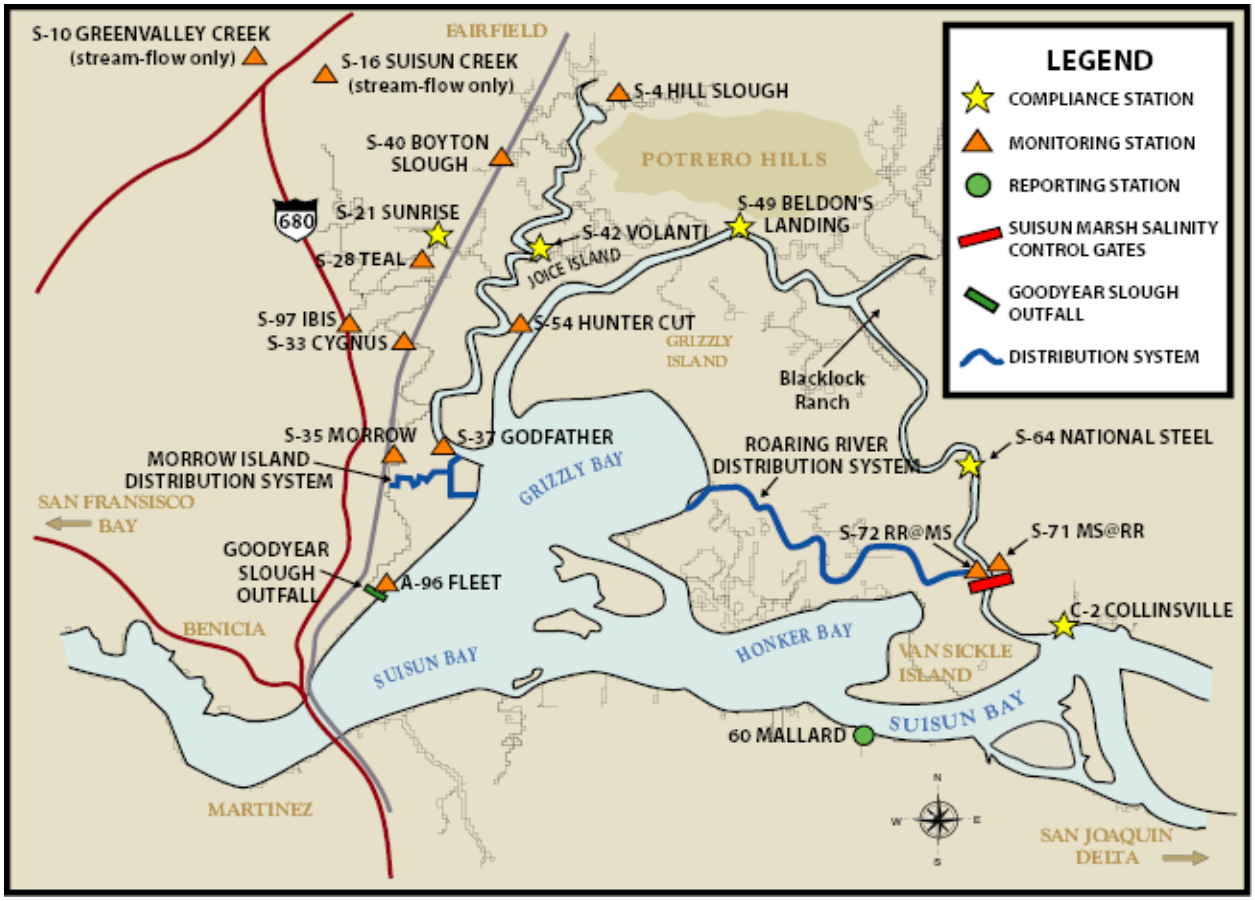


Figure 31. Suisun Marsh Salinity Control Features and Monitoring and Compliance Stations
Source: DWR, http://www.water.ca.gov/suisun/photos/monitor.cfm

The overall effectiveness of the SMSCG is summarized in **Figure 33**. The chart averages several years of salinity response at several stations in the Marsh, nominally arrayed east to west along Montezuma Slough. The pink trace is the 7-year average salinity gradient from west-to-east one day before gate operation. The blue trace depicts the same salinity gradient ten days after commencement of gate operation. In general, the gate reduces salinity by about half from the salinity level ten days prior. The percentage reduction in salinity decreases towards the west. In addition, salinity generally increases at station C2 at Collinsville. **Figure 34** shows the companion salinity change in Suisun Bay. Operation of the SMSCG tidally pumps about 2,500 cfs

through Suisun Marsh, removing the same net flow from Suisun Bay. While the hydrodynamics and transport processes that control salinity are complex, the reduction in outflow through Suisun Bay allows salinity to disperse incrementally upstream. The green arrow indicates the upstream shift in X2 that occurs on average when the SMSCG operates. In general, X2 shifts upstream about 3 kilometers when the SMSCG operates.

The effectiveness of gate operations on salinity control at three stations is illustrated in (**Figure 32**). This figure shows the results of model runs of salinity with and without gate operations at three stations across the marsh from 1920 to 2006. Salinity in the Marsh without SMSCG operations generally ranges from 1 ppt to 25 ppt depending on the season and location. Modeled salinity variability in the eastern marsh is significantly dampened by operation of the SMSCG, benefiting organisms that gain from reduced salinities and potentially adversely affecting organisms that depend on the variability. This modeled dampening effect is less pronounced in the western portion of the Marsh.

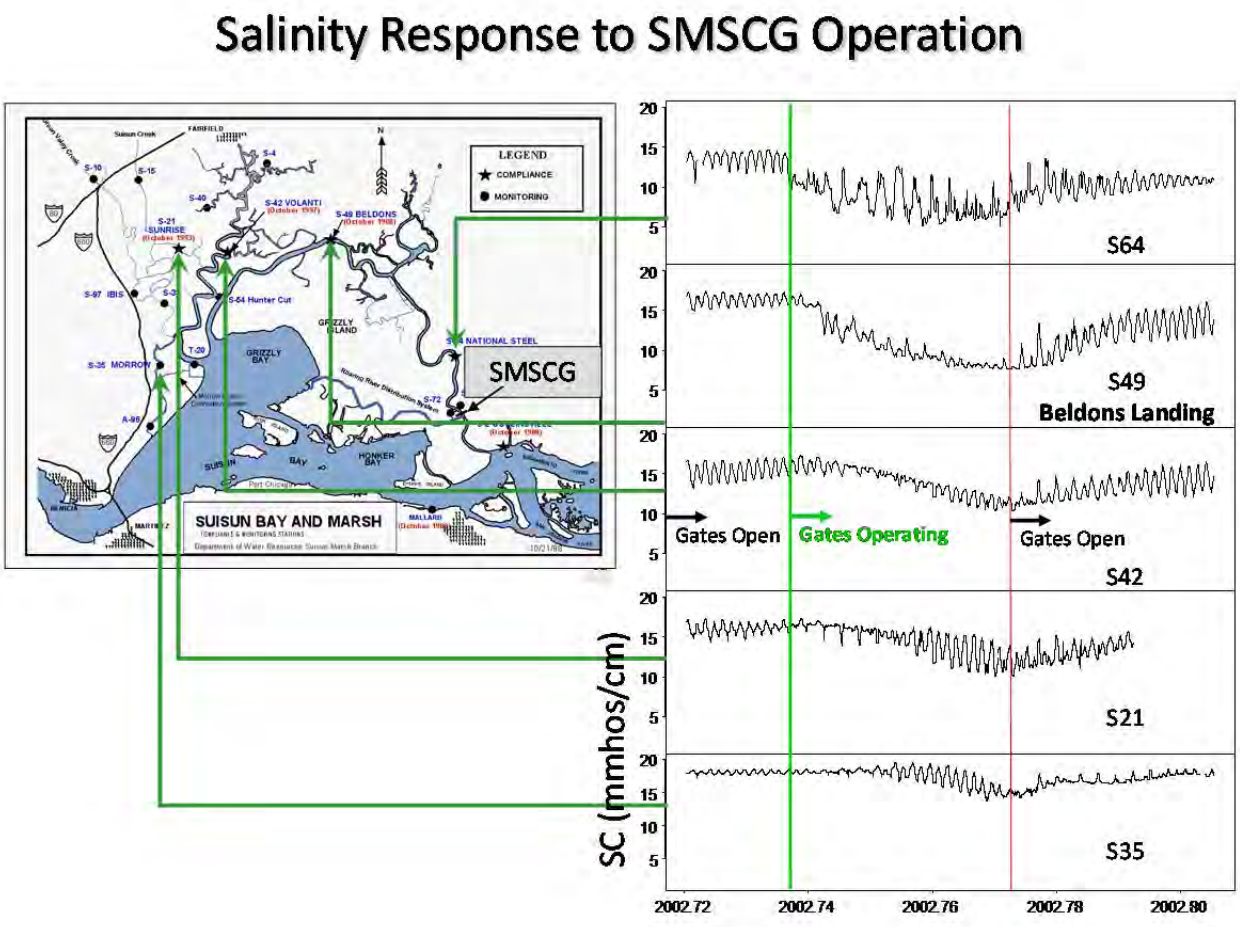


Figure 32. Effect of SMSCG Operation on Suisun Marsh Salinity

The vertical green line indicates when gate operation began, the vertical red line indicates when gate operation ceased about 2 weeks later. The salinity response to gate operation depends on proximity to the gate.

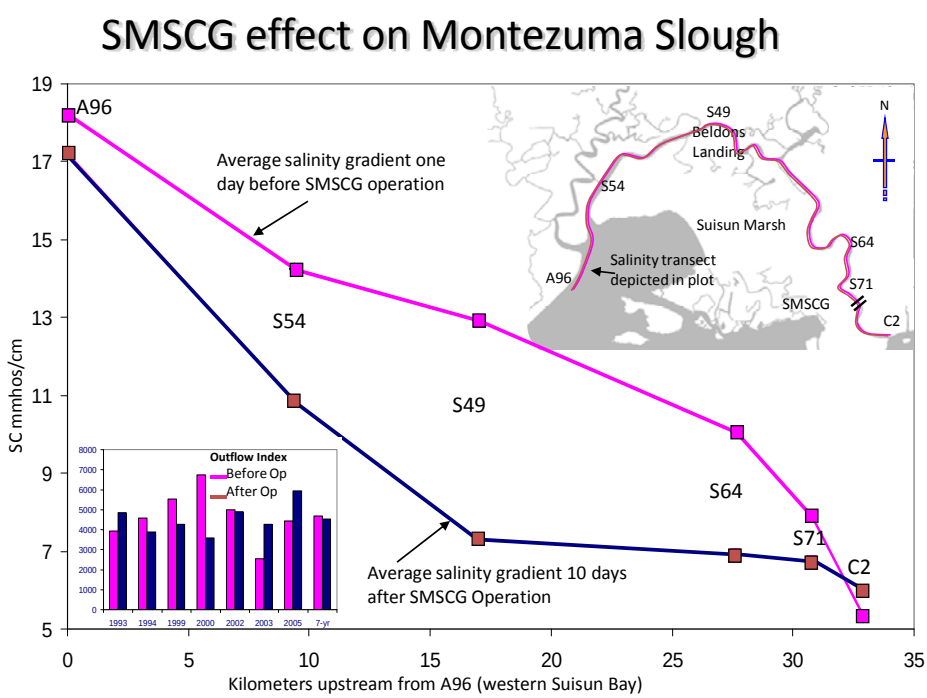


Figure 33. Seven-Year Average of Montezuma Slough Salinity in Response to SMSCG Operation

The pink trace is the 7-year average Montezuma Slough salinity one day prior to SMSCG operation. The blue trace is the 7-year average of Montezuma Slough salinity 10 days after operation begins.

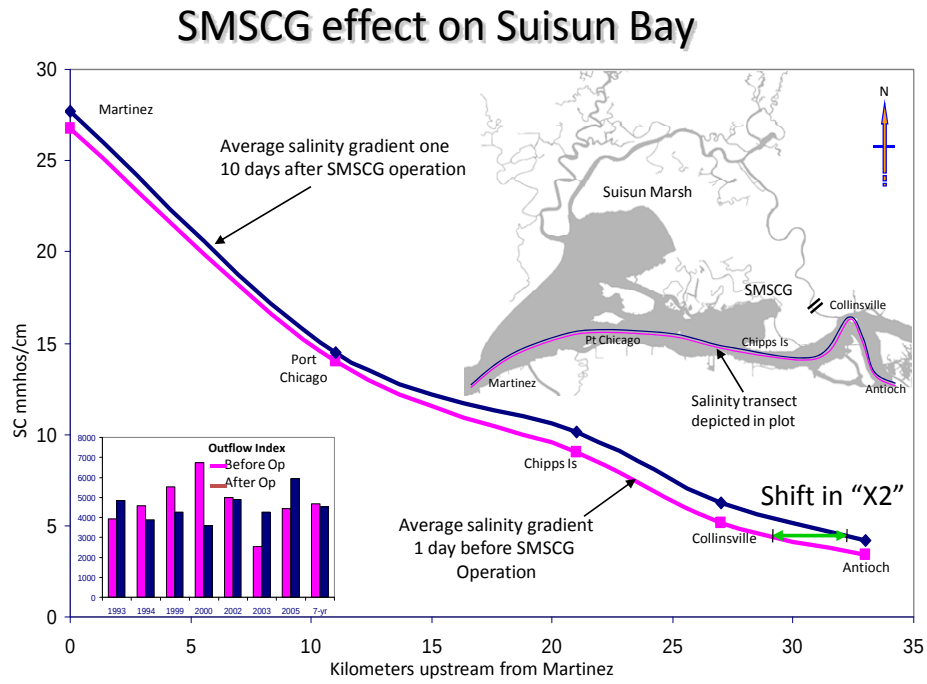


Figure 34. Seven-Year Average of Suisun Bay Salinity in Response to SMSCG Operation

The pink trace is the 7-year average Suisun Bay salinity one day prior to SMSCG operation. The blue trace is the 7-year average of Suisun Bay salinity 10 days after operation begins.

5.3 Dissolved Oxygen

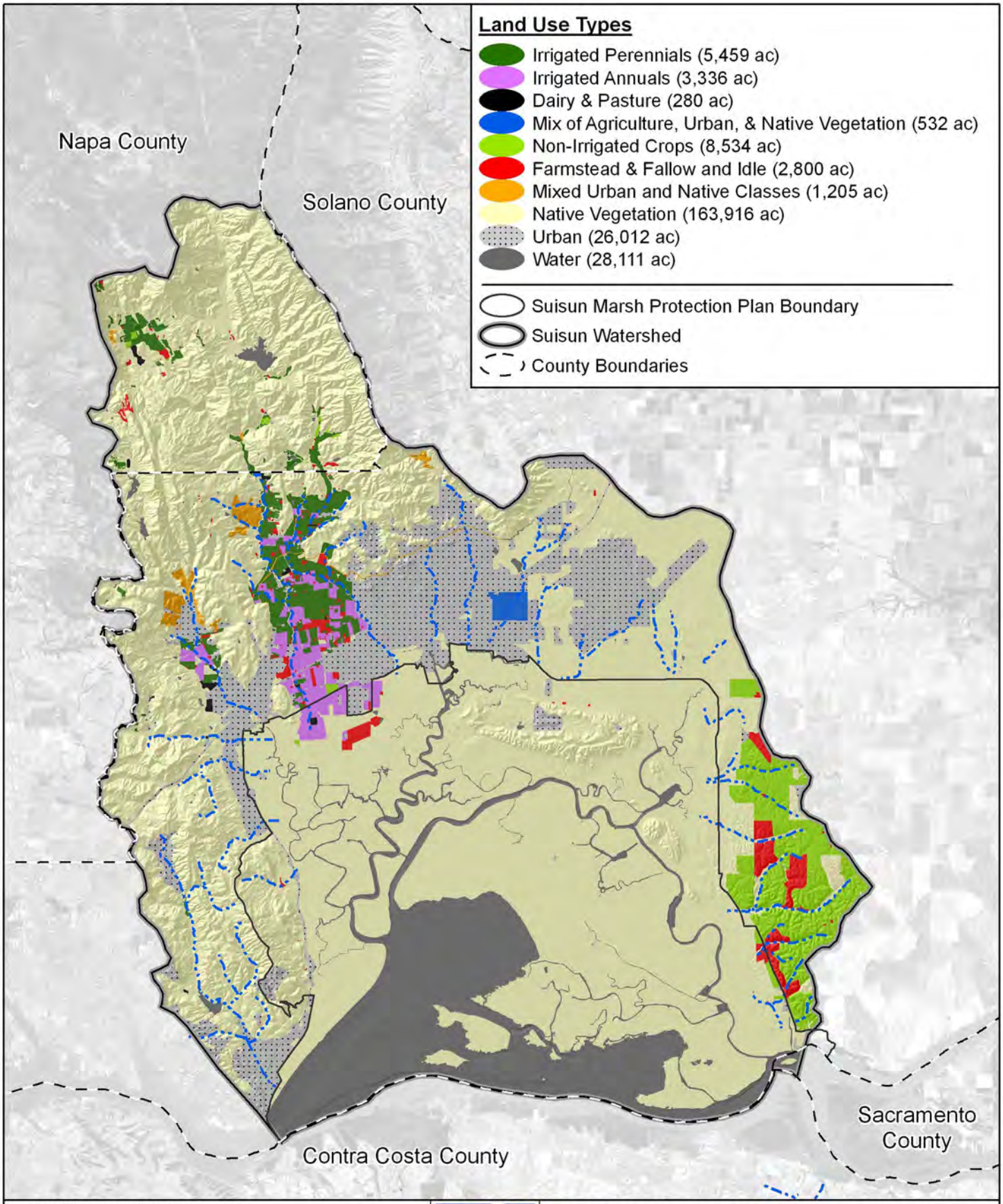
Appropriate levels of dissolved oxygen (DO) are critical to organisms in aquatic environments. The Regional Water Quality Control Board DO standard for Suisun Marsh is 7.0 mg/L, with the median concentration for any three consecutive months not be less than 80 percent of the dissolved oxygen content at saturation. In general, organisms will become stressed when DO drops to 5 mg/L, the water quality standard set by the San Francisco Bay Regional Water Quality Control Board. Hypoxia occurs at DO values between 2 to 5 mg/L and anoxia occurs below 2 mg/L. A DO sag can act as a barrier to the movement of aquatic organisms, depending on the location of the sag and the organisms' ability to tolerate low DO. This sag limits fishes and other organisms' access to areas of the marsh that might otherwise provide predator escapement or are rich in food resources. DO sags can also result in mortality. In addition, other water quality problems for aquatic organisms such as increased methyl mercury concentrations and elevated ammonia and hydrogen sulfide levels are associated with low DO events (Mark Stephenson, pers. comm.). These concerns warrant further research (Schroeter and Moyle, 2004, 2005). According to Cloern et al. (1983), Suisun typically is below 100% oxygen saturation, but these conditions are not static and change interannually, seasonally, and episodically. For example, in the spring large freshwater flows are moving through the marsh; primary productivity during these times often exceeds consumption because the rivers provide an external source of primary production. As freshwater flows decrease and salt water starts to intrude into the Delta, primary production is overtaken by secondary consumption. This pattern has not always been the case. Prior to the introduction of *Corbula amurensis,* Suisun experienced a mild late spring phytoplankton bloom. There is evidence that water clarity in the Delta and Suisun is improving due to the efficiency of *C. amurensis* at filtering the water column (Kimmerer 2004).

Suisun Marsh waterfowl club landowners manage water for the benefit of waterfowl and other wetland species. Most managed wetlands are dry during the summer and early fall months when land managers carry out maintenance activities. Fall flood-up typically involves a series of one or more flood-drain-flood cycles after which the wetlands circulate water through the winter and drain at variable times in the spring depending on particular property management objectives. These managed wetlands activities result in the production of organic matter (OM) in the form of wetland and aquatic vegetation that peak in quantity in spring and summer months. When this OM decomposes, it creates high biological oxygen demand (BOD) from microbial respiration. Operations also keep soil organic matter readily decomposable which can also contribute to BOD. With fall flood-up comes removal of DO from the pond water column by this BOD. The fall flood-up and drain cycle can thus create low DO waters that upon release send low DO plumes into receiving waters (tidal sloughs). These pond releases can also be rich

in nutrients and organic matter that stimulates further microbial activity, thereby increasing biological oxygen demand (BOD) in the receiving waters, which can continue to lower receiving water DO after pond drainage has ceased. Possible sources of excess nutrient loading into Suisun Marsh waterways include the Fairfield-Suisun wastewater treatment plant that discharges into Boynton Slough (**Figure 2**), incidental discharges at the Suisun City marina, and fertilizer in runoff from agricultural and residential areas that enter Suisun Marsh via the creeks and storm drains (**Figure 35**).

The extent to which low DO and high BOD managed wetland discharges adversely affect receiving water quality depends on residence times in the receiving water. Large tidal sloughs exchange water rapidly and thus are not as subject to low DO problems. Small and especially dead-end sloughs exhibit less exchange and thus longer residence times and consequently are particularly susceptible to low DO problems. Recent data collected on the nature of the DO sags in the marsh (Schroeter and Moyle, 2004) have shown that many sags occur in small, dead-end sloughs. The most significant problem areas have been Boynton, Peytonia, and Suisun Sloughs in the northwest marsh.

A recent study on low dissolved oxygen and methyl mercury in Suisun managed wetlands will soon be available. It includes a series of best management practices for managed wetlands that may help to reduce their contribution to low DO events (WWR et al. 2010b).



1:240,000 (1" = 20,000' at letter layout)

0 3 6 mi

0 5 10 km

N W E S

Data Sources: land use (DWR 2007); watershed (SFBRWQCD 2003); SMPP (WWR 2011)
Produced by WWR, September 2011
Map File: Watershed-land-uses-Suisun_AP_1151_2011-0926mdl.mxd

WETLANDS AND WATER RESOURCES

WATERSHED LAND USES AND LOADINGS SOURCES INTO SUISUN

Napa & Solano Counties, California

September 2011	Project No. 1151	**Figure 35**

6 Future Drivers of Change

Suisun Marsh will experience several changes over the next several decades and beyond that have great potential to change conditions in the Marsh: climate change (Section 6.1), large-scale restoration (Section 6.2), land use change within the watershed (Section 6.3), regional declines in sediment supply (Section 6.4), and changes in Delta water operations (Section 6.5). Each of these topics is summarized here.

6.1 Climate Change: Sea Level Rise and Storm Frequency and Intensity

Climate change will affect California and the San Francisco Estuary in several ways. Specific projections are challenging because they are sensitive to many future human actions and to highly complex atmospheric processes. California is projected to retain its Mediterranean climate of cool and wet winters and warm and dry summers, including experiencing a high degree of variability in interannual precipitation amounts. Here we present two scenarios developed by a collective group of large studies funded by the California Energy Commission (CEC) under mandates of the Governor's Biennial Climate Change Report and utilized in early 2010 by the U.S. Environmental Protection Agency in its Climate Ready Estuaries pilot project for the San Francisco Estuary. A majority of the climate change projections presented here were developed by Cayan et al. (2009) based on projections from six leading climate models5. These models were selected based on their reasonable representation of historical simulation of seasonal precipitation, seasonal temperature, the variability of annual precipitation, and El Niño/Southern Oscillation (ENSO). All models were run with both a lower emission scenario (B1 SRES) and a mid-high emission scenario (A2 SRES) to capture a range of plausible future emission trajectories. Regional projections were developed by statistical downscaling.

For sea level rise projections in U.S. coastal locations, relative sea level rise may differ from global estimates due to a number of factors such as changes in local ocean circulation, ocean density, vertical land motion, erosion and sedimentation, gravitational effects, isostatic rebound, etc. Relative sea level rise in California has demonstrated similar rates of rise compared to global estimates (Cayan et al. 2008). Many California studies recommend using projections of global sea level rise estimates, which assumes California relative sea level rises continue at the same rate as global sea level rise. The "lower range" estimate is the mid-range of Rahmstorf (2007) and high-end of IPCC TAR. The "higher range" estimate is the high estimate of Rahmstorf (2007). **Table 2** presents these projections.

[5] (1) NOAA Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; (2) the National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM); (3) NCAR Community Climate System Model (CCSM); (4) the Max Planck Institute ECHAM5/MPI-OM; (5) the Center for Climate System Research of the University of Tokyo MIROC 3.2 medium-resolution model; and (6) the French Centre National de Recherches Meteorologiques (CNRM) models.

Table 2. Summary of Climate Change Scenarios: Averages for Mid 21st Century

Source: U.S. EPA Climate Ready Estuaries Pilot Project for the San Francisco Estuary

Metric		"Lower Range" Scenario	"Higher Range" Scenario
Temperature [a]	Annual average [b]	+2.8ºF (1.6ºC)	+3.5ºF (1.9ºC)
	Average increase of winter temperature [c]	+2.5ºF (1.4ºC)	+2.7ºF (1.5ºC)
	Average increase of summer temperature [c]	+4.0ºF (2.2ºC)	+4.5ºF (2.5ºC)
	Extreme heat days [d]	+10 days/year	+16 days/year
Precipitation	Annual change [e]	-4.5%	-7%
	Winter change	Reduced winter precipitation [f]	
	Heavy events	Decline in frequency of precipitation events (exceeding 3mm/day) but not a clear signal in changes of precipitation intensity	
Sea Level	Total increase for 2050 [g]	+30 cm	+45 cm
	Hourly sea level rise exceedances [h]	1343	1438
Storms and wind [i]		Tendency toward a decline in storms [j]. Projections suggest an increased frequency for heightened sea level events to persist for more hours. ENSO is not projected to increase in frequency or intensity.	
Snow pack change		For the Central valley watershed, April watershed-total snow accumulation projected to drop 64% by 2060 [k]	
Spring runoff		Spring runoff occurring earlier and reduced overall	
Seasonal changes in the amount of freshwater inflow to the Bay from the Delta in 2060 [l]		October through February: inflow +20% March through September: inflow -20%	

Notes:

[a] *Averages are for 2035-2064 projections relative to 1961-1990 baseline for B1 and A2 emission scenarios*

[b] *Approximate results using B1 and A2 emission scenarios and three global climate models (PCM1, GFDL CM2.1, and HadCM3) (CEC 2006)*

[c] *Results for Sacramento, CA. Warming projected to be more moderate along coastline (50km from coast) and rising considerably inland (Cayan et al. 2009). Averages are for 2035-2064 projections relative to 1961-1990 baseline for B1 and A2 emission scenarios*

[d] *Extreme heat days defined as daily maximum temperature exceeding 95th percentile of temperature from 1961-1990 historical averages of May-September days. 1961-1990 baseline approximately 8 days/year based on model runs. Results from Cayan et al. 2009 using three global climate models (CNRM CM3, GFDL CM2.1, and MICRO 3.2 with bias-corrected downscaling) for B1 and A2 emission scenarios. Mid-century projections suggest hot daytime and nighttime temperate increase in frequency, magnitude, and duration (Cayan et al. 2009). Extreme warm temperatures in California, historically a July and August phenomenon, will increase in frequency and magnitude likely beginning in Jane and may continue into September (Hayhoe et al. 2004; Gershunov and Douville 2008, Miller et al. 2008).*

[e] *Results are averaged across six global climate models using the grid point nearest to Sacramento (Cayan et al. 2009) for B1 and A2 emission scenarios*

[f] *CEC (2008)*

[g] *Sea level rise relative to 2000. DRMS (2007) also provides recommended 2050 global sea level rise estimates relative to 1990 of 11 cm (direct extrapolation of observed 20th century data), 20 cm (low end of Rahmstorf (2007) and approximate mid-range of IPCC TAR), 30cm (approximate mid-range of Rahmstorf (2007) and approximate high end of IPCC TAR), 41cm (high end of Rahmstorf (2007)).*

[h] *Hourly sea level exceedance defined as maximum duration (hours) when San Francisco sea level exceeds the 99.99th percentile level (140cm above mean sea level) (Cayan et al. 2009)*

[i] *Cayan et al. 2008*

[j] *Storm defined as sea level barometric pressure falling below 1005 millibar*

[k] *Knowles and Cayan (2004) "business-as-usual" scenario relative to 1995-2005*

[l] *Knowles and Cayan (2004) accounts for reservoirs, in-stream valley diversions, and in-Delta withdrawals and assumes no future management adaptation or altered demand patterns*

6.2 Large-Scale Tidal Restoration in Suisun and the Delta

Large-scale tidal restoration has been proposed for Suisun Marsh for many years and is actively being called for in the Suisun Marsh Plan (SMP), the Bay Delta Conservation Plan (BDCP), and the Delta Plan. The 2000 CALFED Record of Decision identified Suisun restoration in the 5,000 to 7,000 acre range. In the prior year, the Baylands Habitat Goals Report recommended 17,000 to 22,000 acres. The SMP is calling for 5,000-7,000 acres (CALFED ROD target) and BDCP and the Delta Plan may call for greater acreage. The primary effect of this restoration, beyond all of its target benefits to ecosystem functions for native and migratory species, is the potential to alter tidal hydrodynamics within Suisun Marsh. Hydrodynamic modeling conducted by RMA for the Suisun Marsh Plan has demonstrated that restoring tidal action to large areas of subsided lands absorbs significant tidal energy and reduces tidal range in the near region. The most significant effects evaluated in modeled scenarios for the SMP (USBR et al. 2010) suggest that mean lower low water may be up to one-half meter higher than it is with the current channel configuration. This raising of the low water level effectively makes some of the remaining intertidal land area shown in **Figure 18** lower than indicated, relative to the tides. The exact magnitude of this effect on tides depends on where tidal marsh restoration efforts are located. As restoration sites accrete through mineral sedimentation and plant matter accumulation, their tidal prisms will decrease and these tidal effects will reverse.

6.3 Land Use Change in the Watershed

The cities of Fairfield and Suisun City continue to grow, converting open space, abandoned industrial sites, and agricultural lands into urban land uses. The primary effects of these changes are increases in impervious surfaces leading to greater stormwater runoff that reaches Suisun Marsh and a change in nature of potential contaminant loadings associated with the land use changes. The other concern is that of mosquito control; more residences located near Suisun Marsh increases the demand for mosquito control in Suisun.

6.4 Sediment Supply Regional-Scale Declines

The information in this section comes from the DRERIP sediment conceptual model (Schoellhamer el al. 2008) and two recent papers examining sea level rise and sediment supply changes in Suisun Marsh (Ganju and Schoellhamer 2010, Schoellhamer 2011).

The watersheds that drain to the Sacramento-San Joaquin Delta have been heavily impacted by human activities since the discovery of gold along the American River in 1848. In general, human activities tend to increase the amount of sediment transported in rivers through soil erosion, but this increase can be offset by sediment retention in reservoirs, leading Syvitski et

al. (2005) to conclude that the worldwide flux of terrestrial sediment to the oceans has decreased from pre-colonial conditions.

Probably the most significant anthropogenic driver, with respect to river sediment supply, is hydraulic mining. During the late 1800s and early 1900s, large deposits were washed into flumes using high-powered water jets in order to separate out gold. The mine tailings were routed into the rivers which dramatically increased the sediment supply. Gilbert (1917) estimated a 9-fold increase in sediment supply to San Francisco Bay during the mining period. Though the primary pulse of mining sediment has moved through the system, remnant terrace deposits remain in many of the watersheds (Meade 1982, James 1991). Also, recent estimates of river sediment supply to the Delta are substantially higher than Gilbert's pre-mining estimate, but have continued to decrease since the mid-1950s potentially indicating continued exhaustion of remnant mining derived deposits (Wright and Schoellhamer 2005).

Two major water supply projects have been constructed in the watersheds draining to the Delta, the Central Valley Project and the State Water Project, with each project containing multiple large dams are reservoirs. Dams have also been constructed for other purposes, such as trapping hydraulic mining sediments. The U.S. Army Corps of Engineers National Inventory of Dams (http://crunch.tec.army.mil/nid/webpages/nid.cfm) contains 1,483 dams in California (see webpage for inclusion criteria) and Nilsson et al. (2005) classified the Sacramento-San Joaquin basin as "strongly affected" by dams in their recent study of flow regulation of the world's large river systems. The Operations model conceptually describes how these dams are operated and how they affect Delta inflow. The primary effect of dams on sediment supply is retention of sediment in the reservoir; the channel immediately downstream from the dam will erode to a new equilibrium (Porterfield et al. 1978) providing a short-term sediment source, but the long-term effect is decreased sediment supply (Williams and Wolman, 1984). Dams also affect the flow regime, typically reducing high flows and increasing low flows (Singer 2007), which also has the effect of reducing downstream sediment supply.

The reduction of the hydraulic mining pulse and construction of dams led to a 50% decrease in sediment supply from the Sacramento River between 1957 and 2004 (Wright and Schoellhamer 2004). Exchange between estuarine sub-embayments may be more important in the coming century as watershed sediment loads continue to decrease (Ganju and Schoellhamer 2006).

Recent work by the USGS (Schoellhamer 2011) hypothesizes that the San Francisco Estuary cross a threshold in 1999 wherein the erodible sediment pool on the estuary's bottom is depleted. These pools are resupplied by watershed contributions, both local and from Delta outflow. The decline in those sources along with prior resuspension, transport, and deposition

in areas that do not readily erode (e.g., tidal marsh restoration sites) translates into the crossing of this threshold. The ramification of this recent hypothesis is that the estuary will have reduced suspended sediment concentrations, which translates into lower rates of marsh accretion and increased potential for wind-wave resuspension to keep restoration sites from accreting at all or accreting far more slowly.

6.5 Delta Water Operations

Water diversions from the Delta cause changes in the complex flow dynamics in the Delta and Suisun Marsh, which unnaturally affect migration and movement of fish and other aquatic organisms, limit access to suitable habitats, and alter water quality. Together, the CVP and SWP export facilities pump approximately 6 million acre-feet of water annually, and effectively reverse flows in Old and Middle rivers. Other water diversions and consumptive water use within the Delta (over 2,000 diversions) total an additional 1.7 million acre-feet (DWR 1995; Bay Institute, 1998; Healy et al., 2008; Herren and Kawasaki, 2001). Variability in the flow regime and seasonal flooding were historically important drivers of ecosystem structure and processes in the Delta and Suisun Marsh; native plant and animal species evolved under flow regimes of high inter- and intra-annual variability that differ strongly from the current managed regime. Water storage and flow control have dampened such variability across seasons and years, which has greatly changed estuarine hydrodynamics, circulation patterns and nutrient exchanges, and impacted resident species adapted to this natural variability.

As a result of the severe ecological impacts that have resulted from the large-scale water diversions and replumbing of the Delta, two key efforts are underway to attempt to remedy these conflicts: the Bay-Delta Conservation Plan (BDCP) and the Delta Plan. These efforts have numerous political and scientific complexities, and are unlikely to result in dramatic changes to existing Delta outflow regimes in the short-term. However, as these efforts mature into projects that are actually implemented on the ground, the status quo could very well change in the long-term. The mostly likely changes will be to the magnitude, duration, and timing of Delta outflow, which could have potentially significant impacts on habitats within Suisun Marsh. It will therefore be critical that ecological enhancement/restoration efforts in the Delta be integrated with similar efforts in Suisun Marsh to avoid negative impacts to Rush Ranch and other Suisun habitats.

6.6 Salinity Management of Suisun Marsh

Salinity management within Suisun Marsh is predicated upon the maintenance of primarily freshwater conditions within the Marsh to facilitate managed marsh/duck hunting operations. As increasing amounts of managed marshes are converted back to tidal brackish marsh, the need for salinity management within the marsh will change both spatially and temporally.

Combined with sea level rise increasing the upstream transport of more saline waters from the Golden Gate, changes in salinity management operations could alter the salinity of tidal flows throughout Suisun, which could potentially change the structure of estuarine vegetation communities. The magnitude and timing of these changes will likely determine the magnitude of subsequent ecological change observed at existing and restored tidal marshes. Therefore, it is important that existing monitoring programs continue such that adequate "base lines" (characterizations of vegetation communities under current salinity management regimes) are established to allow for change detection over time.

6.7 Changes in Invasive Species Distributions

The San Francisco Estuary is one of the most highly invaded estuaries in the world. Invasions began with the early arrival of Europeans, continue today, and will continue in the future. Changes in water/salinity management within the Delta and Suisun Marsh could potentially impact the distribution and composition of invasive species within Suisun Marsh, especially those within estuarine habitats. Periods of salinity change in Suisun Marsh due to freshwater inputs have been linked to long-term or rapid changes to vegetation community composition (Beare and Zedler 1987, Clark 1986, Clark and Patterson 1985*)*. Decreases in tidal marsh salinity during seedling establishment can increase the spread of invasive plant species, such as the widespread non-native perennial pepperweed (*Lepidium latifolium*). Salinity regime also exerts an important influence on abundance of the invasive clam, *Corbula amurensis*. Under normal conditions, salinity variation generally promotes dynamic plant community composition and diversity by influencing interactions of dominant perennial species and annuals or short-lived perennials which have adapted to varied levels of soil salinity (Callaway et al. 1990, Allison 1992). However, well established invasions can persist through less than favorable high salinity conditions (Zedler 1983).

A persistent issue for restoration is the widespread extent of dominant invasives (*Cotula coronopifolia, Lepidium latifolium, Phragmites australis, Polypogon monspeliensis*) which have already established within a highly salinity regulated marsh system. Such species are expected to be a continued issue in restoration areas when nearby establishment of exotic invasives has previously occurred, which may continue to out-compete native and rare tidal wetland species. Periodic years of high salinity stress is hypothesized to be an important factor in controlling the spread and establishment of invasive exotic species in Suisun Marsh (SEW 2001).

Within the terrestrial landscape, colonization by new invasive plant or wildlife species or the significant spread of existing species due to climatic events or changes in land management practices could significantly alter the species composition and ecological functions of the

landscape. The specific changes that would occur are unknown and would be based on the characteristics of the specific invasive species.

6.8 Terrestrial Land Management Practices

As described in earlier sections of the report, there is no 'natural' mature ecological state within the terrestrial grassland and scrub communities on the site, only the current temporary state that has resulted from the combination of prevailing influences over historic and recent time. Various land management practices including grazing, burning, herbicide applications, and habitat restoration can exert strong influences on the species distribution and composition within the terrestrial landscape. Grazing and burning mimic natural processes that have influenced the plant community characteristics for countless millennia and thus may be regarded as a continuation of these influences thought the timing and intensity may differed significantly from the historic natural conditions.

As a managed landscape, adjacent upland landowners around Suisun Marsh will undoubtedly develop management regimes for the terrestrial landscape that will favor certain desirable plant community elements such as native grasses and forbs and acceptable non-native species, and discourage certain undesirable elements, especially aggressively invasive weeds. These land management regimes, if successful, could result in a shift in the current distribution and cover of plant species within the terrestrial landscape. Of course, these shifts would only be maintained as long as the land management regimes are continued. If regimes were discontinued or significantly changed, the distribution and cover of plant species would adjust based on the new conditions.

7 Vegetation

7.1 Marsh-Wide Vegetation Communities

The composition and structure of vegetation communities within the Suisun Marsh have undergone varying levels of transformation since the 1700's. Beginning with the introduction of non-native species and human induced burning with the arrival of the Spanish and native Americans and evolving with more dramatic influences due to diking and mining discharge sedimentation during the 1800's, tidal wetland habitat has declined to a mere 5 to 10 percent of historic acreage (Atwater and Belknap 1979, quoted in SEW 2001). Early botanical records (Mason 1975 and George et al 1963 in SEW 2001), reporting vegetation community composition before expansive tidal marsh was diked, documented widespread salt tolerant species (salt grass and pickleweed) on high marsh plains and tule/bulrush stands flanking open water (SEW 2001).

Today's Marsh system and an evolved plant community structure have been shaped by hundreds of years of forced alteration but continue to support a diverse species assemblage over a range of land cover types. Current land cover types can be divided into natural and altered/artificial vegetation communities. Though they support native vegetation, diked and managed wetland habitats are classified as artificial vegetation communities. **Table 1** illustrates the most recently estimated land cover type breakdown within the Marsh. Each land cover type represents the predominant land use, which is determined by natural vegetation, water, or human uses.

Subtidal (Perennial Tidal Aquatic)

This stage occurs at elevations at or below the lowest tide levels, or slightly below MLLW. The depth of inundation varies with initial restoration elevations and the tide stage. Subtidal habitats in Suisun Marsh support two species of submerged aquatic vegetation (SAV), wigeongrass (*Ruppia maritima*) and sago pondweed (*Potamogeton pectinatus*). The precise location of abundance of these two species has not been well documented; however, field observations and air photo analysis suggest that beds of SAV may be located primarily in the shallow areas of Suisun, Grizzly, and Honker Bays. There are no special status plant species known to occur in deep water or subtidal habitats within the Suisun Marsh system. Special status plant species which may occur along the border of subtidal habitat (bays and sloughs) would be classified under tidal wetland or other land cover types.

Tidal Wetland Habitats

Being located in the estuary's strongest salinity gradients generates the highest species diversity and richness of the estuary's tidal marshes, supporting species adapted to both fresh

and saline conditions. This mosaic provides high degrees of ecological complexity that supports many fish and wildlife species and a range of ecological processes. Even for plants, which live most of their life cycle fixed in place, habitat diversity can be important in supporting necessary pollinators or controlling environmental factors such as erosion and drainage. The plant community composition of tidal marsh zones in Suisun Marsh are described below and correspond to the tidal inundation regime controlled largely but not entirely by elevation (see **Figure 36**).

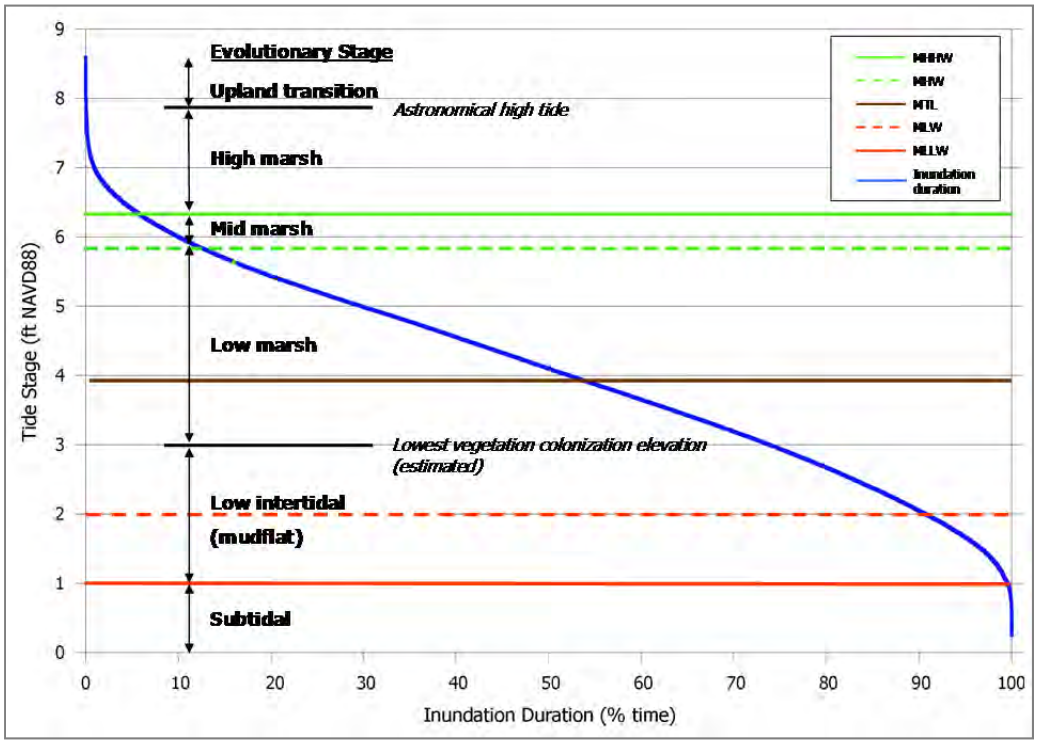


Figure 36. Tidal Marsh Types and Inundation Regime

Low marsh. Low marshes occur between the lowest elevations of marsh vegetation up to about mean high water (MHW). The lowest elevation for emergent marsh vegetation is controlled largely by salinity in Suisun, with fresher water allowing growth to lower elevations (below mean tide level [MTL]) and more saline water limiting vegetation to higher elevations (at or above MTL). Low marsh usually occurs in narrow bands along tidal channel banks, the outboard sides of levees, and in restoration projects early in their evolution. Dominant low marsh vegetation in Suisun includes species in the genus formally called *Schoenoplectus* (bulrushes and tules) and currently called *Bolboschoenus* or *Schoenoplectus* depending on species and *Typha* species (cattails). *Phragmites* is also found in low marsh. Plant zonation is influenced by inundation regime and salinity (Adams 1990; Goals Project 2000). At the lowest elevations, low

marsh vegetation is inhibited by frequent, prolonged, often deep inundation and by disturbance by waves or currents, leading to the lowest species richness.

Mid marsh. The middle marsh usually occurs roughly from MHW to mean higher high water (MHHW) (Goals Project 2000). Species diversity and richness are generally high in Suisun's mid marsh. Common species include saltgrass (*Distichlis spicata*), pickleweed (*Sarcocornia pacifica*), salt marsh dodder (*Cuscuta salina*), Jaumea (*Jaumea carnosa*), Fat-hen (*Atriplex triangularis*), Baltic rush (*Juncus balticus*), American bulrush *(Schoenoplectus americanus),* alkali bulrush *(Bolboschoenus maritimus),* sea milkwort *(Glaux maritime),* Mexican rush *(Juncus mexicanus),* narrow leaf cattail *(Typha angustifolia),* and alkali-heath (*Frankenia salina*). Also found in this zone are sneezeweed (*Helenium bigelovii*) and marsh gumplant (*Grindelia stricta* spp. *angustifolia*). Plants in this zone receive inundating tides at least once per 24-hour period and are not subject to the extremes in soil salinity found in the high marsh. Pickleweed often reaches its most robust form in this zone. Though pickleweed and other middle marsh plants provide food for wildlife, there is relatively little cover and no refuge from higher tides, which completely flood the vegetation of the middle marsh. In wet years, higher areas with poor drainage or areas with depressions may support vegetation more characteristic of lower elevations. Middle marsh elevations of brackish marshes often exhibit high plant species richness although the composition and richness varies widely with salinity. Due to the salinity variations in Suisun Marsh, the species composition and richness vary throughout the marsh.

High marsh. The high marsh generally occurs from MHHW to extreme high water, or roughly 0.5 m (1.5 ft) above MHHW in Suisun. In Suisun, high marsh is now often confined to natural levees along tidal creek banks and edges of artificial dikes except at the Rush Ranch Open Space Preserve (see **Figure 5**). This zone is particularly vulnerable to invasion by non-native species (Adams 1990) and in Suisun is often altered by invasive species and artificial levees. High marsh often accumulates the greatest portion of drift litter, the majority of which is plant matter, and can be autochthonous or allochthonous. Litter may damage existing vegetation and leave patches of bare ground. Mineralization of the litter by invertebrate fauna may be important in the development of marsh soils.

High tidal marsh in Suisun often is dominated by invasive plants, particularly *Lepidium latifolium* (pepper grass), *Conium maculatum* (poison hemlock), and *Foeniculum vulgare* (fennel). However, native species persist in the marsh including: Baltic rush (*Juncus balticus*), pickleweed, and rare or endangered plants such as Suisun marsh aster (*Aster lentus*), Soft bird's beak (*Cordylanthus mollis* ssp. *mollis*), and Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum).*

Upland transition. Upland transition occurs from high marsh to upland elevations. This zone provides refuge to wildlife during high tides. Uplands transitions are generally dominated by a variety of plant species, and typically have fairly high plant species richness and diversity. Plant species include a mix of high marsh species and upland species such as pickleweed and *Juncus* as well as more upland species such as yarrow (*Achillea millefolium*), coyote brush (*Baccharis pilularis*), creeping wildrye (*Leymus triticoides* and *L.* x *multiflorus*), California rose (*Rosa californica*), gumplant (*Grindelia stricta*), and alkali heath (*Frankenia salina*).

7.2 Rare Plants: Habitats, Distributions, and Threats

Multiple rare plant species are known from Suisun Marsh, including several federally listed species. Details of these species and their distribution are elaborated below in **Table 3**. The Fish and Game Code requires that all special status plant species and plant species of special concern as identified by the California Native Plant Society must be evaluated for potential adverse impacts under the California Environmental Quality Act.

Table 3. Special-status plant species and associated habitats within Suisun Marsh

Species		Listing Status			Marsh				Other	
Common Name	Species Name	Federal	State	CNPS	Low Marsh	Mid Marsh	High Marsh	Upland Transition	Upland	Vernal Pool
Soft bird's-beak	*Cordylanthus mollis* ssp. *mollis*	E, X	R	1B			X	X		
Suisun thistle	*Cirsium hydrophilum* var. *hydrophilum*	E, X				X	X			
Contra costa goldfields	*Lasthenia conjugens*	E, X		1B						X
Carquinez goldenbush	*Isocoma arguta*		SC	1B					X	
Suisun Marsh aster	*Aster lentus*		SC	1B		X				
Delta tule pea	*Lathryus jepsonii* ssp. *jepsonii*		SC	1B		X	X			
Mason's lilaeopsis	*Lilaeopsis masonii*		R	1B	X					
San Joaquin spearscale	*Atriplex joaquiniana*			1B					X	
Heartscale	*Atriplex cordulata*			1B					X	
Brittlescale	*Atriplex depressa*			1B					X	
Alkali milk-vetch	*Astralagus tener* var. *tener*			1B					X	
Delta mudwort	*Limosella subulata*			2	X					
Bolander's water-hemlock	*Cicuta maculata* var. *bolanderi*			2	X					
Lyngbye's sedge	*Carex lyngbyei*			2	X					

Listing Status

(X) = Critical habitat listed, (E) = Listed as Endangered under Endangered Species Act, (R) = Listed as Rare under California Native Plant Protection Act and Limited in distribution, declining throughout their range, or with vulnerable life history stage, (SC) = Species of Special Concern: (1B)= rare or endangered in California and elsewhere, CNPS (2) = Rare, threatened, or endangered in California but more common elsewhere

Symphyotrichum lentum (Greene) Nesom (Suisun Marsh Aster)

Suisun aster is currently included on the California Native Plant Society (CNPS) List 1B.2 (rare, threatened, or endangered in California and elsewhere). This species occurs primarily in brackish middle marsh areas that are regularly flooded (estuarine wetlands and intertidal banks) and is commonly associated with *Schoenoplectus californicus, S. cernuus, S. acutus, S. americanus, Agrostis exarata, Euthamia occidentalis, Epilobium* ssp. *Calystegia sepium, Hydrocotyle verticillata, Juncus balticus, J.oxymeris, Potentilla anserina* ssp. *pacifica, Rubus* spp.*, Rosa californica, Triglochin striata, and Typha* spp. *(*Fiedler and Zebell 1995*),* plus *Phragmites australis, Plantago* spp.*, Lilaeopsis masonii, Eryngium articulatum, Helenium bigelovii (*NDDB 1997*).* The widespread range for this species extends along the Sacramento-San Joaquin Delta and Napa River. Distribution of Suisun aster within Suisun Marsh is not currently known. This species was mapped by DWR and DFG staff in 1992; however, in the following year, taxonomic revisions within the Aster genus split (formerly *Aster chilensis* var. *lentus*) and *A. chilensis*. As a result, re-surveying efforts are needed to identify the actual extent of *S. lentum* in Suisun Marsh.

Cirsium hydrophilum (Greene) Jepson var. hydrophilum (Suisun thistle)

Suisun thistle is a federally endangered species and is listed under the CNPS List 1B (rare, threatened, or endangered in California and elsewhere). Critical habitat was designated in 2007. Suisun marsh is the only known location for this species, which occurs in irregularly flooded estuarine wetlands, in mid-to-high marsh areas. Distribution of Suisun thistle was once widespread throughout the Marsh but now is limited to just four localities: Grizzly Island, Peytonia Slough, Rush Ranch, and Hill Slough (USFWS 2010). Common plant associate species include *Typha angustifolia, Schoenoplectus americanus, Juncus balticus* and *Distichlis spicata (*USFWS 1995*),* plus *Sonchus sp., Frankenia salina,* and *Lepidium latifolium (*CNDDB 1997*).* Decline of Suisun thistle has been attributed to extensive diking of Suisun Marsh and conversion of tidal brackish marsh to non-tidal wetlands; current threats include out-competition by invasive *Lepidium latifolium,* trampling by cattle and feral hogs (at Rush Ranch), and herbivory of flowers by an introduced weevil *(Rhinocyllus conicus*) at Rush Ranch (USFWS 2010, SEW 2001).

Cordylanthus mollis Gray ssp. mollis (Soft bird's beak)

Soft bird's beak is a federally endangered species, California state listed rare species, and CNPS List 1B (rare, threatened, or endangered in California and elsewhere) species. Critical habitat was designated for this species in 2006. *C. mollis mollis*, was historically located on the north side of the San Joaquin River (last seen in 1972), Martinez (1881), Mare Island (1885), Napa Marsh (1952), Napa River confluence of Dutchman and South Sloughs (1982), and Petaluma Marsh (1978) (NDDB 1997- SEW 2001). Currently, there are 11 known occurrences of soft bird's

beak in eight general areas of Suisun Marsh: Rush Ranch (reintroduced in 2000), Hill Slough, Benicia State Recreation Area (BSRA), Joice Island, and Denverton (USFWS 2010). One population is also known at Point Pinole Regional Park (Contra Costa County) (USFWS 2009). Soft bird's beak is typically found in high marsh and ecotonal transition zones of seasonal flooded palustrine wetlands, including hypersaline or eurysaline areas within wetland habitats (Fielder and Zebell 1995 in SEW 2001). Common plant associates include: *Sarcocornia pacifica, Distichlis spicata, Jaumea carnosa, Frankenia salina, Triglochin maritima (*USFWS 1995*),* plus *Cuscuta salina* var*. major, Schoenoplectus americanus (*Ruygt 1994 in SEW 2001). Threats to this species include oil spills, changes to drainage patterns, and development of habitats (SEW 2001).

Lathyrus jepsonii Greene var. jepsonii (Delta tule pea)

Delta tule pea is a CNPS List 1B (rare, threatened, or endangered in California and elsewhere) species. This species occurs in middle-to- high marsh zones, in regularly flooded estuarine wetlands and intertidal banks (Fielder and Zebell 1995 in SEW 2001). The range of Delta tule pea extends along the Sacramento-San Joaquin Delta (Contra Costa, Sacramento, San Joaquin, and Solano counties), Napa River marshes, and south San Francisco Bay. Current distribution of this species in Suisun Marsh has not been reported; a 1994 report released by the Department of Water Resources (DWR) described the extent of Delta tule pea in Suisun Marsh as occurring throughout the marsh including: Suisun Bay shoreline, Montezuma Slough and Nurse Slough to Hill Slough, westward to Cordelia and Goodyear sloughs, Brown's Island, the southern shore of Van Sickle and Chipps Island, New York Point, Mallard Island, Sea Islands, and near Belloma Slough (DWR 1994 in SEW 2001). Associated plant species with Delta tule pea include: *Distichlis spicata, Sarcocornia pacifica, Typha* spp*., Rosa californica, Baccharis douglasii, Rubus discolor, Phragmites australis, Lilaeopsis masonii, Schoenoplectus* spp*., Hydrocotyle verticillata,* and *Jaumea carnosa* (NDDB 1997-SEW 2001). Current threats to this species include agriculture, water diversions, and erosion (CNPS online, accessed in 2010).

Lilaeopsis masonii Math. & Const. (Mason's lilaeopsis)

Mason's lilaeopsis is a state protected (rare) species and CNPS List 1B (rare, threatened, and endangered in California and elsewhere) species. This species occurs in regularly flooded estuarine wetlands and intertidal banks of the low marsh zone. The habitat of this species is described as frequently transient due to erosion and out-competition by other species (Fiedler and Zebell 1993, Golden and Fielder 1991 in SEW 2001). Mason's lilaeopsis is found along the Sacramento-San Joaquin Delta (Contra Costa, Sacramento, and San Joaquin counties), Napa River marshes, and was at one time believe to occur in Marin County near Tomales Bay (1936 collection- now believed to be *L. occidentalis*) (SEW 2001). This species is believed to be locally common in Suisun Marsh, along most tidal sloughs and channels; the last detailed report of the

distribution of Mason's lilaeopsis in Suisun Marsh reported a general absence of this species in Goodyear and Cordelia sloughs, which was attributed to poor substrate quality (Golden and Fiedler 1991- SEW 2001). Common plant associates found with Mason's lilaeopsis include primarily *Schoenoplectus californicus, Hydrocotyle verticillata* and *S. cernuus (*Golden and Fiedler 1991 in SEW 2001*)* in the Delta; however, in Suisun Marsh, the primary associates are *S. californicus, S. cernuus,* and *Triglochin striata (*B. Grewell, personal observation in SEW 2001*).* Reported threats to this species include erosion, channel stabilization, development, flood control projects, recreation, agriculture, shading resulting from marsh succession, and out-competition (CNPS 2010).

Limosella subulata Ives (Delta mudwort)

Delta mudwort is a CNPS List 2 (rare, threatened, or endangered in California, but more common elsewhere) species found in regularly flooded estuarine wetlands and intertidal banks of the low marsh zone (Fielder and Zebell 1995 in SEW 2001). The (native) range for this species extends along the Sacramento-San Joaquin Delta (Contra Costa, Sacramento, San Joaquin, and Solano counties) and has been more recently been reported from Point Reyes (Marin County). In Suisun Marsh, the last reported occurrences for this species are from 1997, at which time Delta mudwort was located at Montezuma Slough 0.45 miles southeast of Dutton, and at Brown's Island, near the west end of an intertidal slough (possibly New York Slough) (NDDB 1997 in SEW 2001).

Cicuta bolanderi S. Watson (Bolaner's water-hemlock)

Bolander's water-hemlock is a rare, coarse (up to 3.5 m tall at Rush Ranch) perennial marsh forb that is part of a western North American clade of *Cicuta* including *C. douglasii* distinct from *C. maculata* (Lee and Downie 2007). Suisun Marsh was the type locality for *C. bolanderi*. Until the status of the western North American *Cicuta* clade is resolved, the original rank of *C. bolanderi* may be validly applied over the incorrect *C. maculata* variety rank of *bolanderi*. The distinctiveness of nominal *C. maculata var. bolanderi* from *C. douglasii*, in the absence of specimens from the type locality, is uncertain (Lee and Downie 2007). *C. douglasii* is also a regionally uncommon species in the coastal marshes of central and northern California, but old (late 19^{th} c, early 20^{th} c) are more frequent widespread in inland marshes.

The only recently confirmed locality of Bolander's water-hemlock in Suisun Marsh or the San Francisco Bay Estuary is at Rush Ranch (Rush Landing) and immediately south near Goat Island (P. Baye, unpublished data). The only other populations know in the Bay region are located at the head of Schooner Bay and diked freshwater marsh at Drakes Estero in Point Reyes National Seashore (Peter Baye, pers. comm. 2010). Other California localities are presumed extirpated. Bolander's water-hemlock is not currently federally or state-listed but is included on the CNPS

inventory of Rare and Endangered Plants list 2.1 (rare, threatened, or endangered in CA but common elsewhere).

7.3 Non-Native Invasive Species

There are five non-native invasive species of concern in Suisun Marsh. Common reed (*Phragmites*) and broad-leaved pepperweed (*Lepidium*) are of direct concern in the tidal marshes. Brass buttons (*Cotula*) has the potential to interfere with native vegetation establishment in higher elevation tidal marshes. Rabbit's foot grass (*Polypogon*) and yellow-star thistle (*Centaurea*) are of concern at the upland transition especially at sites with broad edges.

Phragmites australis (Common reed)

Common reed (*Phragmites australis*) continues to present as a predominant non-native species of concern within the Suisun Marsh. Between 1999 and 2006, *P. australis* increased by 780 acres or 93%, mostly within stands of native wetland graminoids (*Typha* and *Schoenoplectus* spp.). *Phragmites* was the only non-native plant species that increased within the Marsh during 2003-2006; *Centaurea* and *Eucalyptus* both decreased by about 20% since 2003 and *Lepidium latifolium* has decreased by 9% since 2003. *Arundo domax* and *Cortaderia selloana* have neither increased nor decreased since 2003 (Boul and Keeler-Wolf 2008).

Distribution of *Phragmites* within Suisun Marsh is scattered throughout diked marsh regions, but also occurs within muted tidal and tidal marsh (**Figure 37**). This species is particularly invasive in recently disturbed areas and along levees and may co-occur with native species such as bulrush (*Schoenoplectus* sp.) and narrow leaf cattail (*Typha angustifolia*). CDFG Suisun vegetation mapping data has indicated that this species continues to thrive and spread in the marsh, and likely more extensively in diked and muted tidal regions, as shown in **Figure 37**, which demonstrates the spread of *Phragmites* on Chipps Island.

Lepidium latifolium (Broad-leaved pepperweed)

The clonal forb broad-leaved pepperweed (*Lepidium latifolium*) is the most invasive plant in emergent marsh of brackish to more saline reaches of the estuary. It ascended from a common to widespread dominant weed in this region between the 1980s and 1990s, and abruptly increased in abundance and distribution following the 1998 El Nino event. It readily forms monotypic stands or similar monotypic canopies above shaded persistent antecedent marsh vegetation it invades. Broadleaf pepperweed is a dominant species of the southern marsh plains (slough system) of Rush Ranch, but has remained a frequent but marginal element of high fringing marsh vegetation along Suisun Slough and Hill Slough. It is not known whether its limited abundance in local fringing marshes is due to greater resistance to invasion, or circumstantial factors (timing, disturbance opportunities). Pepperweed control in brackish

marshes is problematic because of many factors, including important native species diversity or special-status plants around or beneath pepperweed canopies, limited efficacy of most herbicide and surfactant combinations currently available for use in estuarine marshes, problematic indirect or non-target impacts of effective herbicides, and high clonal persistence of colonies. Pepperweed is apparently suppressed in seasonal wetlands of alluvial fans by intensive cattle grazing above Grizzly Island Road, and summer desiccation of saline/alkaline soils below the road, but little is known about factors controlling its spread in local terrestrial wetlands. *Lepedium latifolium* decreased in total acreage between 2003 and 2006 due to eradication efforts; however, as of the 2006 CDFG Suisun Marsh vegetation survey, 552 acres of pepperweed still persist in Suisun Marsh habitats (Boul and Keeler-Wolf 2006).

Cotula coronopifolia (Brass-buttons)

The facultative annual to perennial salt-tolerant amphibious wetland forb brass-buttons (*Cotula coronopifolia*) has been regionally naturalized since the 1850s. It seldom persists as a dominant except in diked marshes with late drawdowns and saline pond beds. It can be an ephemeral dominant early in brackish marsh succession, and it may interfere with establishment or persistence of native annual tidal marsh forbs. It is otherwise not a threat to closed-cover perennial marsh vegetation.

Polypogon monspeliensis (Rabbit's-foot grass)

This widespread naturalized wetland weed rabbit's-foot grass (*Polypogon monspeliensis*) is locally abundant or dominant in disturbed fresh to brackish seasonal wetland depressions, but it is problematic for management primarily in local habitats supporting some special-status plants or annual plant species of local conservation concern, including Contra Costa goldfields, smooth goldfields, and soft bird's-beak. It is otherwise an ephemeral pioneer, early-succession dominant species that is displaced by strongly perennial marsh species developing closed cover.

Centaurea solstitialis (Yellow star-thistle)

The highly invasive, widespread annual or biennial yellow star-thistle (*Centaurea solstitialis*) can form dense stands and displace native vegetation and decrease the forage quality of rangelands (poisonous to horses). In Suisun Marsh, yellow star-thistle occurs along in uplands and along the tidal-upland transition zone. Dense infestations of this species within newly restored habitats, mainly in the upland transition zone, would be problematic due to displacement of native species, habitat fragmentation, and loss of species diversity.

Yellow star-thistle seed is transported by human activities and animals. This species has a deep taproot (one meter or more) that grows quickly and can access and deplete deep soil moisture reserves in grasslands. It can strongly out-compete many other species in both stressed conditions and disturbed conditions (DiTomaso 2001, DiTomaso et al. 2006). Heavy infestations

have been reported to use as much as 50% of annual stored soil moisture in loamy soils, and significantly reduce soil moisture reserves more than six feet deep (DiTomaso 2001). Grazing and fire can both influence the distribution and density of yellow star-thistle either positively or negatively depending on the timing and intensity of the regimes (D'Antonio et al. 2007).

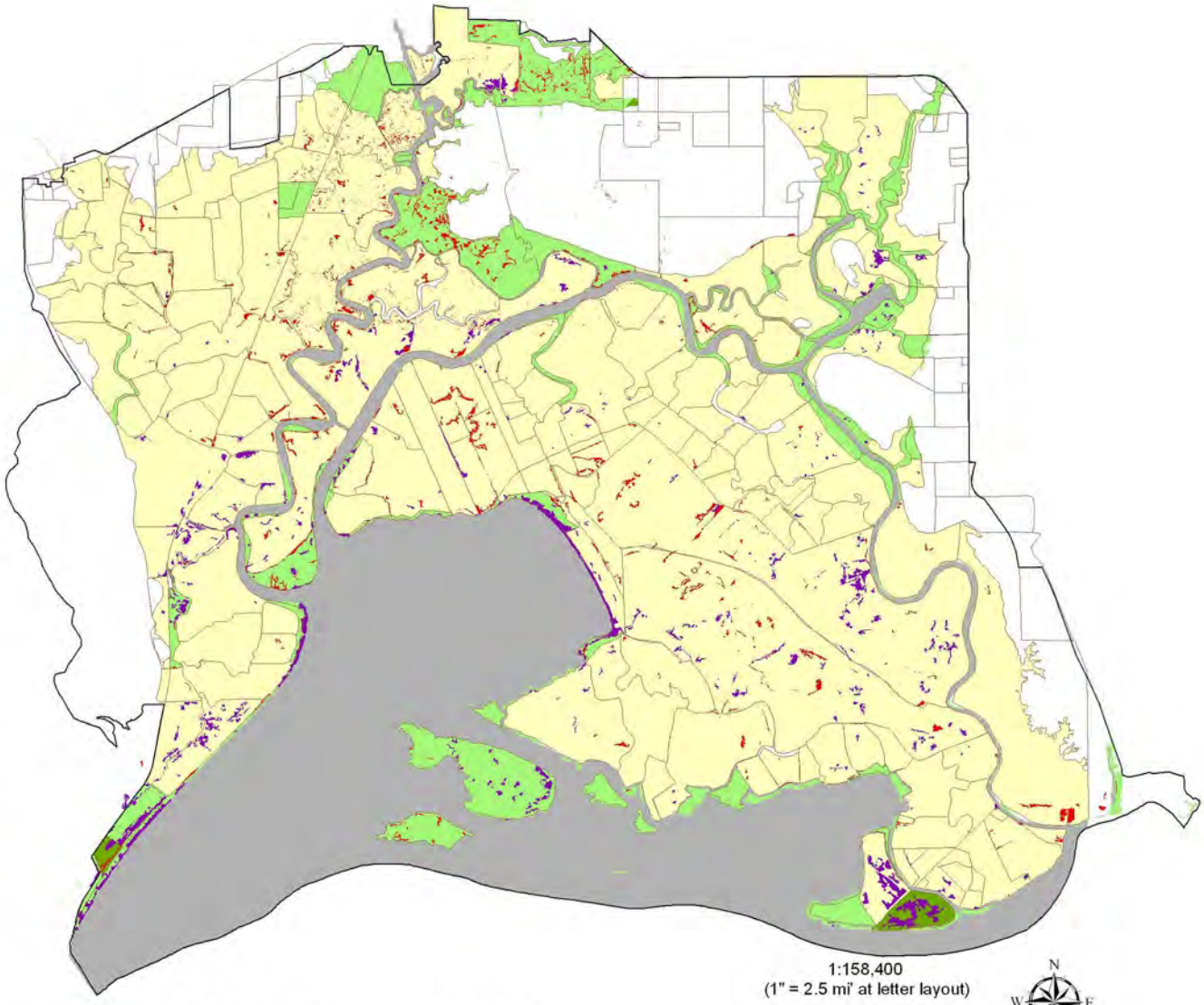
7.4 Viability Assessment

Summary

Overall, non-native plant species continue to encroach upon and displace native plant populations. Of greatest concern is the spread of *Phragmites* within tidal and managed marsh habitats and perennial pepperweed in managed marsh habitats. Native pickleweed has experienced a general decline in recent years, which has an associated impact on salt marsh harvest marsh populations. Special status plant species within Suisun Marsh are generally restricted to certain habitats and in many cases stable. Soft bird's beak continues to be threatened by non-native plant invasions. Mason's lilaeopsis and Delta mudwort are threatened by loss of bank habitat but because both can recruit to new suitable habitat, have the potential to remain stable as long tidal/bank habitats are protected and/or created. Updated surveys are needed for all special status plant species in the Marsh.

DFG Vegetation Surveys

Viability and composition assessments of Suisun Marsh vegetation occur as part of the Plan of Protection for the Suisun Marsh. Under the Plan of Protection implemented after the 1977 Suisun Marsh Preservation Act, a Triennial Vegetation Survey was put in place under the Biogeographic Data Branch of the California Department of Fish and Game (DFG) to document vegetation composition and monitor salt marsh harvest mouse habitat (SMHM). A baseline survey was conducted in 1981 and following a seven year delay, surveying was repeated every three years (beginning in 1988) to compare vegetation composition changes over time. Since the inception of the Triennial Survey, the methodology of the monitoring system has been revised to assess changes to SMHM habitat more accurately and to include data to support the use of a GIS format for additional mapping activities. Beginning in 1999, the Suisun Marsh monitoring agreement required that the Triennial Survey be funded by the Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) (Brown 2004). In 2000 an exploratory change detection study was implemented by Vaghti and Keeler-Wolf (2001), which modified previous analysis methods to locate and quantify significant vegetation changes within the Marsh and implement use of greater resolution aerial photography.



Data Sources: vegetation (DFG 2006, Solano Land Trust 2009);
club boundaries (SRCD, 2006);
Produced by WWR: September 2011
Map File: invasive-plants-Suisun_AP_1151_2011-0930mdl.mxd

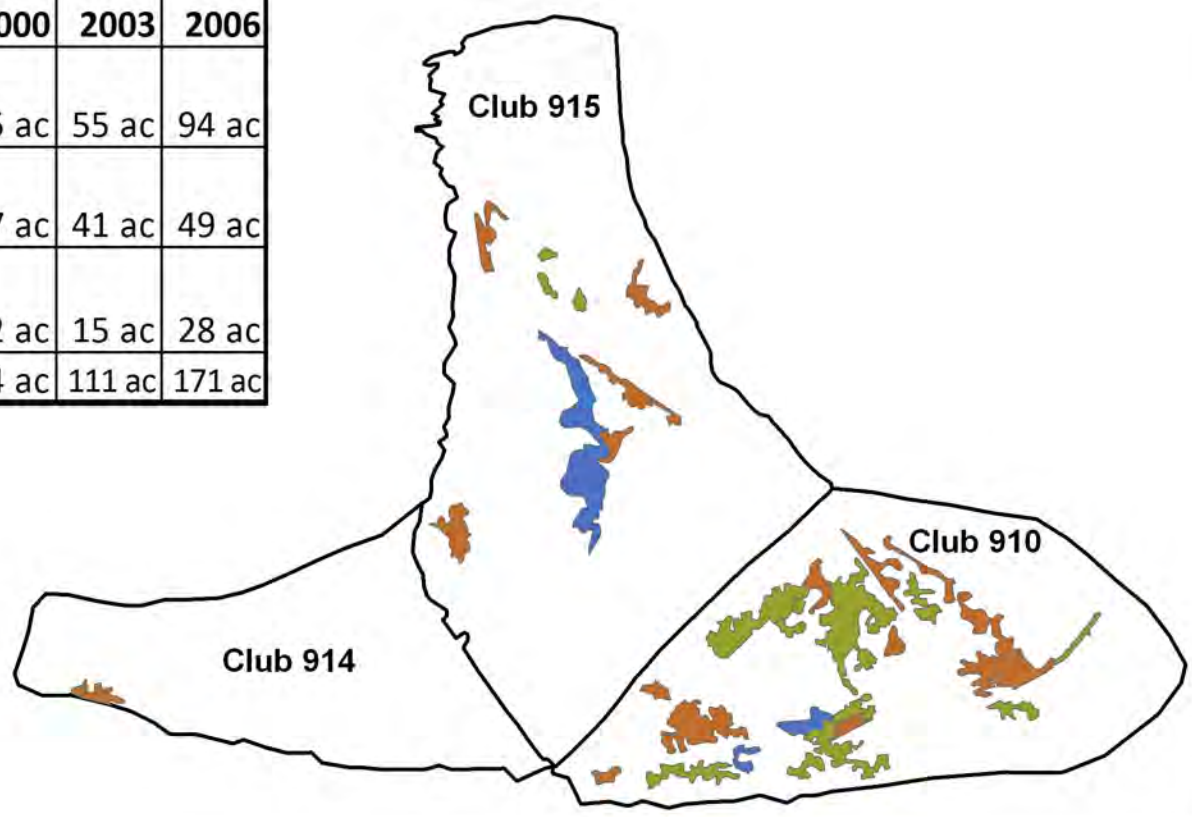
WETLANDS AND WATER RESOURCES

INVASIVE PLANT SPECIES

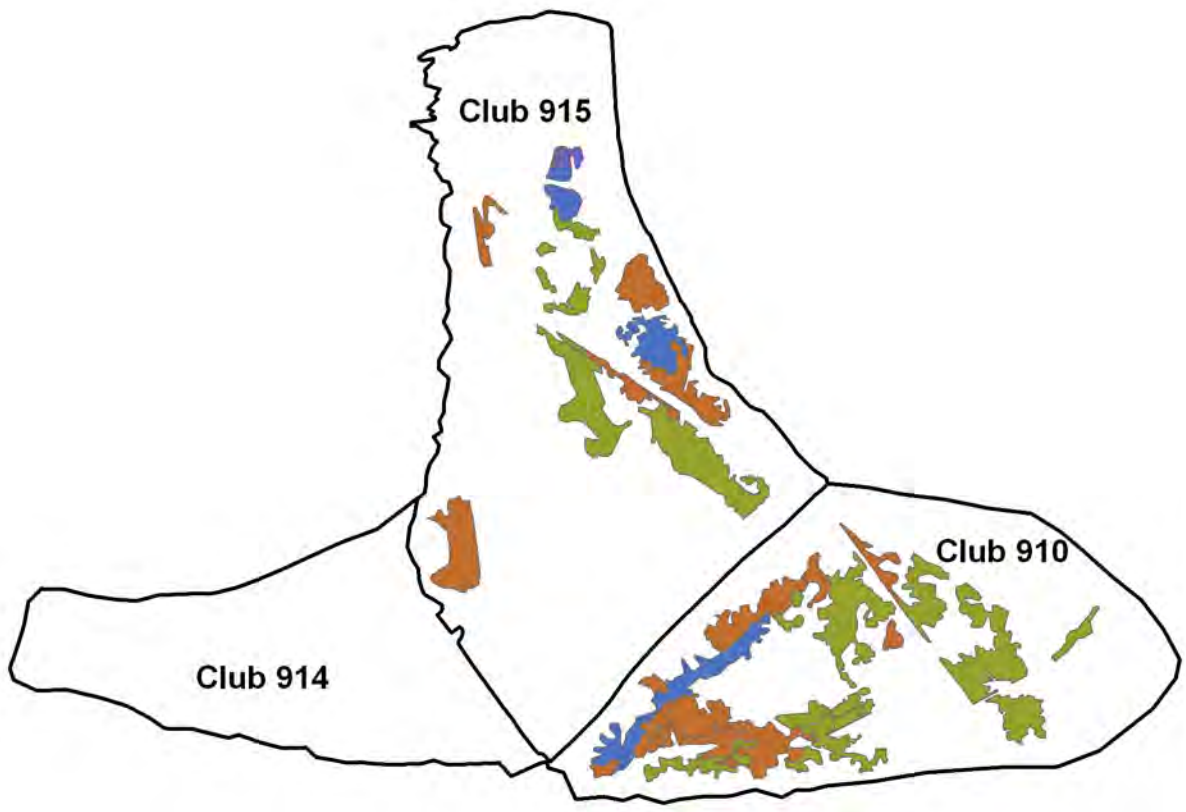
Suisun Marsh
Solano County, California

September 2011	Project 1151	**Figure 37**

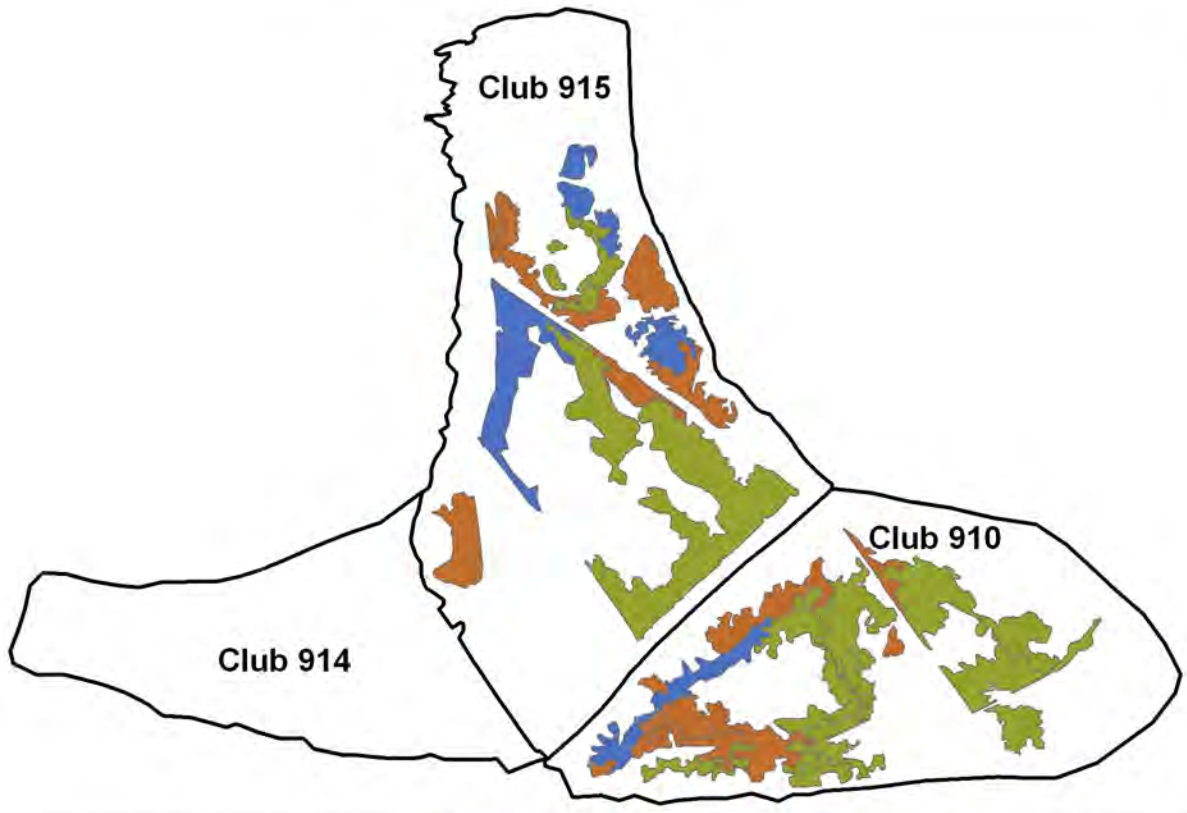
Vegetation Assemblage	2000	2003	2006
Phragmites australis	25 ac	55 ac	94 ac
Phragmites/ Schoenoplectus	27 ac	41 ac	49 ac
Typha angustifolia/ Phragmites	12 ac	15 ac	28 ac
Total acreage	64 ac	111 ac	171 ac



2000 Vegetation Data



2003 Vegetation Data



2006 Vegetation Data

1:21,600 (1" = 1,800' at tabloid size)
*scale applies to each frame individually

0 900 1,800 ft

0 300 600 m

N W E S

Data sources:vegetation (DFG 2000, 2003, & 2006);
property boundaries (SRCD 2006)
Produced by WWR, September 2011
Map file: chipps-veg-compare_BP_1151_2011-0930mdl.mxd

WETLANDS AND WATER RESOURCES

PHRAGMITES EXTENT 2000, 2003, 2006, CHIPPS ISLAND

Suisun Marsh CAP
The Nature Conservancy
Solano County, California

September 2011 | Project 1151 | **Figure 38**

During the 1999 baseline survey, vegetation plots were selected to serve as the primary basis for correctly attributing the vegetation map for Suisun Marsh and to provide a platform for future triennial change detection surveys. Plots were selected such that a representative sampling of the entire study area (the Suisun Resource Conservation District boundary and areas below 10' mean sea level) was captured with few replicates. Additionally, plot sizes range in size based on the characteristics of the vegetation; for example, sites dominated by vegetation taller than 5m were sampled in 1000 m square plots. Other sites dominated by graminoids, scrubs, and herbs are sampled in 400 m sq plots. Percent cover of species (greater than 1%) is documented at each plot location and the geographic location is recorded. Infrared satellite imagery of the marsh is then acquired during the same year of ground sampling. In the initial 1999 survey, vegetation sampling occurred primarily (60%) within public lands in the marsh including the DFG Wildlife areas and Rush Ranch Open Space Area, the remaining sampling occurred within private land holdings (when granted permission to access). Vegetation types were also grouped into generic and stand categories to standardize change detection between sampling years (Keeler-Wolf et al. 2000).

7.4.1 Department of Fish and Game 2003 to 2006 Vegetation Change GIS Assessment

Every three years since 2000, DFG has prepared a vegetation change assessment of Suisun Marsh, based on high-resolution natural color imagery flown by DWR. DFG conducted the most recent assessment with 2006 data and released results in 2008; the 2009 assessment should be available in 2011. In 2003, 99 rapid assessment vegetation plots (from the original 198 established in 1999) were revisited for the change detected study. The existing 1999 vegetation map (with associated vegetation polygons labeled with polygon number and vegetation code) was overlaid onto the 2003 aerial diapositives and each polygon was assessed for vegetation change. A vegetation change was defined as: (1) a greater than 20% change in a small polygon (<1 acre), (2) a greater than 10% change in a mid-sized polygon (1-5 acres), (3) a greater than 5% change in a large polygon (>5 acres), (4) a type conversion of a vegetation polygon dominated by a perennial species, (6) a persistent physical change to a vegetation polygon converting all or part of a vegetated area to a non-vegetated type (building, ditch, new levee, road, etc.), and/or (7) a change in management (actively managed to passively or non-managed).

In 2003, the vegetation study area covered over 69,316 acres divided into approximately 31,200 vegetation polygons. Between 1999 and 2003, there were changes to 5,177 vegetation polygons representing 11,641 acres. This dramatic change in acreage may have been in part due to changes in management style or other modifications in the marsh; however, some variation was likely due to variance in interpretation style. Based on the 2003 survey data,

urban areas increased by 103 acres, mainly in Benicia and Cordelia; construction of new levees and roads contributed to a 54 acre change. Pickleweed (*Sarcocornia pacifica*) decreased in acreage by 682 acres and was replaced primarily by five vegetation category types: *Bolboschoenus maritimus/Sarcocornia,* medium wetland graminoids, short wetlands herbs, flooded managed wetland, and medium wetland herbs. Saltgrass (*Distichlis spicata*) also decreased by 2,064 acres from 1999-2003, and was replaced by five types: short wetlands herbs, *Bolboschoenus maritimus*, annual grasses, medium wetland herbs, and *Sarcocornia* (generic). Several non-native species increased in coverage, representing a total change of 537 acres. *Phragmites australis* represented the greatest increase in acreage over the entire study area. *Lepidium latifolium, Conium maculatum,* and *Eucalyptus* also showed significant acreage increases (Vaghti and Keeler-Wolf 2004). *Lepidium* and *Arundo donax* exhibited the largest increase in acreage within tidal wetlands, which experienced an overall change of 1150 acres

Of the 31,117 vegetation polygons assessed during the 2006 survey, 6,092 had changed or were deleted in 2006 which corresponded to 16,218 acres of the total 69,316 acres within the Marsh assessment area. This change represented an approximate 20% of polygons assessed, which had either changed vegetation type or significantly changed in size. The most significant land cover change observed during the 2003 to 2006 period occurred in diked wetlands, which exhibited an increase in vegetative cover by 5,684 acres. Additional but less significant increases were also observed in several plant community types including *Sarcocornia*/annual grasses, *Distichlis/Sarcocornia, Schoenoplectus (californicus* or *acutus) – Typha* spp. and *Phragmites australis.* Significant decreases in vegetation community type were also observed between 2003-2006; the top five vegetation types that lost acreages included *Bolboschoenus maritimus, Sarcocornia pacifica, Distichlis spicata, Typha* species, and Medium Wetland Gaminoids (Boul and Keeler-Wolf 2008).

7.4.2 Special Status Species

A comprehensive population status assessment of many of the rare plants within Suisun Marsh has not been performed or updated recently. However, some general assumptions and statements have been offered in more recent reports (USBR et al. 2010, WWR et al. 2010a).

Suisun Marsh aster is an obligate outcrossing species which is believed to cross-pollinate with the more common aster species *S. chilensis*; marsh-wide population survey and inventory studies should be conducted to determine the current status of this species within Suisun Marsh.

Suisun thistle was surveyed extensively throughout the Marsh during 1993 (by B. Grewell during a drought year) and again in 2003 (following an el Nino event and several wet years by

Fiedler et al. 2004). The 1993 general survey revealed only a few thousand plants; however, estimates from 2003 were upwards of 137,500 (mean density) individuals. Both studies indicated that this species is restricted to banks of Suisun and Cutoff Sloughs, and First and Second Mallard Branches and their tributaries. Updated and long-term trend studies are required to assess population changes following multiple El Nino events (WWR et al. 2010a).

Soft bird's beak within Suisun marsh is currently believed to consist of 11 populations across nine general areas (discussed above); however, that last comprehensive population survey of this species throughout the Marsh was conducted in 2000 (Grewell et al. 2003, from USFWS 2010). Additional monitoring surveys have been conducted at Rush Ranch for a population seeded in 2000. This population experienced continued growth until 2004 when seed production plummeted for unknown reasons (USFWS 2010).

Delta tule pea reported occurs throughout Suisun Marsh in tidal marsh areas; however, a comprehensive study of this species has not been performed in many years. This species was discontinued as a species of concern in the draft recovery plan for tidal marshes of central California (USFWS 2010).

Mason's lilaeopsis was last extensively surveyed in 1993, at which point Suisun Marsh was believed to support the core of this species geographic distribution. Because its detection is difficult and its habitat inherently unstable, its actual distribution and abundance may both highly variable and underestimated (WWR et al. 2010a). Field and genetic studies have suggested that this species may not be distinct from the more common, coastal species *Lilaeopsis occidentalis* (USFWS 2010).

Delta mudwort's status in Suisun Marsh is also unknown. As stated above, the last reported observations for this species are from 1997 and are limited to two locations within Suisun Marsh (southeast of Dutton and at Brown's Island).

Bolander's water-hemlock was once abundant in Suisun Marsh and was frequently associated with Suisun Thistle. Currently this species is limited to two areas in Suisun Marsh: within fringing marsh habitat at Rush Ranch and immediately south near Goat Island. The population at Rush Ranch is believed to currently consist of approximately 50 individuals (WWR et al. 2010a).

7.5 Threat Assessment

7.5.1 Diked Wetlands Ongoing Management

The primary goal for Suisun Marsh diked managed waterfowl wetland managers is to provide adequate habitat for waterfowl and with this appropriate vegetation for waterfowl species to provide food and shelter from elements and predators. Various methods, including disking, burning, mowing, and flooding are employed by wetland managers to influence a plant community type suited to provide productive waterfowl habitat. Such target species include alkali bulrush (*Bolboschoenus maritimus*) and brass buttons (*Cotula coronopifolia*), which interestingly only occupied an estimated 11 percent of total vegetation cover in the early 1960's (Brown 2004). Managed wetland activities (specifically flooding) that aim to increase desired vegetation for waterfowl has also contributed to a decline in historically dominant Suisun Marsh vegetation. For example, DFG vegetation surveys detected a significant increase in flooded managed wetland habitat between 2003 and 2006 (5650 acre increase) which corresponded with a decline of vegetation, such as *Sarcocornia pacifica* and *Distichlis spicata* (Boul and Keeler-Wolf 2008).

7.5.2 Effect of Non-Native Invasive Plant Species on Native and Special Status Plant Species

Invasive plant species have the potential to outcompete rare species and thus present major threats to conservation efforts of such species. Additionally, aggressive exotics can severely alter or inhibit the natural ecological functions of an area by displacement or eradication of native species and by changing the native plant community and habitat characteristics. Impacts to specific species have been documented in some instances. For example, soft bird's beak is particularly susceptible to displacement or out-competition by invasives. Wild celery (*Apium graveolens*) and sow-thistle (*Sonchus* spp.) have also been identified as invasive species occurring at high density in soft bird's-beak populations; additionally, rabbit's-foot grass (*Polypogon monspeliensis*) has also been identified as posing potential threats to soft bird's-beak persistence. Non-native plants were present in 33% of soft bird's-beak populations patches investigated by Grewell (2005). Other recent non-native invasive plants with demonstrated potential for dominance in the terrestrial-high tidal marsh ecotone in San Francisco Bay, such as Algerian sea-lavender (*Limonium ramossisimum*) and European seashore goose-grass (*Puccinellia maritima*), have not yet dispersed to Suisun Marsh or impacted soft bird's-beak habitat (WWR et. al. 2010a). Invasive plant species within tidal marsh habitats appear to pose additional threats by reducing the quality of such habitats for native wildlife. For example, the invasive species perennial pepperweed (*Lepidium latifolium*) and *Spartina alterniflora* displace pickleweed (*Sarcocornia pacifica*), thereby reducing habitat quality for California clapper rail and salt marsh harvest mouse (USFWS 2010).

Within the terrestrial landscape, colonization by new invasive plant or wildlife species or the significant spread of existing species due to climatic events or changes in land management practices could significantly alter the species composition and ecological functions of the landscape. The specific changes that would occur are unknown and would be based on the characteristics of the specific invasive species.

7.5.3 Special Status Species

Soft bird's beak

The invasion of middle and upper brackish tidal marsh zones by non-native *Lepidium latifolium* is potentially detrimental to soft bird's beak populations due to competition. Lepidium currently threatens at least portions of soft bird's beak populations at Rush Ranch, where populations of Lepidium have steadily increased in the last decade, particularly in high rainfall years (B. Grewell, P. Baye pers. obs. 1991-1999). Other observed threats to soft bird's beak include large-scale alteration of salinity regimes (specifically stabilizing lower salinity levels in summer and fall), disturbance by feral pigs (mainly at Rush Ranch), potential threat by crude oil spills (oil spills tend to deposit near high tide line where the species is most abundant), trampling due to public access and recreation trails (when placed along edges of tidal marshes) and sea level rise (compressed tidal marsh zones due to marsh transgression).

Suisun Marsh aster

Previously primarily threatened by loss of marsh habitat due to development, dredge disposal, diking, and agricultural conversion. Currently this species is threatened by invasive plants, erosion, creek channelization, levee construction, and feral pigs (LSA 2007).

Delta tule pea

Changes or alteration to salinity regimes pose the most significant threat to this species. Delta tule pea ranges from uncommon to locally common within Suisun Marsh persists and thrives in wet, low-salinity years. Abundance of Delta tule pea in Suisun Marsh had decline primarily due to the elimination of all but the largest tidal creeks due to levee creation.

Suisun thistle

Major declines in Suisun thistle abundance and distribution within Suisun Marsh occurred between the 1870s and 1930s (Thompson and Dutra 1983) due to diking and reclamation of tidal marshes for either agriculture or waterfowl production. Current threats include invasion by non-native Lepidium latifolium, disturbance, salinity changes, genetic assimilation by non-native thistle species, and low seed dispersal due to small size of its population.

Mason's lilaeopsis

Erosion and competition are the most significant factors threatening persistence of this species throughout its range. Salinity, though not a threat, is also a major factor by restricting this species to brackish to freshwater tidal marsh habitats.

Delta mudwort

Threats to Delta mudwort are similar as those identified for Mason's lilaeopsis. Both species occur in similar habitats and will sometimes co-occur; as such, the most significant threats to Delta mudwort come from alterations to or destruction of habitat which include bank erosion, trampling, and development.

Bolander's water-hemlock

The decline of this species in Suisun Marsh was likely related to abrupt and extensive diking of Suisun tidal marshes in the early 20th century, as dikes were generally constructed along slough banks and outer marsh habitats that appear to be the principle habitat of this species (WWR et al. 2010a).

7.6 Native Plant Anticipated Responses to Restoration and No Action

The key factors influencing how native plants will respond to tidal marsh restoration and to the lack of restoration (no action) are (1) initial starting elevations of restoration sites (see **Figure 19**), (2) extent and type of emergent vegetation already present at the restoration site, (3) location in Suisun Marsh relative to sediment supply (see **Figure 22**) and salinity gradients (see **Figure 32**), (4) site-specific soil conditions, (5) the extent of upland transition present at the restoration site (i.e., Marsh interior vs. perimeter sites; see **Figure 18**), and (6) potential for invasive plant colonization. The key changes that take place once tidal action is restored are (1) a fundamental shift in the inundation regime to a twice-daily rise and fall of the tides (vs. generally static managed water levels) which has a cascade of biogeochemical changes, (2) a change in salinity regime, and (3) introduction of sediment. Some emergent vegetation will remain at restoration sites where the relative tidal elevations are within each species tolerances, while other species will die back after restoration. For example, at the Blacklock restoration project the bulrush remained growing after restoration whereas the saltgrass died back.

Variability in the salinity regime is believed to relate directly to a more diverse native plant community and persistence of rare tidal marsh species. The Suisun Ecological Workgroup has described several mechanisms of dynamic salinity conditions in facilitating rare plant species persistence and expansion in Suisun Marsh. Episodes of high salinity may be particularly important in two respects. First, such episodes have been correlated with the development of

vegetation gaps, as many dominant species have low salinity tolerances (Callaway et al. 1990; Bertness et al. 1992; Zedler and Nordby 1986 in SEW 2001). Species of the genus *Cordylanthus* have been observed to require vegetation gaps or sparse vegetation for seedling regeneration (Parsons and Zedler 1997 in SEW 2001*).* Secondly, some rare species endemic to Suisun Marsh, have been observed to increase in abundance during dry, high salinity years (i.e., endangered Suisun Thistle and soft bird's beak).

Other uncommon to rare species of Suisun Marsh (such as Delta tule pea) have been found to thrive during wetter, low salinity years, as do tall, dense, "wetter" species and exotic species such as *Lepidium latifolium* and wild celery (*Apium graveolens*). The variation in species abundance between wet and dry years observed in Suisun Marsh supports the hypothesis that fluctuations between high and low salinity maintains a diverse native plant community.

Peter Baye (SEW 2001) stated that it is unlikely that the saltier years under an extremely variable regime would result in the extirpation of the most endangered species or create a monotype of vegetation to the detriment of the rare species, but, rather, the lack of variation that would cause harm. Mike Vasey (SEW 2001) stated allowing such variability should be approached cautiously and accompanied by good monitoring, since conditions in the marsh today are much more constrained and there may not be opportunities for species to find appropriate refugia during highly stressful times as there once were in the historical marsh. These constraints may pose added risks to certain species under extreme conditions.

Many special-status species would likely benefit greatly from tidal marsh restoration efforts due to creation of suitable habitat and increased habitat complexity. Creation of tidal banks would encourage recruitment of multiple species including most notably Mason's lilaeopsis, Delta mudwort, Suisun Marsh aster, and Delta tule pea. Restoration construction activities could potentially impact suitable habitat and populations of soft bird's beak in Suisun Marsh; however, these impacts are believed to temporary and will be offset by the creation of suitable habitat as a range of marsh elevations and associated habitats are created (USBR et al. 2010).

7.7 Invasive Plant Anticipated Responses to Restoration and Effects

Variability in wetland soil salinity especially during the seedling germination season (late winter into spring) has been suggested as the critical control of establishment of invasive plant species in Suisun brackish marshes, alongside habitat structural diversity (SEW 2001). Reduced tidal marsh salinity during seedling establishment can increase the spread of invasive plant species, such as the widespread non-native perennial pepperweed (*Lepidium latifolium*). Under natural conditions, salinity variation generally promotes dynamic plant community composition and diversity by influencing interactions of dominant perennial species and annuals or short-lived

perennials that have adapted to varied levels of soil salinity (Callaway, Jones & Ferren 1990; Allison 1992 in SEW 2001). However, well established invasions can persist through less than favorable high salinity conditions (Zedler 1983 in SEW 2001).

Restoration of tidal areas within Suisun Marsh is expected to promote dynamic habitat structure and with this an associated plant community characterized by a high diversity of plants adapted to a variable environment. A persistent issue is the widespread extent of dominant invasives (*Cotula coronopifolia, Lepidium latifolium, Phragmites australis, Polypogon monspeliensis*) which have already established within a highly salinity regulated marsh system (WWR et al. 2010a). Such species are likely to continue to be an issue following restoration activities within Suisun Marsh.

The 2010 Suisun Marsh Habitat Management, Preservation, and Restoration Plan Draft EIS/EIR (USBR et al. 2010) provides a brief and general discussion of invasive plant control practices to minimize new introductions into restored areas. Proposed measures include minimizing surface disturbances where possible, using certified weed free native mixes and plantings for restoration revegetation efforts (as well as weed-free erosion control materials), and eradication of current infestations within restoration areas (combined with education of construction supervisors and managers on weed identification and control measures). These guidelines, if followed, would likely be effective in preventing extensive colonization by exotic species; however, due to the nature of spread of certain problem exotics, particularly perennial pepperweed, construction activities will likely facilitate invasions into restored habitats. Additional measures and adaptive management strategies may be necessary following restoration to control such species.

7.8 Plant Productivity Responses to Restoration and No Action

As with discussions of rare plant and exotic plant distributions in Suisun Marsh and tidal restoration areas, salinity will likely play out as an important factor in productivity response to restoration. Salinity has a significant effect on biomass production because it determines which plants can grow in a given location based on their salt tolerance. More saline conditions favor smaller plants with smaller root and rhizome systems, whereas more brackish conditions favor larger plants with larger root and rhizome systems (Whigham et al. 1989).

However, other factors will also likely prove to be equally influential including hydroperiod, nutrient status, soil redox potential, soil type, disturbance factors, herbivory, dispersal, and interspecies competition and facilitation (BROWN 2004). Nutrient availability is also influenced by the substrate parent material; for example, the relatively lower proportion of cellulose in cattail (*Typha* spp.) relative to bulrush (*Schoenoplectus* spp.) results in relatively faster

decomposition rates, which increases the relative availability of nitrogen and carbon from these plants (Hume et al. 2002). There are also several biotic drivers that influence below-ground biomass production. Individual species will allocate biomass in the roots and shoots at different ratios. Perennial plants in mature tidal freshwater marshes have root:shoot ratios far exceeding 1, indicating that a significant portion of the biomass is below ground, while high-marsh annual plant assemblages generally display root:shoot ratios < 1 (Mitsch and Gosselink 2000). Common fresh and brackish marsh species such as *Bolboschoenus maritimus* and *Schoenoplectus americanus* allocate almost 70% of their biomass to below-ground structures (Karagatzides and Hutchinson 1991), while the below-ground biomass of *Typha latifolia* stands is generally only 40-50% of the aboveground biomass (Sharma and Pradhan 1983). Competition between plants for resources in a marsh will alter the community composition, thereby affecting the below-ground biomass production. If plants with root:shoot ratios >1 dominate there will be significantly more below-ground biomass than if plants with root:shoot ratios <1 dominate.

Vegetation productivity controls in restored areas in Suisun Marsh are therefore directly linked to these factors as well as the inundation regime, which controls soil moisture and water depth and then in turn controls which species of vegetation can grow in a given area based on their tolerance to inundation. The “tidal subsidy” hypothesis (Odum 1980) states that the tides influence marsh vegetation growth by (1) flushing salts off of the marsh plain so they do not accumulate to toxic levels and (2) transporting nutrients into the marsh that stimulate plant growth.

The historical assumption that water project operations have increased salinity far above presumed food plant tolerances is shown by the data to not hold. Moreover, water management is most often cited as the key factor determining plant productivity and assemblage. Therefore, the assumption that channel water salinity is the primary determinant of plant productivity is incomplete at best. Accepted principles of plant ecology consider that productivity depends on many other factors including hydroperiod (controlled by management), nutrient status, soil redox potential, soil type, disturbance factors, herbivory, dispersal, and interspecies competition and facilitation. For the current conceptual model to be useful, it must explain the linkage between these physical, chemical, and biological factors and applied water salinity (Brown 2004).

7.9 Marsh Vegetation Response to Climate Change

Tidal marsh responses to climate change drivers – increased rates of sea level rise, reduced sediment loads, increased atmospheric CO_2, warmer temperatures, and increased storm intensity – raise two broad considerations. First, will the marshes themselves remain or become

submerged. And second, how might the marsh plant community change and thus consequent ecological functions.

7.9.1 Geomorphic Responses

Tidal marshes can respond geomorphically in one or more of three possible paths: estuarine transgression, marsh vertical building, marsh drowning. Which path(s) a given natural or restored tidal marsh follows in Suisun is about its location relative to upland edge (transgression accommodation), salinity regime (plant community productivity), and sediment supply (accretion). It is possible that different parts of a marsh may respond in multiple ways.

Estuarine Transgression

Estuarine transgression is the lateral advancement of the marsh into the adjacent uplands. This mechanism occurred on a massive scale over the past several thousand years as Holocene sea level rise flooded inland to create the San Francisco Estuary. Modern estuarine transgression is highly constrained by hardened shorelines that protect developed areas (**Figure 39**). **Figure 18** shows where the landscape could topographically accommodate 5 feet of sea level rise around the margins of Suisun.

Suisun exhibits mixed 'sea level rise accommodation space' opportunities; generally the northern Marsh has the broadest slopes whereas the east and west Marsh rise relatively comparatively steeply. Some regions of the Marsh abut hillsides that would allow marsh continuance but at a very small magnitude; the edges of Potrero Hills and the steeper small hills at Rush Ranch exemplify this setting. Some areas are very low-gradient offering significant opportunity; the Nurse-Denverton Slough area in the northeast, the Cordelia area in the northwest, and much of the northern boundary of Suisun, all south of Highway 12. Expansion north of Highway 12 around Denverton Slough may be possible depending on bridges and culverts under Highway 12 and road elevations.

Marsh Vertical Building

The ability of marshes to keep pace vertically with rising sea level depends upon sediment accretion and plant biomass accumulation. Where sediment supply is higher, mainly in the south and around Little Honker Bay (Nurse-Denverton Slough area), sediment accretion can contribute significantly to vertical accretion so long as wind-wave resuspension does not preclude net accretion. Away from these higher sediment source areas, accretion would probably occur more slowly, placing greater importance upon biomass accumulation. Plants aid in sediment capture (French and Spencer 1993, French et al. 1995), so plant community composition could have some influence on net accretion rates. **Figure 22** illustrates the general pattern of sediment supply geographic variability in Suisun Marsh. It is important to note that sediment supply

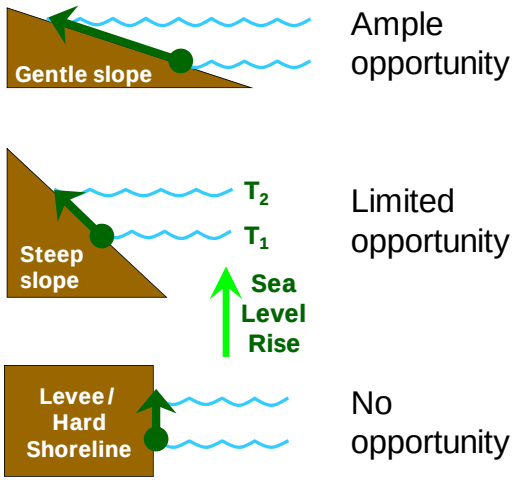


Figure 39. Conceptual Diagram of Potential for Continued Tidal Marsh Estuarine Transgression

Ganju and Schoellhamer (2010) conducted exploratory computer modeling to evaluate the potential for topographic and bathymetric changes in Suisun based on sea level rise, reduced Delta sediment supply, and changed Delta outflow. Their work made several findings. Processes favoring deposition, such as watershed sediment supply, are balanced against erosional processes such as tidal velocities and wind-wave resuspension. Increased depths from sea level rise lead to decreased bottom scour, reducing sediment redistribution and promoting overall sediment deposition in the shallowest 2 meters of Suisun Bay. Decreased watershed sediment supply decreased deposition through most of Suisun Bay. The modeling found that net deposition was not sufficient to counteract increase in sea level. Dry years facilitate transport of the large pool of San Pablo Bay sediments upstream to Suisun, which over time could result in western Suisun Bay being more depositional whereas the decreased watershed sediment supply results in eastern Suisun Bay being more erosional. The modeling suggests the shallowest areas will not keep up with SLR but Ganju and Schoellhamer state that model does not account for wetting/drying, wave break on mudflats, nor marsh sediment trapping all of which can change the outcome.

Many of the brackish marsh plant species found in Suisun Marsh have high above- and below-ground biomass production and are likely to keep pace with sea level rise. However, plant species composition may change to more saline species with sea level rise, as the higher tide stage will allow greater upstream transport of saline ocean water. Saline marsh plants typically have lower biomass productivity and thus less capacity to keep pace with sea level rise compared to brackish marsh species (Parker et al. accepted; Parker et al. in press). As a

consequence, the western portion of Suisun Marsh may, under more rapid rates of sea level rise, have greater likelihood of plant biomass not keeping pace.

Marsh Drowning

Under conditions where rates of sea level rise exceed the combined ability of sediment accretion and biomass accumulation to maintain the emergent marsh vegetation cover in tidal marshes, the marshes will slowly become submerged or 'drowned' and revert to intertidal mudflat (Parker et al. accepted; Parker et al. in press). At present, Suisun Marsh has very little intertidal mudflat (see **Figure 2**) primarily because the brackish vegetation community grows low in the tidal range (see **Figure 4**). Mudflats are far more common in the lower saline reaches of the San Francisco Estuary. Were Suisun to become significantly more saline with sea level rise, it is possible that some marshes could drown.

7.9.2 Plant Community and Ecological Function Responses

The key climate change drivers that will affect plant community composition and thus cascade to ecosystem functions are (1) sea level rise increasing tidal inundation and (2) increased atmospheric CO_2 concentrations, temperatures, and salinity challenging physiological tolerances. The resulting changes include a decline in plant biodiversity, shifts in community composition in unpredictable ways, and shift in rates of mortality. Plant biomass productivity may decline, though changes to overall tidal marsh productivity are complex and thus difficult to predict. Changes in productivity magnitude and/or composition would cascade into the terrestrial and aquatic food web dynamics also in complex and unpredictable ways (Parker et al. accepted; Parker et al. in press).

7.9.3 Implications for and Role of Tidal Marsh Restoration

The ecological functions provided by restored tidal marshes are driven importantly by their initial elevations and thus the extent and composition of the vegetation community (Siegel et al. 2010). Since existing elevations vary across Suisun (**Figure 18**), then restoring sites with some degree of variability in that initial topography will yield sites that span range of ecological functions. Then add variable rates of marsh restoration evolution based on different rates of sediment and biomass accretion to gain a suite of sites across Suisun providing diversity across the range of ecological functions. At the scale restoration is proposed, such diversity could be high. Climate change effects then would add another variable to the factors influencing Suisun Marsh-scale ecological functions and, so long as marsh drowning is not the predominant condition which seems likely to hold for much of Suisun, this added factor could contribute greatly complexity and thus diversity to the tidal marsh landscape.

7.10 Scientific Uncertainties and Testable Hypotheses

1. How will an increase in salinity regime variability resulting from tidal marsh restoration impact vegetation composition and diversity throughout the marsh?

- **Hypothesis 1.** A more variable salinity regime will result in greater species diversity.
- **Hypothesis 2.** A more variable salinity regime will result in establishment and expansion of native plant species.
- **Hypothesis 3.** A more variable salinity regime will result reduce establishments of new invasive species and will reduce the spread of established invasives.

2. How will changes in hydroperiod resulting from tidal marsh restoration impact vegetation composition and diversity throughout the marsh?

- **Hypothesis 1.** Subsided sites experiencing greater frequency, depth, and duration of flooding, will experience a shift to dominance by low-marsh vegetation and open water in deeper areas.

3. How will climate change impact vegetation composition and diversity throughout the marsh?

- **Hypothesis 1.** Climate change will result in increased establishment and expansion of invasive plant species.
- **Hypothesis 2.** Climate change will result in decreased presence of native plant species.

8 Fish and Aquatic Food Web

8.1 Habitat Associations and Distributions

Important habitats to the native fish species of the Suisun marsh are the shallow bays, small and large tidal sloughs, tidal flats, and tidal marshlands (Goals Project 1999, USBR et al. 2010). Suisun Marsh provides vital habitat and food resources for native and non-native fish species, with use varying seasonally and interannually based on life histories of each fish species and water quality conditions. Native fish assemblages appear to peak in abundance in winter, spring, and early summer (Matern el al. 1998 in USBR et al. 2010) and favor areas with higher habitat complexity (SEW 2001). Non-native invasive fish species are most abundant during the warmer months of the year (mid-June to September) and generally prefer low salinity environments (USBR et al. 2010). Many native fish species tolerate higher salinities but require low-salinity periods (e.g., less than 5 ppt) for spawning and rearing in the Marsh (USBR et al. 2010).

Previous studies have attributed long-term fish population size reductions to the tremendous loss of tidal marsh channel habitat in the San Francisco Estuary in the late 19th Century (Bennett and Moyle 1996). More recently, fish abundance, both native and non-native, within the Suisun Marsh has experienced a general decline during the first 15 years (1980-1995) of annual surveying conducted by the UC Davis Suisun Marsh Monitoring Program. From 1995-2006, fish catches remained relatively stable but then experienced another dramatic decline from 2006-2008, which was correlated with lower Delta outflows and higher marsh salinities (this decline is known as the Pelagic Organism Decline or POD). The most current 2009 fish catch data show a slight increase in fish abundance, though catches were still comparatively low from the study's 30-year history (O'Rear and Moyle 2010). In terms of diversity, native fish species have experienced a greater rate of decline relative to non-native species, as was evident in 1996 when natives declined by 51% while exotics decline by 19% (Matern et al. 1996). Additionally, non-native fish species abundance has been highly variable over the study's history, while native fish catch declines have been generally consistent and precipitous (O'Rear and Moyle 2010). Peter Moyle has postulated that several factors may limit Suisun Marsh fish abundance and distribution including recruitment from outside the Marsh, poor water quality within the Marsh (e.g., dissolved oxygen sags in channels when managed wetlands are drained), low habitat quality and structural complexity, invasive species affecting food resources as well as direct competition and predation, and species-specific factors (Brown 2004).

Sloughs and Bays

Channel habitats are an especially integral part of marsh habitat for fish species and their supporting food web (Brown 2004). Sloughs consist of the largest tidal sloughs of Suisun

(Montezuma and Suisun), the intermediate sloughs (Hill, Nurse and Denverton), and the many smaller sloughs around the margins of Suisun Marsh (Peytonia, Boynton, Goodyear, Chadbourne, and so forth). Bays in Suisun include Grizzly, Honker, and Suisun bays in the south and the small Little Honker Bay in the northeast Marsh (**Figure 21**). Moyle et al. (1983) identified two main fish assemblages in the Marsh: a native fish assemblage existing in the dead-end sloughs and a non-native constituency occurring in the main channels. However, an additional study by Meng et al. (1994) confirmed presence of native species in dead-end sloughs but also found that seasonal species occurred in larger sloughs and non-native species existed in both habitat types. As a general rule, larger sloughs have had lower fish catches in surveys (though this could be attributed to sampling issues) compared to smaller sloughs. An exception to this rule is Boynton Slough; though it is one of the smaller sloughs, it has had low fish numbers and diversity. This observation could be attributed to outflow into this slough from the Fairfield Sewage Treatment Plant (Matern et al. 2002 in USBR et al. 2010). The physical properties of sloughs (such as substrate and position to other water bodies) may also influence fish species distributions, for example, high numbers of threespine stickleback were caught near duck ponds, indicating habitat preference (Matern el al. 2001 in USBR et al. 2010).

Fish species commonly utilizing the channels and bays of Suisun include salmonids (including listed winter-run and spring-run and steelhead), pelagic species (including Delta smelt, longfin smelt, splittail, striped bass, northern anchovy, tule perch), and demersal fishes (prickly sculpin, starry flounder, and green and white sturgeon) (see **Table 4**).

Tidal Marshes

Tidal marshes consist of three general geomorphic attributes each of which has direct or indirect functions for estuarine fish species: channels, marsh plains, and marsh ponds. Tidal marsh channels are the primary aquatic component of tidal marshes. Channels perform two fundamental functions in marshes for fish: first, they provide a conduit through which water, sediment, nutrients, and aquatic organisms circulate into, around, and out of the Marsh, thus providing critical habitat connectivity between marsh plains and open water environments. Secondly, tidal marsh channels provide forage habitat and ingress/egress routes for a wide variety of fish species. The marsh plain produces a range of invertebrate food resources for fish, including benthic, epibenthic, and terrestrial invertebrates. The marsh plain also exports detritus which provides bacterial productivity for the aquatic food web. Lastly, some tidal marshes also contain ponds connected at higher tides; these ponds can provide forage habitat as well as export productivity. Tidal marshes are likely utilized directly by salmonids and some demersal fish species and perhaps during high tide in the large tidal marsh channels by pelagic fish species (**Table 4**).

Tidal Marsh Restoration Projects

Restoration projects have the added element of time-varying conditions and thus proportions of emergent vegetation and open water. Depending on the starting elevation of a restoration site, tidal marsh restoration projects can provide a range of benefits to estuarine fishes. In addition, these functions are tide-stage dependent, with high tides providing access and habitat not necessarily present at low tide.

Subtidal and Low Intertidal. Subtidal and low intertidal open water within deeper restoration sites will provide habitats similar to shallow pelagic habitats with their phytoplankton-zooplankton food web productivity function as well as serving as the initial 'receiving waters' for marsh plain productivity. These areas would likely have soft mud bottoms (at least over time) and be surrounded by emergent vegetation on the developing marsh plain. The primary species using this habitat include juvenile Chinook salmon, splittail, striped bass, sturgeon, and native resident species such as prickly sculpin, threespine stickleback, tule perch, Delta smelt, and longfin smelt (Engle et al. 2010; **Table 4**).

Low Marsh. This stage of marsh elevation includes low marsh vegetation and marsh plain habitat with sinuous tidal channels. Plant communities would likely be comprised primarily of *Schoenoplectus* and *Typha* species with more saline sites possibly supporting *Spartina*. Fish would gain access to the invertebrate communities in these restored marshes either directly or through a 'trophic relay' of the smallest fish feeding on the invertebrates and becoming prey to the larger fish (Engle et al. 2010). Tidal marshes are likely utilized directly by salmonids and some demersal fish species and perhaps during high tide in the large tidal marsh channels by pelagic fish species (**Table 4**).

Mid and High Marsh. As elevations increase in tidal marsh restoration sites, the marsh becomes less 'aquatic' and more 'marsh' in character. This shift favors the food web productivity elements of the marsh plains of 'mature' tidal marshes and the direct aquatic habitats of tidal marsh channels. Tidal marshes are likely utilized directly by salmonids and some demersal fish species and perhaps during high tide in the large tidal marsh channels by pelagic fish species (**Table 4**).

Table 4. Fish and Aquatic Invertebrates and Habitat Associations within Suisun Marsh

	Species		Listing Status		Tidal Aquatic				Tidal Marsh			
	Common Name	Species Name	Federal	State	Bays	Major Sloughs	Minor Sloughs	Sloughs w/in Tidal Marsh	Low Intertidal	Low Marsh	Mid Marsh	High Marsh
FISH												
Salmonids	Central Valley steelhead	*Oncorhynchus mykiss*	T		A/M, A/F, J/M, J/F	A/M, A/F, J/M, J/F	J/M, J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R
	Central California Coast steelhead	*Oncorhynchus mykiss*	T		A/M, A/F, J/M, J/F	A/M, A/F, J/M, J/F	J/M, J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R
	Central Valley spring-run chinook salmon	*Oncorhynchus tshawytscha*	T, X	T	A/M, J/M, J/F	A/M, J/M, J/F	J/M, J/F	J/F	J/F	J/F	J/F	J/F
	Winter-run chinook salmon, Sacramento River	*Oncorhynchus tshawytscha*	E, X	E	A/M, J/M, J/F	A/M, J/M, J/F	J/M, J/F	J/F	J/F	J/F	J/F	J/F
	Central Valley fall/late fall-run chinook salmon	*Oncorhynchus tshawytscha*	C	SC	A/M, J/M, J/F	A/M, J/M, J/F	J/M, J/F	J/F	J/F	J/F	J/F	J/F
Pelagic	Delta Smelt	*Hypomesus transpacificus*	T, X		A/F, J/F, L	A/F, A/B, J/F, L, E	A/F, A/B, J/F, L, E	A/B , L, E				
	Longfin Smelt	*Spirinchus thaleichthys*	P		A/F, J/F, L	A/F, A/B, J/F, L, E	A/F, A/B, J/F, L, E	A/B, E, L				
	Northern Anchovy	*Engraulis mordax*			A/F, J/F, J/R	A/F, J/F	A/F, J/F	A/F, J/F				
	Splittail	*Pogonichthys*		SC	A/F, J/F	A/B, A/F, J/F, L, E	A/B, A/F, J/F, L, E	A/B, A/F, J/F, L, E				
	Striped Bass*	*Morone saxatilis*			A/M, A/F, J/F, L, E	A/M, A/F, J/F, L, E	A/F, J/F , L					
	Tule Perch	*Hysterocarpus traski*				A/B, A/F, J/F	A/B, A/F, J/F	A/B, A/F, J/F				
	Three-spine stickleback	*Gasterosteus aculeatus*	S									
Benthic	Prickly Sculpin	*Cottus asper*			L	A/F, J/F, L, E	A/B, A/F, J/F, L, E	A/B, A/F, J/F, L, E				
	Starry Flounder	*Platichthys stellatus*			A/F, J/F, J/R	A/F, J/F	A/F, J/F	A/F, J/F	A/F, J/F	A/F, J/F	A/F, J/F	A/F, J/F
	Green sturgeon	*Acipenser medirostris*	T, PX		A/M, A/F, J/M, J/F,	A/M, A/F, J/M, J/F,	A/F, J/M, J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R
	White Sturgeon	*Acipenser transmontanus*			A/M, A/F, J/M, J/F,	A/M, A/F, J/M, J/F,	A/F, J/M, J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R	J/F, J/R
AQUATIC INVERTEBRATES												
	Corophium Amphipods	*Corophium* spp.			RFB	RFB	RFB	RFB				
	Asian Clam*	*Corbicula fluminea*					RFB					
	California Bay Shrimp	*Crangon franciscorum*			RFB	RFB	RFB	RFB				
	Dungeness Crab	*Cancer magister*			J/F	J/F						
	Oposum Shrimp	*Neomysis mercedis*			RFB	RFB	RFB	RFB				
	Oriental Shrimp*	*Palaemon macrodactylus*					RFB					
	Overbite Clam*	*Corbula amurensis*			RFB	RFB						

Life Stage:
(A) = Adult, (J) = Juvenile, (L) = Larval, (E) = Egg

Habitat Function:
(B) = Breeding, (R) = Rearing, (F) = Foraging, (M) = Migrating, (Lo) = Loafing

Listing Status
(P) = Species proposed, (PX) = Species listed, critical habitat proposed, (X) = Critical habitat listed, (E) = Listed as Endangered under Endangered Species Act, (SC) = Species of Special Concern, (T) = Listed as Threatened under Endangered Species Act, (S) = Sensitive (CDFG and USBLM)

*** = Non-native species**

8.2 Special Status Species

Delta smelt

Delta smelt are currently State and federally listed as threatened. This species is an estuarine resident that spawns in tidal freshwater (Moyle et al. 1992; Hobbs et al. 2007) but can briefly tolerate salinities as high as 19 psu (Swanson et al. 2000). Most individuals have been collected at salinities less than 2 psu as larvae (Dege and Brown 2004) and less than 5-6 psu as juveniles (Feyrer et al. 2007). Delta smelt are the only native fish species in the Sacramento-San Joaquin estuary with a life history completely dependent on the estuary (Moyle and Light 1996).

This species select waters that are well oxygenated and have relatively cool temperatures, usually less than 20-22 degrees Celsius (68-72 degrees Fahrenheit) in summer. Delta smelt are endemic to the upper San Francisco Estuary, and occur principally in the Delta and Suisun Bay (Moyle 2002). This species has been found seasonally throughout Suisun Marsh in small numbers (Matern et al. 2002). Delta smelt use of tidal marshes in Suisun Marsh may be largely limited to a secondary function – consumption of productivity exported from the marshes. Thus, connectivity of the tidal marshes to the tidal aquatic environment is the key process linking delta smelt to tidal marsh productivity (Siegel et al. 2010).

Longfin smelt

Longfin smelt are currently listed under CESA as threatened (March 9, 2009). On August 8, 2007, The Bay Institute along with the Natural Resource Defense Council submitted a petition to have longfin smelt listed as endangered under the Endangered Species Act due to its persistent decline in numbers in the San Francisco Estuary in the last 20 years. Their petition was accepted in 2008 and in 2009 the longfin smelt listing status was reclassified throughout its range (CDFG 2009). Longfin smelt is an anadromous fish species that inhabits open waters of estuaries along the Pacific coast of North America. For juveniles through pre-spawning adults, optimum salinity ranges are typically 15 to 30 psu (Moyle 2002; Baxter *et al*. 1999), whereas during their spawning migration they prefer fresher water habitats where salinities are 0-2 parts per thousand. Spawning generally occurs from November until June, with the peak spawning period being from February through April, in areas that provide an adequate amount of rocks and/or submerged vegetation for eggs to adhere to. According to data from U.C. Davis monitoring, longfin smelt can occur in the Marsh year-round, but is mostly used during the larval stage when they use the brackish waters as nurseries. Longfin smelt abundance in the Marsh declined sharply in the early 1980s and has remained low since then (Matern et al. 2002). Annual mean catches between 1980 and 1985 were about 1 smelt per trawl, with a peak of 7 per trawl in 1980. Since 1985, values have always been < 2 smelt per trawl (DWR data). There has historically been a strong positive correlation between winter and spring Delta

outflow and longfin smelt abundance during the subsequent fall (Jassby et al. 1995; Kimmerer 2002). High freshwater outflows increase the volume of low-salinity water rearing habitat required by larval and juvenile smelt. Historically, high freshwater flows also increased prey production for longfin smelt, but this changed after the introduction of the overbite clam (Kimmerer 2002).

Chinook salmon

Protection and listing of Chinook salmon is divided into two groups (spring-run and winter/fall run) which reflect the variation in the timing when adult salmon reenter fresh water for spawning and correlates to juvenile rearing states. Naturally spawned spring-run Salmon are federally and state listed as threatened, with critical habitat designated primarily in San Francisco-San Pablo-Suisun Bays; fall/winter run naturally spawned Chinook salmon are federally and state listed as endangered, with critical habitat designated for the Sacramento River and including areas of Suisun Marsh at Chipps Island westward to Carquinez Bridge.

Spawning occurs in the Central Valley rivers, downstream of terminal dams, and in tributary streams. Juvenile salmon spend 3-14 months in freshwater reaches before migrating to the ocean for another 2-5 years before returning to spawn (USBR et al. 2010). Movement of juvenile salmon downstream is in response to many factors such as inherited behavior, habitat availability, flow regime, resource competition, and water temperatures. High flow events, following major storms, result in substantial movement of juveniles in spring and fall (Kjelson et al. 1981 in USBR et al. 2010). Low numbers of young Chinook salmon in the Delta during the summer months may be a result of higher than optimal water temperatures (Kjelson et al. 1982). Cover, space, and food are necessary components for Chinook salmon rearing habitat in the tributaries. Suitable habitat is areas with instream and overhead cover in the form of cobbles, rocks, undercut banks, downed trees, and large, overhanging tree branches. The organic materials forming fish cover also provide sources of food in the form of both aquatic and terrestrial insects. In the estuarine environment, mainly San Pablo and San Francisco Bays, crustaceans such as water fleas (*Cladocera*), copepods (*Copepoda*), and amphipods (*Amphipoda*) are consumed. Fly larvae (*Diptera*), aquatic bugs (*Homoptera*), and fish larvae also are consumed (Kjelson et al. 1982 in USBR et al. 2010).

Steelhead

Steelhead are protected in the Central Valley and Central Coast as federally threatened ESUs; critical habitat was designated for five ESUs of steelhead in conjunction with Chinook Salmon. Steelhead generally follow the typical Pacific salmon lifecycle in that they hatch in freshwater, migrate to the ocean, and return to freshwater to spawn. However, steelhead are iteroparous, meaning they do not die after spawning and are capable of spawning more than once.

Steelhead also exhibit greater variation than most anadromous fish in the time spent at each life stage. The Distinct Population Segments that utilize Suisun Marsh are Central California Coast and Central Valley steelhead.

The Distinct Population Segment for Central California Coast steelhead pertinent to the Marsh includes all naturally spawned populations of steelhead in tributary streams to Suisun Marsh including Suisun Creek, Green Valley Creek, and an unnamed tributary to Cordelia Slough (commonly referred to as Red Top Creek). Suisun Marsh is the easternmost extent of their range. NMFS reconfirmed the threatened status of Central California Coast steelhead on January 5, 2006.

The Distinct Population Segment for Central Valley steelhead consists of naturally spawned populations in the Sacramento and San Joaquin Rivers and their tributaries. NMFS reconfirmed the threatened status of Central Valley steelhead on January 5, 2006.

Eleven steelhead have been captured in Suisun Marsh (1982 to 2002) during the UC Davis sampling. One juvenile, one smolt, and 9 adults ranging from 293 millimeters (mm) to 398 mm have been caught— all in November through February, with most caught in January (Bay Delta and Tributaries no date). Most fish were caught in Denverton Slough, followed by Peytonia, Spring Branch, Cutoff, Montezuma, and Grant Sloughs. Steelhead have not been caught since 2002 (Bay Delta and Tributaries no date). It is unknown how steelhead are using Suisun Marsh, but possibly they are using the Marsh as a migratory area either to freshwater streams such as Green Valley Creek and Suisun Creek to spawn (adults) or outmigration to the ocean (juveniles and smolts) (USBR et al. 2010).

Green sturgeon

Sturgeon are an anadromous, iteroparous and long-lived fish species. The largest fish have been aged at 42 years, but the maximum age is probably closer to 60-70 years (Moyle 2002). Sexual maturity is reached for male green sturgeon at 15 years and for females at 17 years. The Southern Distinct Population Segment of North American green sturgeon consists of coastal and Central Valley populations south of the Eel River. Current spawning habitat for Southern Distinct Population Segment green sturgeon has been reduced to a limited area of the deep turbulent sections of the upper reaches of the Sacramento River (Moyle 2002). On April 7, 2006, NMFS listed the Southern Distinct Population Segment green sturgeon as threatened. In September 2008, NMFS proposed critical habitat for the Southern Distinct Population Segment that includes Suisun Marsh.

Adult Southern Distinct Population Segment green sturgeon return to freshwater to spawn every two to five years, and generally show fidelity to their upper Sacramento River spawning sites. Adults typically migrate into fresh water beginning in late February, spawning occurs from March to July, with peak activity from April to June. Juvenile green sturgeon move from freshwater rivers within their first year to estuaries, where they spend approximately 3 years before migrating to the ocean (Kelly et al. 2006). Juveniles use estuarine waters year-round. The distribution and physical parameters that may influence movement in the estuary are not well known (Moyle 2002). After out-migration, green sturgeon disperse widely in the ocean. Tagged fish from the Sacramento River have been captured to the north in coastal and estuarine waters, such as the mouth of the Columbia River in Oregon (Adams et al. 2002).

The Suisun Marsh Fish Monitoring (SMFM) program has documented the presence of juvenile green sturgeon in the Marsh (BDAT 2007). However, the methods used for sampling are not effective at capturing fish with strong swimming abilities. Therefore, the number of green sturgeon sampled should not be considered an accurate population estimate for individuals that utilize the Marsh. Essentially no information exists regarding green sturgeon use of the Marsh. Montezuma Slough, as well as Suisun and Grizzly Bay, are located between Central Valley freshwater spawning habitat and the Pacific Ocean. Adult and juvenile green sturgeon likely utilize these areas as a migratory corridor, although it is unclear what portion of the population utilize these routes. Based on the known life history of the species, it is assumed that juvenile green sturgeon could be present in all regions of the Marsh throughout the year. The primary drivers that likely influence green sturgeon habitat connectivity throughout the Marsh are physical barriers and adverse water quality conditions, that render the water column unsuitable by this species.

8.3 Non-Native Invasive Fish Species

Striped bass

Striped bass was first introduced from the East Coast in 1879; through the early part of the 20th century following this introduction, annual catches in the San Francisco Bay estuary yielded over 450 tons of fish. Though catches of striped bass declined, this species remains as the primary sports fishery in the San Francisco Bay (Nichols et al. 1986). They are presently the principal sport fish caught in the San Francisco Bay. Striped bass move regularly between salt and freshwater, and they usually spend much of their life cycle in estuaries (Moyle 2002). Adults and juveniles can survive temperatures up to 34°C for short periods of time, although once temperatures exceed 25°C they are under stress. They can also withstand oxygen levels as low as 4 mg/L, as well as high turbidity, although extreme conditions can inhibit reproduction. Spawning begins in the spring during April and May and optimal temperatures for spawning

range from 15.6° to 20.0°C (Goals Project 2000). About one-half to two-thirds of the striped bass move into the Sacramento River to spawn, while the remaining spawn in the lower San Joaquin River (SEW 2001). Spawning occurs where there are moderate to swift currents that carry the striped bass eggs downstream to their rearing habitat. If the current is too slow, the eggs will sink and die.

The abundance of striped bass in the estuary has been on the decline. A number of factors are believed to be playing a part in the decline, including climate factors, South Delta pumps and other diversions, pollutants, reduction of estuarine productivity, invasions by alien species, and exploitation (Moyle 2002). According to the UC Davis studies (Moyle et al. 2006), it appears that lower Suisun, Spring Branch, and Goodyear sloughs are the three areas that are heavily used by striped bass. In 2004, it was observed that fewer striped bass were caught in Goodyear Slough, which may suggest that the low levels of dissolved oxygen in Goodyear Slough during 2004 may have affected their use of that slough. It is also likely that high availability of prey, shallow depth, and proximity to larger bays are determining factors for use of the marsh as important rearing areas. Larval growth and survival rates are highest in areas of brackish water, which is thought to be due to a reduction in energy costs for osmoregulation.

Large striped bass frequently feed heavily on threespine sticklebacks that are coming out of marsh drains from managed wetlands in Suisun Marsh (Moyle 2002). Striped bass are also often found hanging out near screened diversions feeding on small fish. Kimmerer et al. (2000) found a significant positive relationship between the abundance of mysids and the abundance of juvenile striped bass, which suggest that the extended period of low mysid populations may have contributed to poor survival of juvenile striped bass (Feyrer et al. 2003). The low mysid population has been linked to the invasion of the overbite clam and striped bass have been observed to have significantly less stomach fullness during the spring after the invasion of the overbite clam (*Potomacorbula amurensis*) when compared to the pre-clam period.

Yellowfin goby

Yellowfin goby is native to Asian estuaries and was recently introduced (during the 1960's) to the San Francisco Estuary. This species rapidly expanded following its introduction and was first reported from Suisun Marsh in 1967. Since this time, yellowfin goby has continued to thrive; this species is able to tolerate high salinity and following several drought years, may have gained an advantage of native fish less tolerant of high salinity (Meng et al. 1994).

A study conducted by Matern and Brown (2004) made an interesting observation of the yellowfin goby's feeding ecology in the estuary; their study found that this species utilized two exotic prey (hydroids, *Cordylophora caspia*, and barnacle, *Balarus improvisus*) not exploited by

other fish species. Results of this study suggest that this species' feeding behaviors are well-matched to the fluctuating environment of the San Francisco Estuary, which may explain this species abundance and persistence in the estuary and Suisun Marsh. Meng et al (1994) have suggested that the introduction of yellowfin goby and other exotic species combined with environmental disturbances have likely accelerated native fish decline in California.

Shimofuri goby

Shimofuri goby (*Tridentiger bifasciatus*) is native to Asian estuaries and was first documented in Suisun Marsh in 1985; by 1990 this species had dispersed from the San Francisco estuary south to Pyramid Lakes in Los Angeles County. It has been suggested that fish larvae were pumped through the aqueduct and were able to establish small populations at the end of the aqueduct in Pyramid Reservoir. Trawls conducted in 1989 (Meng et al. 1994) reported shimofuri goby as the most abundant adult fish in Suisun Marsh. This species may compete with the federally listed, endangered tidewater goby (*Eucyclogobius newberryi*) if they co-occur (Matern and Fleming 1995).

A study released in 2004 found that shimofuri gobies fed significantly on two non-native prey resources, barnacles (*Balanus improvis*) and hydroids (*Cordylophora caspia*), contributing to a perception that the invasion success of this species in an altered ecosystem may be due to its ability to feed on an underutilized prey base. However, the study also found that shimofuri gobies fed substantially on *Corophium*, which is a primary prey source for a number of native species (Matern and Brown 2004).

8.4 Aquatic Food Web Community

Phytoplankton and Zooplankton

Primary production in the Suisun region's tidal areas is dominated by phytoplankton, but green algae and blue-green algae also contribute to overall production (SFEP 1992). Phytoplankton abundance, species composition, and distribution can be limited by temperature, light, nutrients including micronutrients, inorganic carbon or grazing, and high levels of contaminants such as copper which can inhibit phytoplankton production (Kimmerer 2004). The distribution of phytoplankton with regard to salinity has not been shown (Kimmerer 2004). Changes in these environmental conditions cause extreme seasonal and annual variability in phytoplankton standing stocks (SFEP 1992). Phytoplankton thrive in conditions of greater residence time, more nutrients, warmer temperatures, and more light (i.e., shallow, less turbid). These conditions vary in dependent and independent ways and the resulting alignment across each of these factors at any particular time controls production (Kimmerer 2004). Factors controlling these conditions include Delta outflow (e.g., volumes, sediment load, and temperature), depth, incident sunlight, seasonal variation, and thermal discharges.

Summer months generally have produced the highest densities in phytoplankton concentrations with historical ranges between 40-100 µg/liter (Ball and Arthur 1979). Phytoplankton community composition has been mainly comprised of diatom species such as *Melosira distans*, *Cyclotella* spp., *Skeletonema costratum*, and *Thalassiosira decipiens* (Cole *et al*. 1986). Over the last 20 years there has been a dramatic decline in phytoplankton biomass in Suisun Bay which may be due to stressors such as "overgrazing" by the nonnative invasive overbite clam, *Corbula* spp. (Kimmerer 2004). Since its establishment in 1986, densities of the clam have increased to a mean of 19,000 individuals per square meter (m^2) with maximum observed densities up to 48,000 clams/m^2 (Cohen 2005).

The functions of zooplankton species include grazing on phytoplankton and providing a critical food web link to small fish and higher trophic levels in open water environments. Zooplankton communities are generally dominated by tintinnids, rotifers, and copepods. However, zooplankton species respond differently to a number of environmental conditions (especially salinity) causing species abundances to exhibit seasonal and annual variability (Kimmerer 2004). Similar to phytoplankton, there has been a substantial decrease in abundances of native zooplankton species over the last few decades coupled with establishment of nonnative species, (especially the small copepod *Limnoithona tetraspina*) (Bay Institute 2004). One particular effect of this shift in species composition is a change in prey size, distribution, and palatability which alters food availability dynamics. These nonnative zooplankton species have directly and indirectly affected the food supply of fish species such as Delta smelt (*Hypomesus transpacificus*), splittail (*Pogonichthys macrolepidotus*), and striped bass (*Morone saxatilis*).

Aquatic Invertebrates

The tidal water column in Suisun Marsh supports several native invertebrate species including several large shrimp of the genera *Palamenon*, *Exopalaemon*, and *Crangon* (the California bay shrimp, *C. franciscorum*), as well as macrozooplankton of the genus *Acanthomysis* and *Neomysis* (opossum shrimp *N. mercedis*) and Dungeness crab (*Cancer magister*) (Brown 2004, Goals Project 2000). California bay shrimp are a member of the crangonid family (grass shrimp) that are usually distributed from the western Delta to Suisun and Honker bays, but have been collected as far upstream as the San Joaquin River at Middle River (DFG 2006). Juvenile bay shrimp are found in shallow (<15'), low salinity waters and migrate to deeper, higher salinity waters as they grow (DFG 2006). The diet of bay shrimp varies with size and includes copepods, amphipods, bivalves, caridean shrimp, and polychaets. In addition, bay shrimp are an important food source for estuarine fishes such as green and white sturgeon, striped bass, and starry flounder (Reilly et al*.* 2001). Opossum shrimp are a member of the mysid shrimp family and are found in the greatest abundance in Suisun Bay and the western Delta. The diet of opossum

shrimp also varies with size and includes phytoplankton, rotifers, and copepods (Goals Project 2000). The opossum shrimp was historically an important food source for fish throughout the San Francisco Estuary (Feyrer et al. 2003). Juvenile Dungeness crabs forage in bay and major slough habitat in Suisun Marsh. Juvenile crabs feed opportunistically on clams, crustaceans, and small fishes. Juvenile crabs are food source for bottom dwelling fishes such as starry flounder (Goals Project 2000).

In addition to the native invertebrates, several non-native species have established in the marsh including the oriental shrimp (*Palaemon macrodactylus*), Siberian prawn (*Exopalaemon modestus*), and several non-native mysids (*Acanthomysis bowmani* and *A. bowmani, Neomysis kadakensis*). Oriental shrimp have been primarily collected in shallow areas and tidal sloughs and creeks as juveniles, and in deeper waters as they mature (DFG 2006). Siberian prawn have been collected throughout the Marsh but occur in highest abundance in areas where California bay shrimp are rare (O'Rear and Moyle 2009).

Aquatic Benthos

Less data is available on the diversity and abundance of aquatic benthic invertebrates in Suisun Marsh. Two primary organisms are known to occur in high numbers: the invasive overbite clam (*Potamacorbula amurensis*) and oligocheate worms. Oligochaetes are an important dietary component for some Suisun Marsh fish species and are common throughout the Marsh (LSA 2007).

8.5 Viability Assessment

Summary

Native fish populations, especially protected or listed species, within Suisun Marsh are unstable and generally in decline for most species. Yearly surveys indicate variability in population abundances, which is primarily linked to environmental conditions (salinity, DO, temperature, etc). Overall, fish populations in Suisun Marsh have remained relatively stable but this is due mainly to increases in the abundance of invasive fish species. Relative to other San Francisco Estuary native fish populations, Suisun Marsh fish species are in better health.

UC Davis Annual Fish Surveys

An ecological scorecard of fish viability in San Francisco Bay released in 2003 by the Bay Institute indicated that the greatest decline of native fish abundance had occurred in Suisun Bay. Major declines were observed in the late 1980's and early 1990's, which corresponded with a period of prolonged drought and high rates of water diversion. Native fish abundance has appeared to rebound since that time, but was still observed to be lower that levels measured 20 years prior to the decline events (Bay Institute 2003). The Bay Institute also

reported in their study that the percentage of native species was significantly lower in Suisun Bay and was on average 68% natives from 1997-2001 (2003).

2009 UC Davis Suisun Marsh monitoring data showed a slight increase in fish abundance from 2008 levels. This increase was due mainly to higher catches of non-native, introduced species, which nearly doubled from 2008-2009 (5.7 to 11.3 non-native fish per trawl, **Figure 40**). Striped bass (*Morone sacatilis*) was the most common non-native species identified; this species more than tripled in catch per unit effort from 2008-2009. Three other non-native species of high abundance included yellowfin goby (*Acanthogobius flavimanus*), shimofuri goby (*Tridentiger bifasciatus*), and American shad (*Alosa sapidissima*).

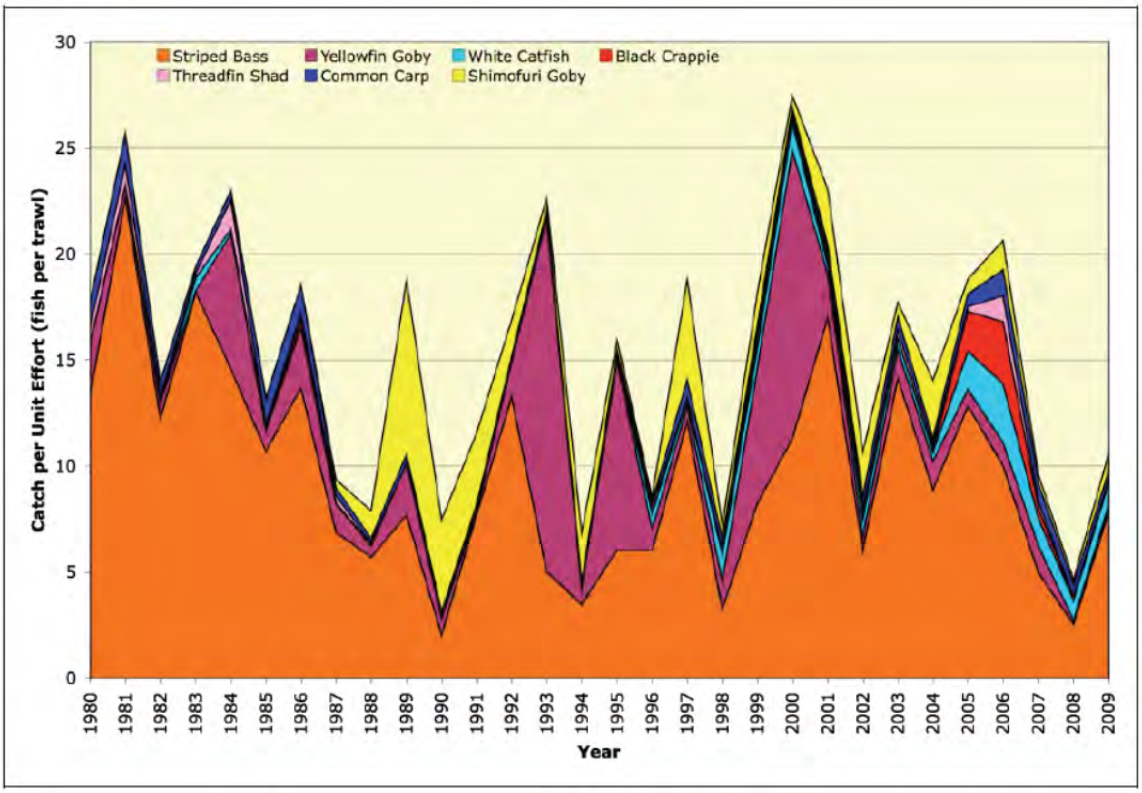


Figure 40. Annual trawl catch per unit effort from 1980-2009 for seven common non-native fish species in Suisun Marsh.
Source: O'Rear and Moyle 2010.

Native fish trawl catches in 2009 remained relatively constant for most species; longfin smelt decline slightly, while tule catch per unit effort tripled from 0.6 to 1.9 fish per trawl. Splittail has been the most commonly captured native fish in Suisun Marsh, but have steadily decreased since 2006. In 2009, catches of splittail reached their lowest point (only two fish per trawl) in ten years. Catches of Delta smelt during the UC Davis monitoring efforts have been consistently

low since 1984. On average, total catches have totaled only 7 fish per year; during the 2009 survey, only four Delta smelt were caught. Overall, the increase in fish abundance from fish trawls in 2009 was contributed to an increase in non-native fish catches (O'Rear and Moyle 2010).

The UC Davis SM Monitoring Program has also used beach seining to document fish abundance in the Marsh. Unlike trawl catches, beach seining catch per unit efforts have increased over the study's history; however, native fish catches have remained consistently low and the majority of beach seine catches have been dominated by non-native species (O'Rear and Moyle 2010) (**Figure 41**).

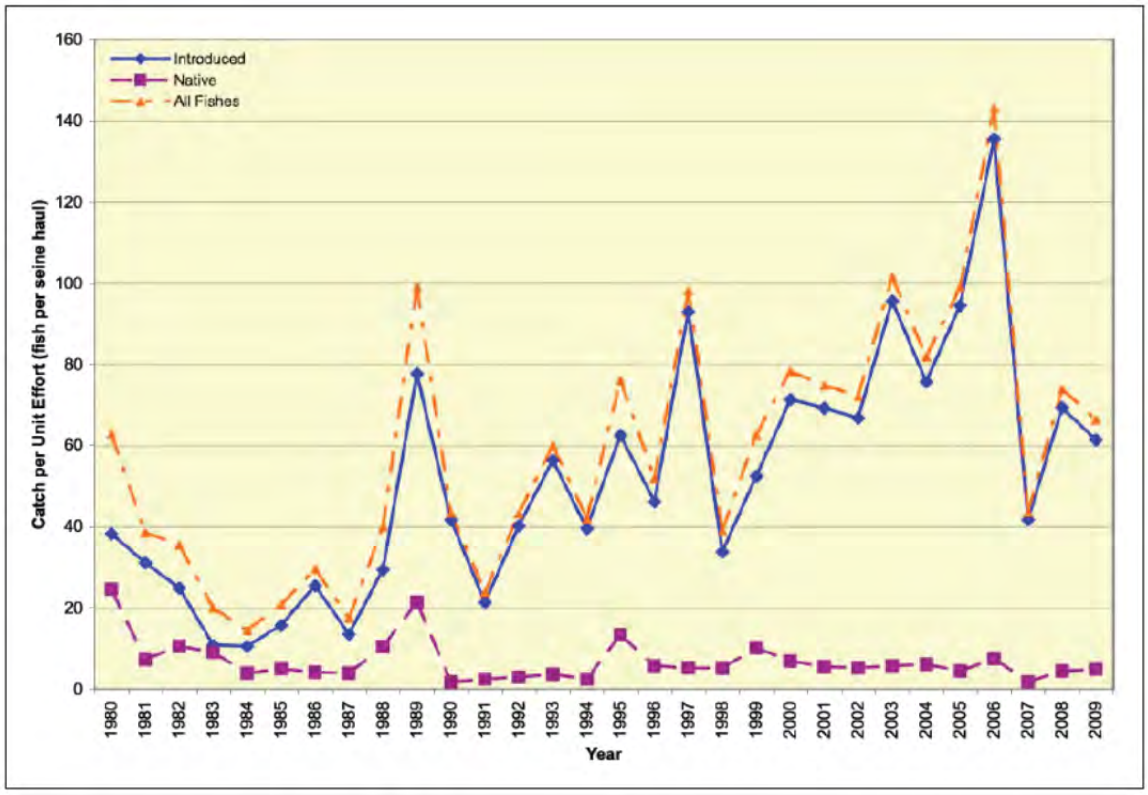


Figure 41. Annual beach seine per unit catch effort from 1980-2009.
Source: O'Rear and Moyle 2010.

8.6 Threat Assessment

The primary factors affecting native estuarine fish in Suisun Marsh include: water quality (salinity variability and dissolved oxygen [DO]), salinity control structures and non-native invasives (invertebrates and fish).

8.6.1 Water Quality: Low Salinity Variability

Native fish use of Suisun Marsh reflects salinity preferences – fish species that prefer higher salinity are present in the Marsh when salinities are higher and vice versa for fish species with lower tolerance. The majority of nonnative fish species prefers low salinity and inhabits the Marsh during low-salinity periods. Low-salinity periods typically are from spring to early summer when outflow is high. During the months of February through June, native fish species are spawning and rearing in the Marsh and require salinity less than 5 ppt. Many fish are larvae, juveniles, and young-of-the-year fish that were spawned upstream in freshwater areas but rear in the Marsh in the spring (SEW 2001). During dry and critical years, salinities are high and may preclude native fish from spawning. Higher salinities are seen in the summer into fall. The Suisun Ecological Workgroup (2001) has suggested keeping salinity variable from July to January to preclude nonnative fish species from establishing in the Marsh (USBR et al. 2010).

8.6.2 Water Quality: Low Dissolved Oxygen

Suisun Marsh low dissolved oxygen (low DO) water quality concerns were first noted by UC Davis researchers in Peytonia Slough and Goodyear Slough as early as 1993 (Schroeter and Moyle 2004). In fall of 1999, researchers began measuring and reporting low DO sags in detail in response to increased fish mortality observed during monthly sampling activities. Low DO events accompanied by abnormally high levels of fish mortality (fish kill) were documented in the fall of 1999, 2001, and 2003 (Robert Schroeter, personal communication). In October 2004 a widespread fish kill was observed across several kilometers of Peytonia, Boynton, Goodyear, and Suisun Sloughs that coincided with managed wetland low DO discharges. Fishes including Sacramento splittail, Sacramento sucker, Chinook salmon, striped bass, various introduced gobies, and common carp were found dead in areas where low DO events occurred (Schroeter and Moyle 2004). Investigations are not known to have taken place to determine whether there may have been other contributing factors to this fish kill. This event may have been exceptionally severe but it was detected only because the UC Davis researchers happened to be there on the day it happened. Fish kills can be difficult to detect and the monthly sampling frequency by UC Davis researchers means that other events may have gone unnoticed. Fish mortality was reported in Hill Slough and the Suisun City Marina in fall 2009, but no water quality data from that time period are available to verify if low DO conditions were the cause.

Water quality issues, such as low DO, have also been linked to abundance of chironomid midges (Chironomidae), the primary food source for salmonids in freshwater streams. These small larvae and other fly larvae (Diptera) are sensitive to both water quality and substrate changes (USBR et al. 2010).

2009 Goodyear Slough Fish Kill

During the 2009 UC Davis monitoring effort, the upper section of Goodyear Slough experienced an extremely low dissolve oxygen concentration (roughly 1.0 mg/L). Unsurprisingly, fish catches within the portions of the slough with depleted oxygen netted only dead fish (primarily splittail). The low DO event in upper Goodyear Slough was attributed to multiple interacting factors including an accumulation of dead algae and plant material, poor circulation in Goodyear Slough, and discharges of anoxic water from saline duck ponds (sampling coincided with the beginning of waterfowl season). The report suggested that oxygen levels likely declined rapidly based on the presence of dead, fast-swimming fish (such as striped bass) which could have swam away from unsuitable environmental conditions; additionally the authors suggest that anoxic conditions may be important in determining the composition of fish communities and that the effects of low DO on fish may be more severe than expected (O'Rear and Moyle 2010). Average DO concentrations in Suisun Marsh are shown in **Figure 42**.

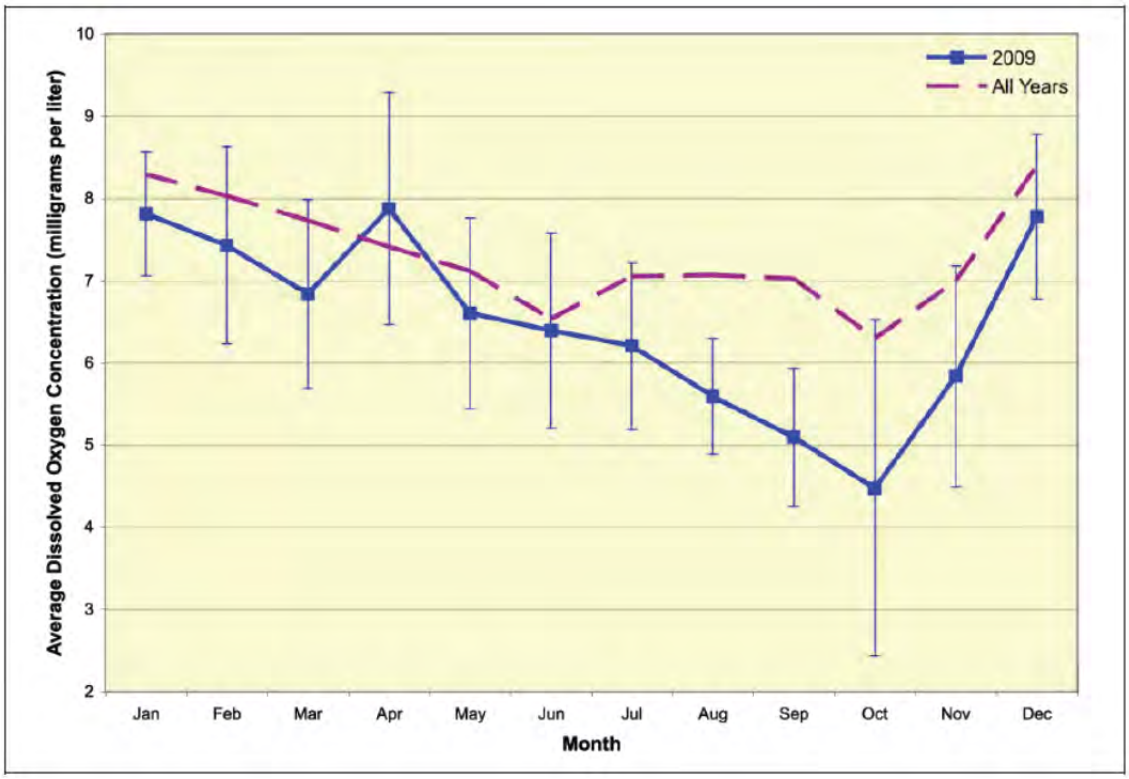


Figure 42. Monthly average dissolved oxygen concentrations for 2009 and from 2000-2009 (all years).

Source: O'Rear and Moyle 2010.

8.6.3 Suisun Marsh Salinity Control Gates and Fish Passage

As mandated by the U.S. Army Corps of Engineers permit for construction of the SMSCG (Suisun Marsh Salinity Control Gate), DWR developed a monitoring program to determine the SMSCG negatively impact fish passage. This program has focused primarily on adequate passage of adult Chinook salmon through Montezuma Slough. Results of this program have been analyzed by the Interagency Ecology Program (IEP) for the periods of 1993-1994, 1998-1999, and 2001-2003.

Preliminary results of these studies indicate that the SMSCG does affect salmon migration, which have been found to exhibit milling behavior (i.e., entering the slough from the west, travel a short distance up the slough, and then exit from the west to spawning areas). The IEP has suggested that alterations to the control gates could improve fish passage without significant impacts to water quality downstream of the gates (R.Vincik, DFG, personal communication in Brown 2004).

8.6.4 Food Web Competition from Invasive Non-Native Invertebrates

Two species of non-native, Asiatic clams are present within Suisun Marsh: *Corbula amurensis* and *Corbicula fluminea*. *Corbula* is a saline to brackish species found elsewhere in the San Francisco Estuary and *Corbicula* is the freshwater species found in the Delta. The invasion of the overbite clam (*Corbula amurensis*) in the late 1980's has created a fundamental shift in the benthic community of the San Francisco Bay estuary and with this a major effect on food availability for pelagic organisms (Baxter et al. 2008 in USBR et al. 2010). Abundance of the introduced, non-native overbite clam was reportedly at its highest (based on unit per catch data) in 2009, based on UC Davis SM monitoring data results (O'Rear and Moyle 2010). Catches increased from 22.9 clams per catch in 2008 to 191.1 in 2009, with most clams caught in lower Suisun and during summer months.

Researchers from UC Davis have been monitoring clam populations and their impact on aquatic productivity throughout the Marsh since 2006. The distribution of this species is mostly limited to more saline regions of Suisun Marsh; most of the clams in recent times were recorded from lower Suisun, indicating that this species is becoming denser in the locations it has already invaded (O'Rear and Moyle 2009). As such, this region will likely experience a continued and perhaps increased reduction in available primary producers. In contrast, in the tidal channels at Rush Ranch, these two species are thought to have minimal local impacts. Both these sloughs have high phytoplankton biomass above that of their downstream counterparts (e.g., Suisun and Montezuma Sloughs), so the relatively low populations of clams within the sloughs do not appear at this time to be sufficient to negatively affect higher trophic levels (Schroeter, pers. comm. 2010; WWR et al. 2010a).

Prior to the invasion of the overbite clam, all carbon and energy was filtered and processed through pelagic zooplankton and fish. In the once primarily brackish system, clams were limited within Suisun Marsh except during dry years, and thus the Marsh supported an abundance of diatoms (primary producers), zooplankton, and their primary predators (fish and shrimp) (Lund et al. 2007). Since *Corbula* has established in the San Francisco Estuary, there has been a significant decline in the abundance of most pelagic invertebrates (Feyrer et al. 2003).

8.6.5 Potential Effects of Invasive Fish Species

It is generally assumed that invasion and permanent establishment of exotic fish species will have a negative impact on native fish assemblages. However, direct evidence of such impacts is difficult to quantify because habitat conditions may vary from year to year, and such conditions may play a more important role in determining fish abundances. Additionally, fish assemblages change throughout the year depending on a set of specific habitat conditions such as temperature and salinity (Moyle and Light 1996). Some exotic species, such as the shimofuri goby have rapidly invaded the San Francisco Bay estuary and quickly established thriving populations. Given the abundance of exotic species in certain areas of the Marsh, it is reasonable to assume that invasive species are consuming prey resources and thereby further jeopardizing vulnerable native fish species. The shimofuri gobi in particular is believed to feed opportunistically on a variety of prey including non-native hydroids and barnacles; however, this species will also consume seasonally abundant amphipods, which constitute a significant prey source for several native fish (Matern and Brown 2005).

8.7 Native Fishes Anticipated Responses to Restoration and No Action

Tidal marsh restoration activities proposed for the Suisun Marsh are predicted to provide both direct and indirect habitat and ecosystem functional benefits for native fish species. Increased habitat connectivity between marsh habitat and bays and sloughs are expected to provide direct benefits for all species by increasing access to shallower and brackish waters with higher prey productivity (USBR et al. 2010).

Delta smelt and Longfin smelt

Delta smelt and longfin smelt are primarily pelagic species, so it is unlikely they would directly use the structural complexity provided by marshes. However, they are expected to benefit from prey production exported from the marsh. Delta smelt and longfin smelt may also physically enter restoration sites that have more extensive aquatic habitats expected at more subsided restorations sites (early stage of 'tidal marsh' evolution), as such sites are essentially shallow tidal aquatic environments during higher tide stages. The subtidal and low intertidal stages are most likely to provide such habitat.

Chinook salmon

Inundation regime may influence the use of restored tidal marshes by Chinook salmon. Within estuarine habitat, juvenile Chinook salmon movements are generally dictated by tidal cycles, following the rising tide into shallow water habitats from the deeper main channels, and returning to the main channels when the tide recedes (Levy and Northcote 1982, Healey 1991). As juvenile Chinook salmon increase in length, they tend to school in the surface waters of the main and secondary channels and sloughs, following the tides into shallow water habitats to feed (Allen and Hassler 1986).

Juvenile Chinook salmon are known to forage in shallow areas with protective cover such as intertidal and subtidal mudflats, marshes, channels and sloughs. If provided appropriate accessibility, water quality conditions and prey items, juveniles will likely directly utilize restoration sites at all developmental stages for foraging. Restoration sites may also provide benefits to Chinook salmon in adjacent aquatic habitats through an increased export in productivity.

Steelhead

The availability of prey items will likely influence the use of tidal marshes by steelhead. Juvenile steelhead feed on a wide variety of drifting aquatic organisms and terrestrial insects, but as size increases fish become more important in their diet (Moyle 2002). Emergent vegetation communities support invertebrate populations and provide refuge from water currents and predation. Cover is an important habitat component for juvenile steelhead, both as a velocity refuge and as a means of avoiding predation (Shirvell 1990, Meehan and Bjornn 1991).

Juvenile steelhead are likely utilizing the Marsh for migration, foraging and rearing. If provided appropriate accessibility, water quality conditions and prey items, juveniles will likely directly utilize restoration sites at all developmental stages. These restoration stages may also provide benefits to steelhead in adjacent aquatic habitats through an increased export in productivity.

Green sturgeon

Since no scientific data currently exists relating to green sturgeon use of the tidal marsh habitat, it is unknown what features of marsh geomorphology would provide the most valuable habitat.

Although it is uncertain if and for what functions green sturgeon would utilize tidal marsh habitat in Suisun, the availability of prey items could influence potential site use for foraging. Sturgeon are highly adapted to prey upon benthic species, with primary diet items made up of bottom dwelling estuarine invertebrates. Juveniles in the San Francisco Estuary feed on opossum shrimp and amphipods (Moyle 2002). Adults captured in the Sacramento-San Joaquin

Delta feed on invertebrates, including shrimp, mollusks, amphipods, and even small fish (Adams et al. 2002). Colonization of invasive benthic invertebrates is wide-spread throughout the Bay-Delta and it is currently unknown how green sturgeon is responding to invasive species as a source of prey. Green sturgeon may be feeding on the exotic overbite clam (Corbula amurensis) that is common in white sturgeon diet (Moyle 2002). Invasive overbite clams are known to effectively bioaccumulate toxic levels of the trace element selenium, which is known to have deleterious health effects to fish (Deng et al. 2007, Higashi et al. 2005).

Green sturgeons are likely utilizing the Marsh for migration, foraging and rearing. Although it is unknown if juvenile green sturgeon would utilize any restoration stages of tidal marsh habitat, appropriate accessibility, water quality conditions and prey items could increase the likelihood of providing suitable habitat for direct use. Restoration stages such as subtidal, low intertidal, low marsh, mid marsh and high marsh could provide indirect benefits to green sturgeon in adjacent aquatic habitats through an increased export in productivity.

8.8 Non-Native Fishes Anticipated Responses to Restoration and No Action

The conditions of the San Francisco Bay estuary and associated bays (including Suisun Marsh) have been altered dramatically over the past century. Following these changes was an overwhelming invasion of exotic species; as example, studies have suggested that most invertebrate species in the estuary are introduced species (Moyle and Light 1996). Early introductions of fish species into the estuary lead to the immediate establishment of three species, American shad, white catfish (*Ameiurus catus*), and striped bass. Since there introductions in the late 19th century, the number of exotic species in Suisun Bay and the Delta has increased significantly but is dominated by Striped bass and two euryhaline gobies-yellowfin goby and Shimofuri goby (Moyle and Light 1996).

Data presented by UC Davis researcher Peter Moyle in the 2004 Suisun Marsh Workshop final report, indicated that fish communities in the Marsh are divided into two groups, a marine/estuarine group and a freshwater species pool. Interestingly, the freshwater species group was dominated by a much larger percentage of exotic species (40 exotic species of 68 total). This dynamic provides strong evidence for observations that non-native species thrive in low salinity waters and are primarily observed during low-salinity, wet periods of the year (USBR et al. 2010). Following this logic, as well as recommendations made by the Suisun Ecological Workgroup, the use of variable salinities coupled with removal of salinity control gates and tidal restoration, may prove to be an effective method for preventing exotic fish persistence and dominance in the Marsh.

8.9 Scientific Uncertainties and Testable Hypotheses

1. How will the restoration of tidal marsh affect the occurrence of discrete low DO events and resultant fish kills throughout the marsh?

- **Hypothesis.** Tidal marsh restoration will reduce the frequency, magnitude, and duration of discrete low DO events and resultant fish kills throughout the marsh

2. How will an increase in salinity regime variability impact fish community composition?

- **Hypothesis 1.** A more variable salinity regime will reduce the presence of many non-native fish species that are dependent upon continuously low salinities.
- **Hypothesis 2.** A more variable salinity regime will result in an increase in numbers of native fish species. This increase will be indicated by greater total numbers of native fish as well as native species richness.

3. What are the true impacts of invasive fish and mollusk species upon native fish?

- **Hypothesis 1.** Invasive fish species outcompete native fish for important prey items
- **Hypothesis 2.** Aquatic areas colonized by invasive filter-feeding mollusks have lower levels of suspended organic matter, resulting in lower food availability for primary pelagic consumers.

9 Birds

9.1 Habitat Associations and Distributions

Suisun Marsh provides important waterfowl habitat in California because it is one of the largest contiguous areas of remaining wetland habitat in California. "The Marsh represents approximately 13% of California's remaining wetlands and has historically wintered up to 28% of the wintering waterfowl in California"(SEW 2001). The Marsh is used as a permanent wintering area, as a resting area prior to completing migration, and depending upon regional habitat availability, opportunistically (Miller 1987). As more wintering habitat is lost, Suisun managed wetlands will become increasingly valuable to migratory waterfowl

The first available water for most wintering California waterfowl, south of the Siskiyou Mountains, is provided by the Marsh. Wetland habitat in the Central Valley and elsewhere is limited when waterfowl populations peak in October and early November. With peak population numbers and limited water, Suisun Marsh and its available water is critical to arriving waterfowl. During droughts, water in the Central Valley is limited throughout the wintering period. Suisun becomes especially important at these times. Marsh water supplies remain very stable during droughts while Central Valley water supplies are reduced. As a result, many areas within the Central Valley may not be flooded during a drought, thereby reducing available Central Valley waterfowl habitat.

Suisun Marsh also supports 38 species of shorebirds during fall and spring migrations and over the winter (SRCD, pers. comm.). A few shorebird species nest in Suisun Marsh, e.g., American avocet. Some species such as dunlins use the marsh all winter with periodic infusions of dunlins from Tomales Bay and other small estuaries along the coast in response to winter storms (Kelly 2001). This is true of other species as well, such as the dowitchers (Takekawa et al. 2002b). Baker (1979) found that few microhabitats are available to shorebirds in the winter and therefore they share much of the same habitat with the exceptions related to morphology and the ease with which substrates can be probed.

Suisun Marsh also supports several rookeries (centralized nesting colonies) for great blue herons (*Ardea herodias*) and great egrets (*Ardea alba*). These species are large wading birds that feed on fish and other aquatic organisms in shallow, open-water areas and along the edges of channels in diked and tidal marshes. The managed wetlands of Suisun Marsh provide high quality foraging habitat for these species. A recent study of landscape influences on heron and egret colony site selection and nest productivity in the Bay Area found that the availability of nearby suitable foraging habitat and low intensity urban development around much of the

marsh contributed to highly successful colonies of both species (Kelly et al. 2008). Regional foraging densities for these birds was highest in Suisun Marsh and nest productivity (i.e. brood sizes) in Suisun Marsh rookeries were estimated to be among the highest for all study locations (Kelly et al. 2008).

Many other bird guilds exist in Suisun Marsh. Rail species including the federally endangered California clapper rail (*Rallus longirostris obsoletus)* and the state threatened California black rail (*Laterallus jamaicensis coturniculus*) inhabit wetland areas of the marsh, particularly tidal marshes with well developed channel networks. A wide range of raptor species forage within the marsh on an abundant prey base of small mammals (especially rodents) as well as snakes and other reptile and amphibian species. Passerines forage in a wide variety of habitats common throughout the marsh. Gulls and terns are also common throughout areas of the marsh.

Specific bird guild habitat associates within Suisun Marsh are discussion in greater depth in the following subsections. **Table 5** summarizes special status bird species and their habitat associations.

Table 5. Special-Status Birds and Associated Habitats in Suisun Marsh

	Species		Listing Status		Tidal Aquatic				Tidal Marsh				
	Common Name	Species Name	Federal	State	Bays	Montezuma and Suisun Sloughs	Minor Sloughs	Sloughs w/in Tidal Marsh	Low Intertidal	Low Marsh	Mid Marsh	High Marsh	Upland Transition
BIRDS													
Diving Ducks and Allies	Bufflehead	*Bucephala albeola*			F	F	F						
	Common Goldeneye	*Bucephala clangula*			F	F							
	Barrow's Goldeneye	*Bucephala islandica*		SC	F	F							
	Canvasback	*Aythya valisineria*		SC	F	F	F						
	Ring-Necked duck	*Aythya collaris*			F	F							
	Greater Scaup	*Aythya marila*			F	F							
	Lesser Scaup	*Aythya affinis*			F	F							
	Redhead	*Aythya americana*		SC	F	F							
	Ruddy Duck	*Oxyura jamaicensis*			F	F							
	Surf Scoter	*Melanitta perspicillata*			F	F							
	Double-Crested Cormorant	*Phalacrocorax auritus*		WL	F	F							
	Eared Grebe	*Podiceps nigricollois*			F	F	F	F	F	F	F		
	Pied-Billed Grebe	*Podilymbus podiceps*			F	F	F	F	F	F	F		
	Western Grebe	*Aechmophorus occidentalis*			F	F							
	Clark's Grebe	*Aechmophorus clarkii*			F	F							
	Common Merganser	*Mergus merganser*			F	F							
	Red-breasted Merganser	*Mergus serrator*			F	F							
	Common Loon	*Gavia immer*		SC	F	F							
	American Coot	*Fulica americana*			F	F	F	F					
	California brown pelican	*Pelecanus occidentalis californicus*	E	E	F	F							
	American white pelican	*Pelecanus erythrorhynchos*		SC	F	F							
Dabbling Ducks and Allies	Mallard	*Anas platyrhynchos*					F	F	F	F	F	F	F, B
	American Wigeon	*Anas americana*					F	F	F	F	F	F	F
	Green-winged Teal	*Anas crecca*					F	F	F	F	F	F	F
	Northern Pintail	*Anas acuta*					F	F	F	F	F	F	
	Northern Shoveler	*Anas clypeata*					F	F	F	F	F	F	
	Tule Greater White-Fronted Goose	*Anser albifrons elgasi*		SSC	F	F	F	F	F	F	F	F	
Herons, Egrets, and Bitterns	Great Blue Heron	*Ardea herodias*		S			F	F	F	F	F	F	F
	Black-crowned Night Heron	*Nycticorax nycticorax*	S				F	F	F	F	F	F	
	Snowy Egret	*Egretta thula*					F	F	F	F	F	F	
	Great Egret	*Ardea alba*		S			F	F	F	F	F	F	
	Least Bittern	*Ixobrychus exilis*		SC			F	F	F	F	F		
Gulls and Terns	California Gull	*Larus californicus*			F, Lo	F, Lo							
	Ring-Billed Gull	*Larus delawarensis*			F, Lo	F, Lo							
	Elegant Tern	*Sterna elegans*	SC		F	F							
	California Least Tern	*Sterna antillarum browni*	E	E	A/F,J/F	A/F,J/F	A/F,J/F					R	R
Passerines	Salt Marsh Common Yellowthroat	*Geothlypis trichas sinuosa*		SC						A/F,J/F	A/F,J/F	A/F,J/F	A/F,J/F
	Suisun Song Sparrow	*Melospiza melodia maxillaries*		SC					A/F,J/F	A/F,J/F	A/F,J/F, R	A/F,J/F, R	
	Tricolored blackbird	*Agelaius tricolor*		SC									
Raptors	Bald Eagle	*Haliaeetus leucocephalus*		E, S, FP	F	F							
	White-tailed Kite	*Elanus leucurus*		FP								F	F
	Osprey	*Pandion haliaetus*		S	F	F							
	Northern Harrier	*Circus cyaneus*		SC							F	F	F
	Swainson's Hawk	*Buteo swainsoni*		T								F	F
	American Peregrine Falcon	*Falco peregrinus anatum*		E, S, FP								F	F
	Burrowing Owl	*Athene cunicularia*		SC									F, B
	Short-eared Owl	*Asio flammeus*		SC							F	F	F
Rails	California black rail	*Laterallus jamaicensis coturniculus*	SC	T					A/F,J/F	A/F,J/F,	A/F,J/F	A/F,J/F, R	A/F,J/F,R
	California clapper rail	*Rallus longirostris obsoletus*	E	E					A/F,J/F	A/F,J/F	A/F,J/F	A/F,J/F	A/F,J/F
Shorebirds	Long-billed Curlew	*Numenius americanus*		WL	F	F	F	F	F	F	Lo	Lo	
	Western Sandpiper	*Calidris mauri*			F	F	F		F	F	Lo	Lo	
	Least Sandpiper	*Calidris minutilla*			F	F	F		F	F	Lo	Lo	
	Long-Billed Dowitcher	*Limnodromus scolopaceus*			F	F	F	F	F	F	Lo	Lo	
	Short-Billed Dowitcher	*Limnodromus griseus*			F	F	F	F	F	F	Lo	Lo	
	Marbled Godwit	*Limosa fedoa*			F	F	F		F	F	Lo	Lo	
	Willet	*Tringa (= Catoptrophorus) semipalmata*			F	F	F		F	F	Lo	Lo	

Life Stage:
(A) = Adult, (J) = Juvenile
Habitat Function:
(B) = Breeding, (R) = Rearing, (F) = Foraging, (M) = Migrating, (Lo) = Loafing
Listing Status
(E) = Listed as Endangered under Endangered Species Act, (SC) = Species of Special Concern, (T) = Listed as Threatened under Endangered Species Act, (S) = Sensitive (CDFG and USBLM), (WL) = Watch List (CDFG), (FP) = Fully Protected (CDFG)

9.1.1 Bird Use of Subtidal/Low Intertidal Habitats

Rails

The California clapper rail (federally and state-listed as endangered) is known to occur in the Suisun Marsh and at one time, were abundant in San Francisco salt marshes, which supported the largest populations in the State. Historically, the California clapper rail was restricted to western, more saline areas of the Marsh. Currently this species may utilize the intertidal zone as marginal foraging habitat. The California black rail (state-listed as threatened) has been documented mainly in the northern and northwestern portions of the Marsh. This species is also known to use the shallow edge of the low intertidal zone for foraging, which provides an abundant source of invertebrates, this species primary food source. (USBR et al. 2010).

Waterfowl

Diving ducks- subtidal areas (bays and sloughs) provide important foraging habitat for certain diving duck species. All three species of scoters (*Melanitta* spp.) use the bays and large sloughs of Suisun Marsh.

Shorebirds

Western sandpiper is the most numerous shorebird species in the San Francisco Bay estuary, particularly in fall, early winter, and spring. Western sandpipers have a distinct preference for foraging in wet, fine sand or muddy substrates (Wilson 1994). At low tide in winter, western sandpipers prefer tidal sloughs and mudflats, followed by salt marsh plains and tidal salt ponds.

Herons and Egrets

All species of herons and egrets found within Suisun Marsh utilize the bays, sloughs, and shallow intertidal areas for foraging.

Gulls and Terns

The California Least tern (federally and state-listed as endangered) occurs along the Pacific Coast from San Francisco Bay to Baja California. There has been only one documented occurrence of California Least tern in the Marsh, on the east side o Montezuma Slough; however, it is possible this species may use subtidal habitats to forage for fish, shrimp, and invertebrates (USBR et al. 2010).

Passerines

Adult and juvenile Suisun Song Sparrows utilize the bays, sloughs, and shallow intertidal areas for foraging.

9.1.2 Bird Use of Low Elevation Tidal Marsh Habitats

Rails

California clapper rail is believed to use the low marsh zone for foraging and refugia habitat. The California black rail is also known to use the shallow water edge of the low marsh zone for foraging (USBR et al. 2010).

Waterfowl

Dabbling ducks- may forage in tidal marsh habitat (primarily seeds) or middle marsh depending on species.

Shorebirds

Tidal flats (exposed during low tide) provide primary foraging habitat for shorebirds.

Herons and Egrets

All species of herons and egrets found within Suisun Marsh may utilize low marsh areas for foraging when flooded.

Passerines

Adults and juveniles of two species of passerines, the saltmarsh common yellowthroat and the Suisun song sparrow, will forage in low elevation tidal marsh areas.

9.1.3 Bird Use of Mid-Elevation Tidal Marsh Habitats

Rails

California clapper rail is believed to use the middle marsh zone for foraging and refugia habitat. The California black rail uses middle marsh habitat for foraging and potentially nesting above the limits of tidal inundation (USBR et al. 2010).

Waterfowl

Dabbling ducks- may forage in tidal marsh habitat (primarily seeds) or middle marsh depending on species.

Shorebirds

Not likely to use these areas unless inundated on extreme high tides; substrate consistency and invertebrate composition influence use of these areas by shorebirds.

Herons and Egrets

All species of herons and egrets found within Suisun Marsh may utilize mid marsh areas for foraging when flooded.

Passerines

The Suisun song sparrow (state species of special concern) is a distinct subspecies of song sparrows and is completely endemic to Suisun Bay. This species uses well developed middle marsh habitat, for foraging and nesting, which are characterized by cattails, bulrush, and other emergent marsh vegetation. Salt marsh common yellowthroat (state species of special concern) has also been reported to use similarly vegetated areas for foraging (USBR et al. 2010).

Raptors

Two species of raptors, northern harriers and short-eared owl, may forage in mid-elevation tidal marshes.

9.1.4 Bird Use of High Elevation Tidal Marsh Habitats

Rails

The high marsh zone is believed to provide optimal foraging, refugia, and nesting habitat for the California clapper rail, which are often associated with marsh vegetation that includes bulrush, cattail, and silverweed (*Potentilla anserina*). The California black rail uses high marsh habitat for nesting and refugia (USBR et al. 2010).

Waterfowl

Dabbling ducks- may forage in tidal marsh habitat (primarily seeds) or middle marsh depending on species

Shorebirds

Not likely to use these areas unless inundated on extreme high tides; substrate consistency and invertebrate composition influence use of these areas by shorebirds.

Herons and Egrets

All species of herons and egrets found within Suisun Marsh may utilize high-elevation marsh areas for foraging when flooded.

Gulls and Terns

California least tern may utilize high elevation tidal marsh areas as rearing habitat.

Passerines

The Suisun song sparrow uses high marsh habitat, above the limits of tidal inundation, for nesting and foraging for seeds and invertebrates. The Salt marsh common yellowthroat (state species of special concern) has been observed in tidal marsh habitat in Suisun Bay. This species also uses the high marsh zone (above the level of tidal inundation) for nesting and foraging. Salt Marsh common yellow throat is also known to use the higher marsh zone, above the limits of tidal inundation, for nesting (USBR et al. 2010).

Raptors

Several raptor species in Suisun Marsh will forage in high elevation tidal marsh areas.

9.1.5 Bird Use of Upland Habitats

Rails

Both the California clapper and black rail likely use upland habitat for refugia and escape from high tides (USBR et al. 2010).

Waterfowl

Several species of dabbling ducks may forage and/or breed in the upland areas adjacent to tidal marshes.

Shorebirds

Upland areas may be useful refugia habitat for shorebirds, but generally they only upland areas around ponds for nesting.

Herons and Egrets

Great blue heron may forage in the upland transitional areas adjacent to tidal marshes during or following extreme high tides.

Gulls and Terns

California least tern may utilize upland areas adjacent to tidal marsh areas as rearing habitat.

Passerines

Both adult and juvenile salt marsh common yellowthroat may utilize upland areas as foraging habitat.

Raptors

The Western burrowing owl has previous been observed in upland habitats in the northern portion of Suisun Marsh and on the east side of Montezuma Slough near Collinsville Road. Suitable habitat for this species likely occurs in upland areas and in the vicinity of agricultural lands. Short-eared owls have only once been observed in Suisun Marsh, though this species may occur in tall grass stands in lower-lying areas during winter months.

9.1.6 Bird Use of Managed Wetland Habitats

Rails

The California black rail is likely not found in this habitat type possibly because they have lower food resource levels (USBR et al. 2010).

Waterfowl

Waterfowl represent the primary avian sub-group utilizing managed wetland habitats, which are diked to create suitable habitat for waterfowl species. Suisun Marsh managed wetland habitat provides valuable nesting, foraging, and wintering habitats for waterfowl and is a key wintering area in the Pacific Flyway. Single day winter tallies of waterfowl in Suisun Marsh commonly total more than 125,000. Tidal, brackish wetland, bays, and sloughs also provide important habitat for waterfowl. Waterfowl species can be further subdivided into dabbling ducks, diving ducks, geese, and swans (USBR et al. 2010).

- *Dabbling Ducks*- Use managed wetland habitat for foraging (primarily seeds)
- *Diving Ducks*- Use of managed wetlands is species dependent
- *Geese and Swans*- known to occur in managed wetland habitat

Shorebirds

Managed wetlands provide important habitat for numerous species of shorebirds, particularly migrating and overwintering species. Use of managed wetland habitat varies between species based on water level, salinity, and available vegetation communities. Some examples of species using managed wetlands include the black-necked stilt (*Himantopus mexicanus),* yellowlegs (*Tringa melanoleuca*), dunlin (*Calidris alpine*), and long-billed dowitcher (*Limnodromus scolopaceus*) and nesting habitat for the killdeer (*Charadrius vociferous*), black-necked stilt, and American avocet (*Recurvirostra americana*) (Hickey and W.D. Shuford 2003 in USBR et al. 2010)

Herons and Egrets

Herons and egrets will forage in shallow, open water areas within managed wetlands. Their use of the managed wetlands will be dependent upon management activities as they will only forage when wetland areas are flooded. Deep-water perimeter ditches along the inside of levees may serve as year-round foraging habitat, even when wetland fields are not flooded (e.g. summer dry-land management period).

Passerines

The Tricolored blackbird (California species of special concern) is a colonial nester in emergent marsh and riparian scrub habitat that forages in surrounding marsh and terrestrial habitats, including grasslands. Data from the UC-Davis Tricolored Blackbird Working Group indicates that tricolored blackbirds have been consistently observed nesting at Rush Ranch from 2004-2008 (Sara Estrella, pers. comm. 2010). Salt marsh common yellowthroat has also been observed utilizing managed wetlands for foraging and nesting.

Raptors

A broad suite of raptor species, many of which are special-status, utilizes habitats within and around Suisun Marsh for foraging, nesting, and roosting. Species such as the golden eagle and Swainson's hawk hunt in upland grasslands and nest in large trees near wetlands, in grasslands, and along the edges of ephemeral creeks. Burrowing owls occupy burrows excavated by ground squirrels, often in ranch areas among piles of debris. Species such as northern harrier and white-tailed kite forage over both wetland and grassland areas. Short-eared owls both winter and nest in the Marsh, comprising the only regular nesting location for this species along the California coast. All of these species take advantage of an ample prey base of small mammals (especially rodents) as well as snakes, birds, and other reptile and amphibian species. Due to the high development pressure in habitats to the north, south, and west, and the unique adjacency between different habitat types within the Marsh, it is a regionally important area for raptor conservation (National Audubon Society 2010).

The White-tailed kite (California species of special concern) has only once been documented in the Suisun Marsh; however, this species is expected to occur in suitable habitat (managed wetlands, ruderal habitat, and agricultural/pasturelands) for foraging (and limited nesting) throughout the Marsh (USBR et al. 2010).

9.1.7 Bird Use of Riparian Habitats

Swanson's hawk has once been documented in riparian habitat in the Marsh; this occurrence was an active nest located along Cordelia Slough. This species is expected to occur only in small numbers due to the lack of suitable habitat in the Marsh (nest primarily in riparian areas near agriculture/pasturelands).

9.2 Viability Assessment

Summary

Overall, bird populations throughout most guilds are stable but in many cases vulnerable to habitat changes outside of their range (migratory or nesting) within Suisun Marsh. California clapper rail populations are currently very low mainly due to a lack of suitable habitat with the exception of habitats within Rush Ranch.

9.2.1 Special Status Bird Species

California clapper rail

The California clapper rail (*Rallus longirostris* obsoletus) is a Federal (1970) and State (1971) listed Endangered Species. California clapper rails 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. Habitat that has direct tidal circulation is preferred and is characterized by predominant coverage by pickleweed (*Sarcocornia pacifica*) with extensive stands of Pacific cordgrass (*Spartina foliosa*), and, in the North Bay, *Schoenoplectus maritimus*, abundant high marsh cover, and an intricate network of tidal sloughs which provide abundant invertebrate populations (Grinnell et al. 1918, DeGroot 1927, Harvey 1988, Collins et al. 1994) as well as escape routes from predators (Zembal and Massey 1983, Foerster et al. 1990). Research suggests that rail density is positively correlated to channel density.

California clapper rails were first systematically surveyed in the San Francisco Estuary during the 1970's at which point they were only in marshes west of Suisun Bay. Clapper rails have since consistently been detected in the Marsh but their abundance has remained low. Currently, California clapper rails are restricted almost entirely to the marshes of San Francisco Bay where the only breeding populations are known to occur. Within Suisun Marsh, clapper rails have consistently been observed along shoreline marshes from Martinez east to Concord Naval Station, marshes near the mouth of Goodyear Slough, Suisun and Hill Sloughs, and the western reaches of Cutoff Slough. DFG survey results have documented sporadic and low numbers of clapper rails, in 2006 five clapper rails were observed in the marsh and zero were observed in 2007 (USFWS 2010). Lack of extensive blocks of tidal marsh with suitable structure is the ultimate limiting factor for the species' recovery; vulnerability to predation is exacerbated by reduction of clapper rail habitat to narrow and fragmented patches close to urban edge areas that diminish habitat quality. Dikes provide artificial access to terrestrial predators, and displace optimal cover by high marsh vegetation. Non-native plant species management is also essential to protect from invasives such as smooth cordgrass (*Spartina alterniflora*) and pepperweed (*Lepidium* spp.).

California black rail

The California black rail is a State Threatened Species and a Federal Species of Management Concern. A majority of California black rails occur within the tidal marshes of the San Francisco Bay Estuary (greater than 80 percent), though some smaller populations occur along the outer coast of Marin County and the freshwater marshes of the Sierra Nevada foothills and the Colorado River Area (Spautz et al. 2005). Of the black rail populations occurring in the Estuary, many are currently found in the historical marshes of San Pablo Bay, Suisun Bay, and the Carquinez Strait (Evens et al. 1991). The highest concentrations are in marshes associated with large rivers and sloughs (Petaluma River Marsh, Black John Slough, Coon Island, Fagan Slough, Napa River) (Evens et al. 1991, Spautz and Nur 2005); thus freshwater input to tidal marshes appears to correlate positively with black rail abundance. Manolis (1978) found black rails only in the upper elevations of marshes, near the limit of tidal inundation. Black rails prefer saturated substrates; therefore, marshes with muted tidal influence are more likely to provide habitat in years when there is above average precipitation.

PRBO conducts annual bird surveys and in 2005 performed a detailed survey for California black rail within 31 tidal marshes in San Francisco Bay, Suisun Bay, northern San Francisco Bay, and western Marin County. Results of the survey estimated that approximately 3.44 birds/ha occur within Suisun Bay tidal marsh habitats and that their presence was strongly correlated with the density of vegetation below 10 cm in height (Spautz et al. 2005). There is some evidence that California black rails are migratory and may disperse from breeding grounds in the winter months. Winter areas are believed to include Benicia State Recreation Area (Solano County) and Olema Marsh (Marin County) (USFWS 2010).

Suisun song sparrow

Suisun song sparrow is currently considered by the CDFG as a Bird Species of Special Concern (year round), priority 3. The Suisun song sparrow is a distinct subspecies of song sparrows completely endemic to Suisun Bay. Previous literature suggested that these birds are confined to undiked tidal marshes. However, field surveys by DFG and DWR have observed Suisun song sparrows along distribution ditches, permanent ponds, and other areas in diked wetlands of Suisun Marsh where required plant assemblages and brackish water conditions exist (Collins et al. 1994). Marshall (1948) and Cogswell (2000), point out that song sparrows use freshwater marsh, riparian vegetation along stream courses, coastal scrub, brackish marsh and salt marsh. Non-tidal seasonal wetlands may be used for foraging, but much less than fully tidal marsh.

Intermixed stands of bulrush (*Schoenoplectus* spp.), cattail (*Typha* spp.), and other emergent vegetation provide suitable habitat. Suisun song sparrows use the tallest, centermost *Schoenoplectus acutus* patch for song and calling perches and find concealment in the piles of dead stems below. Individuals seldom move more than 9 meters (30 feet) from cover and, once a territory is established, adults occupy it for their lifetime, seldom moving more than 100 meters (328 feet) away (Johnston 1956). Juvenile dispersal is the main means by which individuals transfer between salt marsh song sparrow populations. Suisun song sparrow nests are strung along edges of sloughs and bays in linear fashion, at 48 to 70 yard intervals. As the fringe marsh widens, distances between adjacent nests increase. Open marsh more than ten yards from the winding tidal channels is avoided. Each territory must have enough area for nesting and foraging (Walton 1975).

Suisun song sparrows are distributed over most of their original range, occurring in marshes from Martinez (Contra Costa County) eastward along the south bayshore of Suisun Bay to Pittsburg (Contra Costa County), then north of Suisun Bay throughout the extensive Suisun marshlands (Solano County). The reproductive success of the Suisun song sparrow was monitored at Rush Ranch and calculated to be approximately 27 percent. The density of Suisun

song sparrows was estimated to be 11 birds per acre, with a total population estimated to be 22,000 to 53,000 (Nur et al. 1997).

Salt marsh common yellowthroat

The salt marsh common yellowthroat is a State and Federal Species of Concern and is one of four subspecies of common yellowthroat that nest in California. Salt marsh common yellowthroats are winter residents of tidal marshes, but occur in other habitats (often wetland ecotones) such as riparian thickets, freshwater marshes, marshy coastal forb vegetation, and brush or scrub near wetlands (Terrill 2000). Most breeding (60 percent in the San Francisco Bay region) occurs in brackish marsh, about 5 percent in salt marsh, and the remainder in other wetland or peripheral wetland habitats. Salt marsh common yellowthroats nest in a variety of habitats around San Francisco Bay wetlands and adjacent uplands; moisture appears to be the factor common to all types of breeding habitat. Nesting occurs in areas in or next to wet ground and dense vegetation (Bent 1953; Hobson et al. 1986).

Survey data determined that yellowthroats are associated with large amounts of brackish marsh vegetation, notably bulrush (*Bolboschoenus maritimus*) and common cattail (*Typha latifolia*), and non-native perennial pepperweed (*Lepidium latifolium*). Although pickleweed (*Sarcocornia pacifica*) is often the dominant plant in tidal marshland, the more *Sarcocornia* present, the fewer yellowthroats (Nur et al. 1997).

Salt marsh common yellowthroat nesting territories were observed in five habitat types: brackish marsh, salt marsh, riparian woodland or swamp, freshwater marsh, and upland/or grassland (Hobson et al. 1986). Yellowthroats frequently use borders between various plant communities, and territories often straddle the interface of riparian corridors or the ecotones between freshwater or tidal marsh and upland vegetation (Shuford 1993). Outside of the breeding season, some populations of salt marsh common yellowthroat shift habitat use from brackish or freshwater marshes to more saline marshes dominated by *Sarcocornia* or *Spartina*. Female yellowthroats construct the nest, which is typically placed no higher than 60 centimeters (23.6 inches) above the ground, close to water, and well concealed in dense vegetation. Nests are constructed of grasses and sedges held firmly to the surrounding vegetation and covered by loosely woven materials (Bent 1953; Erlich et al. 1988). Yellowthroats are primarily insectivorous, and glean insects on or near the ground (to about 1.5 meters [5 feet] above the ground or water) from low herbaceous vegetation, bushes, and small trees, or from the surface of mud (Shuford 1993).

The current status of salt marsh common yellowthroat in Suisun Marsh is currently unknown due to a lack of distribution and abundance survey data. Surveys conducted in 1977 and 1985 indicated that this species continues to occur in all counties where it was historically known but

that they are present in only 19 out of 51 historic locations within these counties (USFWS 2010).

9.2.2 Waterfowl

As most of Suisun Marsh is purposefully managed to support waterfowl populations, waterfowl are among the most viable biological communities within the Marsh. At least 25 different species of diving ducks, dabbling ducks, and allies (cormorants, pelicans, etc.) have been observed within the Marsh. Historic surveys have indicated that the Marsh supports hundreds of thousands of waterfowl during the fall and winter months, which is approximately 5% of the waterfowl in California's Central Valley (Brown 2004). There is a broad base of literature that discusses waterfowl populations within and outside the Marsh; summarizing that literature is outside the scope of this document.

9.2.3 Other Birds

Gulls and Terns

Gulls in Suisun Marsh are primarily associated with open water habitats and the Potrero Hills Landfill north of the Marsh. Common species include the Western Gull, California Gull, and Ring-billed Gull. Populations of all species within the Marsh are highly viable; Western Gulls in particular have been known to have a nesting colony near the "Mothball Fleet" in Suisun Bay (Carter et al. 1992). Terns also utilize open water habitats within and along the Marsh. There is a rare nesting colony of Least Terns within the Montezuma Wetlands Restoration project along the eastern side of the Marsh; this population, though small, has persisted in recent years (Marschalek 2010).

Herons and Egrets

The Marsh supports ample populations of herons and egrets (ardeiids) that forage in shallow open water/managed marsh habitats and along the edges of tidal sloughs. Common species include great blue heron, great egret, snowy egret, and black-crowned night heron. This community is highly viable in the Marsh due to the regional emphasis on managing for the shallow, open water/marsh conditions that facilitate foraging for these species. Ardeiids' local viability is emphasized by the presence of multiple nesting colonies (see Section 9.1 above).

Passerines

The Marsh supports a broad range of passerines, including the special-status salt marsh common yellowthroat, Suisun song sparrow, and tricolored blackbird discussed above. Other common species include marsh wren and red-winged blackbird in wetland habitats, western meadowlark and house finch in upland/grassland habitats, and black phoebe in riparian habitats. Population viability of passerines is variable depending on the species; in general, wetland-dependent species are more at-risk than upland species.

Raptors

The populations of most raptor species that utilize Suisun Marsh will likely remain roughly equivalent with current population levels in the near future. Many raptor species, such as short-eared owl and Swainson's hawk, have localized populations whose presence or absence at a site from year to year may be attributable to factors unrelated to site conditions (e.g., conditions at wintering/breeding habitat, cyclical pattern in prey populations, etc.). Some species such as peregrine falcon are still recovering from sharp population declines in the mid-20th-century due to the impacts of the pesticide DDT; these populations are expected to continue their gradual increases into the future as long as adequate habitat is conserved or restored.

9.3 Threat Assessment

9.3.1 Special Status Species

California clapper rail

Non-native mammalian predators represent the most severe short- and long-term threat to the species. Non-native species, such as the red fox (*Vulpes fulva*) and feral cats (*Felis domestica*), pose a serious threat to adult clapper rails (Foerster et al. 1990, Foerster and Takekawa 1991, Zembal 1992, Albertson 1995). Norway rats (*Rattus norvegicus*) and raccoons (*Procyon lotor*) also pose serious threats to clapper rail eggs (DeGroot 1927, Applegarth 1938, Harvey 1988, Foerster et al. 1990). No studies have been conducted to confirm these threats in Suisun Marsh.

Lack of extensive blocks of tidal marsh with suitable structure is the ultimate limiting factor for the species' recovery; vulnerability to predation is exacerbated by reduction of clapper rail habitat to narrow and fragmented patches close to urban edge areas that diminish habitat quality. Dikes provide artificial access to terrestrial predators, and displace optimal cover by high marsh vegetation. Non-native plant species management is also essential to protect from invasives such as smooth cordgrass (*Spartina alterniflora*) and pepperweed (*Lepidium* spp.). The rapid invasion of San Francisco Bay by exotic *Spartina alterniflora* (smooth cordgrass) also threatens to cause major long-term structural changes in tidal salt marsh creek beds and banks, creek density, and marsh plains, and could impair future habitat for California clapper rails.

Contaminants, particularly mercury, selenium, and polychlorinated biphenyls (PCBs) are significant factors affecting viability of California clapper rail eggs (Schwarzbach et al. 2002, 2006, Novak et al. 2005). Restoration in heavily subsided areas could benefit from the addition of dredge material, but this could potentially introduce contaminants (Foin et al. 1997).

California black rail

Black rails may suffer from predation pressure by great egrets, northern harriers, as well as other birds and mammals if they move into areas without cover during high tides. Therefore, a transitional zone of peripheral halophytes, between the marsh and uplands, is an essential component of suitable habitat for this species because it provides high tide refuge (Evens et al. 1991). Contaminants may impact rails. Although there is no literature on the subject, contaminants have been found to affect the viability of California clapper rail eggs (Schwarzbach et al. 2002, 2006, Novak et al. 2005) which share similar habitats.

Suisun song sparrow

High rates of predation by birds of prey during high tides pose a serious threat to the survival of individuals. Mortality rates for Suisun song sparrows are 80 percent during the first year of life, and 43 percent per year for adults (Larsen 1989). Diking, channelization, development, and a substantial decrease in freshwater outflow from the Sacramento- San Joaquin Delta have greatly reduced the habitat that supports this subspecies. The remaining habitat is highly fragmented, existing in thin strips along the inside edges of tidal sloughs. Suisun song sparrows are very sedentary, never making long flights over unfamiliar habitat. This behavior coupled with the severe fragmentation of brackish tidal marsh habitat predisposes the Suisun song sparrow to the threat of local extinction.

Salt marsh common yellowthroat

Common yellowthroats, as a whole, are known to be hosts to the parasitic brown-headed cowbird. Brown-headed cowbirds are brood parasites that lay eggs in the nests of other species, directly affecting their hosts by reducing nest success (Mayfield 1977; Brittingham and Temple 1983). Stewart (1953), as cited by Foster (1977), found parasitism by cowbirds to be a significant cause of mortality among yellowthroats in Michigan. It is still unknown whether salt marsh common yellowthroats are impacted as heavily by cowbirds.

Salt marsh common yellowthroats may be susceptible to high rates of predation. Reduction of cover, especially in drought years or as a result of human disruption, can increase the incidence of predation. Predators that typically affect passerines include domestic cats, raccoons, opossums, red foxes, rats, crows and ravens, scrub jays, snakes, and raptors.

9.3.2 Waterfowl

As long as Suisun Marsh is managed for duck production, the primary threats to waterfowl in the Marsh are (1) habitat impacts to off-site waterfowl breeding habitat (many waterfowl in Suisun winter there, but do not breed there) and (2) the bioaccumulation of methylmercury from managed marsh habitats. Research into the production of methylmercury in Suisun managed marshes is ongoing (WWR et al. 2010b).

9.3.3 Other Birds

Gulls and Terns

With the exception of Western gulls and least terns, most gull/tern species that frequent Suisun Marsh breed off-site. Therefore, the primary threats to gulls and terns at Suisun are impacts to off-site breeding habitat, at locations such as Alcatraz Island, the Salton Sea, and the Farallon Islands. Threats to least tern breeding success include predation by gulls, corvids, and raptors (Marschalek 2010). Suitable habitat utilization by least terns at Montezuma is variable; the factors that lead to this variance are unclear (ibid) and could indicate an incomplete understanding of the threats to this species.

Herons and Egrets

The primary threats to ardeiids are similar to those for waterfowl with the addition of disturbance of the known nesting colonies within the Marsh. Since the ardeiid food base (fish and other aquatic organisms) is higher in the food chain than that of waterfowl, they may have a relatively higher susceptibility to methylmercury bioaccumulation.

Passerines

Threats to passerines in the Suisun region include (1) agricultural practices (application of herbicides and pesticides, overgrazing, etc.) that impact upland habitats, (2) loss/low persistence of riparian habitat along ephemeral streams, (3) predation by terrestrial mammals such as foxes, raccoons, and domestic cats. The first two threats can be managed via appropriate O&M strategies; the latter is primarily addressed through decreasing the encroachment of urban development on the Suisun Marsh edge in places like Suisun City.

Raptors

The primary threats to raptor populations within Suisun Marsh are (1) increased development of wind power facilities (turbines) in the Montezuma Hills Wind Resource Area (WRA) and (2) a sudden decline in the prey base within and around the Marsh (rodents and other small mammals, birds, snakes, and other reptiles and amphibians). The latter threat is unlikely to materialize in the near future since most of the Marsh is owned by government agencies or private duck clubs that are unlikely to implement significant pest control strategies or significantly alter the nature of the prey base (prey species that utilize diked marshes would likely also utilize restored tidal marshes). In regards to the first threat, increased raptor mortality has been observed in areas that support wind turbines (Orloff and Flannery 1992, Ecology and Environment 2007), and there is much controversy about how increased wind energy development in locations such as the Montezuma Hills and Altamont Pass might impact local raptor populations. It is likely that the WRA will continue to see expansion and modernization of its operations as investment in “alternative” energy projects increases. A detailed assessment of the threat this development might pose to raptor populations in the

Marsh is outside the scope of this report. However, it is reasonable to conclude that the cumulative effect of increased wind power development in the Montezuma Hills and other areas could potentially impact raptor populations within the Marsh, and should be considered in future planning efforts.

9.4 Anticipated Responses to Restoration and No Action

9.4.1 Special Status Species

California clapper rail

Historically, the California clapper rail has been restricted to the western, more saline portions of Suisun Marsh, however more recent surveys have documented California clapper rails primarily in the northcentral portion of Suisun Therefore, it is anticipated that restoration sites in the western or northcentral portion of the marsh are more likely to provide habitat for the California clapper rail. Low intertidal sites may provide marginal foraging habitat for the California clapper rail. Sites at the low marsh stage may be used for foraging and refugial habitat. Mid marsh sites may provide foraging and refugial habitat, and marginal nesting habitat along the fringing higher elevation areas. High marsh sites would be optimal for the California clapper rail and may provide foraging, refugial and nesting habitat. Sites with upland transition may be used for foraging and refuge, but are not likely to be used for nesting.

California black rail

California black rails are associated with habitat features representative of mature, well-developed marshes. Newly restored marshes have not been found to support black rails (Thelander 1994). However, most studies of black rails have been conducted to detect breeding activity; therefore, while we would not expect black rails to breed in newly established marshes, they may use these areas for dispersal or foraging, especially once vegetation becomes somewhat dense. The length of time it takes for marsh to mature enough to support black rails will likely depend upon the following factors: beginning site elevation, availability of sediment to create high marsh habitat, tidal influence, proximity to existing sites in use by black rails, freshwater influence, and distance from urbanization. High marsh transitional zones that offer cover from predators, or the potential for these areas to develop, is an important restoration consideration. Where upland transitions or levees are planned, site characteristics which prevent easy access to the marsh zone by mammalian predators should be included in restoration designs. Partial restoration of tidal flows or managed wetland enhancements that result in muted tidal flows are not likely to benefit black rails as much as full tidal restoration. Black rails are most often found in larger marshes and in close proximity to other large marshes; therefore, marsh size should be should be considered when selecting sites for California black rail habitat restoration.

Suisun song sparrow

Given their need for dense and tall stands of cover, Suisun song sparrow populations will likely depend upon well developed mid- and high-marsh vegetation for their nesting, rearing and refuge needs. Under ideal conditions, *Schoenoplectus* and *Typha* species have been observed to establish quickly following restoration of full tidal connectivity to some sites such as Carl's Marsh on the Petaluma River, which was fully vegetated within 3 years of breaching. The time period required for the development of established marsh and subsequent use by Suisun song sparrows in Suisun Marsh will depend upon beginning site elevation, availability of sediment, proximity to existing sites in use by the sparrow and other factors.

Studies to date indicate that the Suisun song sparrow needs all its functional requirements integrated into a relatively small area. Because the Suisun song sparrow is an obligate tidal flat feeder, high topographic variability is an important component in restoration planning for this species. Its feeding behavior could be accommodated by initial stages of low marsh restoration, provided these sites are exposed during low tides and sufficiently near enough to cover and nesting sites.

For either managed wetland or full tidal restoration sites, channel banks and other upland transitions must be sloped in order provide tidal flats for grazing by song sparrows. Evidence of Suisun song sparrow presence in diked wetlands suggests that the species may be able to use managed wetlands if conditions are established which provide the needed cover, topographic variability, and tidal exchange.

Salt marsh common yellowthroat

If there is enough cover, salt marsh common yellowthroat can occur in low marsh, mid marsh, high marsh, and upland transition.

9.4.2 Migratory Waterfowl and Shorebirds

Takekawa et al. (2002b) noted the San Francisco Bay estuary is a migratory and wintering area for more than 1.5 million waterbirds on the west coast of North America. Because of this, the 70% cumulative decline in shorebirds and the loss of more than 90% of the historic San Francisco bay wetlands since the mid-1800's (Josselyn 1983), Takekawa et al. (2002b) and others, caution that the effects of tidal restoration of diked wetlands for endangered species is largely unknown and therefore should proceed cautiously. They also point out that waterbirds show strong site fidelity to San Francisco Bay estuary subregions and therefore mitigation for impacts in one subregion should not take place in another subregion.

The large-scale conversion of managed marsh into tidal marsh will likely alter the waterfowl community composition by reducing the amount of dabbling duck habitat available throughout

the tidal cycle and potentially increasing in some discrete areas (primarily broad, deep tidal channels) the amount of diving duck habitat (Raabe et al. 2010). Due to the considerable subsidence of most managed marshes, waterfowl habitat will have a strong dependency upon tide stage. The more subsided areas will be diving duck habitat at high tide while serving as dabbling duck habitat at low tide. As restored tidal marsh restores and elevations rise and emergent vegetation spreads, the nature of waterfowl habitats will also change. Diving duck habitats will become more limited to the tidal marsh sloughs. Dabbling duck habitat will be present during higher tide stages. Emergent vegetation will reduce the extent of open water overall. Taking no action would maintain the status quo for waterfowl viability within Suisun Marsh, with the attendant risk factors regarding the long-term requirements for levee and water control structure maintenance.

Shorebirds would primarily benefit from the restoration of tidal wetlands in Suisun by utilizing interim unvegetated intertidal habitats (mudflats along the bottoms and fringes of former managed marshes) for foraging. Once intertidal areas are colonized by vegetation, they become less suitable for most shorebird species. In the long-term, the restoration of large areas of tidal marsh in Suisun could potentially decrease the amount of shorebird habitat by converting occasionally-available managed marsh/pond bottoms to permanently unavailable tidal marsh plains.

Taking no action would maintain the status quo for shorebird viability within Suisun Marsh in the short-term, but could potentially leave populations vulnerable to the loss of bayward foraging habitat from increased SLR (see Section 9.3). If fringing mudflat habitats within Suisun Bay are not replaced (even on an interim basis) by mudflat habitat within the Marsh itself, it could result in the gradual “squeezing” of these species from the Suisun landscape.

9.4.3 Other Birds

Gulls and Terns

Restoration of tidal marsh would not likely have a significant effect on populations of gulls and terns within Suisun Marsh, as these species would utilize tidal marsh habitats in similar ways to those in which they utilize managed marsh habitats. Increased pelagic food web production from tidal marsh restoration could potentially help support increased populations of these species, especially terns, but it is unclear how significant this effect would be. Taking no action would maintain the status quo for gull/tern viability within Suisun Marsh.

Herons and Egrets

Restored tidal marsh habitats within Suisun would likely benefit herons and egrets in areas that, when currently flooded, are too deep to support heron/egret foraging. In areas that are shallow

enough to facilitate foraging, the restoration of tidal flows would primarily change the frequency at which these habitats could be utilized by ardeiids. Currently, foraging habitat availability in the managed marshes is controlled by flooding depths and flood/drain operations; tidal restoration would affect both of these habitat characteristics. The development of broad networks of dendritic tidal channels in mature would provide high-quality foraging habitat.

Passerines

As described above special-status passerines such as salt marsh common yellowthroat and Suisun song sparrow would reap significant benefits from the restoration of tidal marsh habitats in Suisun. It is unclear how terrestrial passerine species might benefit from tidal wetland restoration in Suisun, though the potential benefits from increases in overall regional food web productivity could be significant. Taking no action would maintain the status quo for passerine viability within Suisun Marsh.

Raptors

Raptor populations are unlikely to be negatively impacted by the restoration of tidal marsh habitats within the Marsh. Since historic tidal marsh habitats were converted to diked marsh habitats, not to upland agriculture that would otherwise support increased foraging by terrestrial raptors, the restoration of these habitats back to tidal marsh should not significantly change the prey base upon which local raptors depend. The increases in food web productivity from tidal marsh restoration would likely ultimately benefit raptors and other species that sit at the top of the food web.

The consequences of "No Action" would likely not have a significant effect on local raptor populations, though it may limit somewhat the foraging success of northern harriers, which are one of the few local raptor species that specializes in foraging over tidal marsh habitats.

9.5 Scientific Uncertainties and Testable Hypotheses

1. How will restoration of tidal marsh impact waterbirds?

- **Hypothesis 1.** Reduced area of permanent open water and alterations in food availability will decrease waterfowl habitat quality, resulting in decreased waterfowl use of Suisun Marsh.
- **Hypothesis 2.** Decreased hunting pressure in restored tidal marshes will increase survivorship of waterfowl.

10 Mammals, Reptiles, and Amphibians

10.1 Habitat Associations and Distributions

Suisun Marsh provides valuable habitat for 45 large and small mammal species, nine reptiles, and six amphibians. The variety of terrestrial and aquatic habitats and tidal stages serve as important foraging, breeding, and nesting habitat for many species throughout the year. A description of use of these habitats follows.

Bays and Sloughs

Bays and sloughs provide foraging grounds for several aquatic mammals including river otters, beavers, and California sea lions. Other species such as mink, muskrat, and raccoons with use bays and sloughs for foraging provided that they have sufficient adjacent upland areas for denning and refuge. Open water habitats also serve as foraging areas for amphibians and reptiles, such as the western bond turtle (USBR et al. 2010).

Tidal Wetlands

Tidal wetlands habitats are used by multiple wildlife species in the Marsh. Suisun shrew and salt marsh harvest mouse use the middle marsh zone for foraging, while the high tide zone provides cover and escape habitat for both species. Upland transition habitats are also used by salt marsh harvest mouse for foraging and in areas near open water, as denning areas for mink, beaver, and muskrats. Tule elk use upland transition areas for foraging and rearing/breeding (USBR et al. 2010).

Managed Marsh

Managed marsh provide seasonal habitats for numerous wildlife species including tule elk, coyote, beaver, river otter, skunk, raccoon, black-tailed jackrabbit and long-tailed weasel (USBR et al. 2010).

Riparian

Riparian areas, including smaller riparian trees and scrubs, provide cover for many common wildlife species such as mammals (skunks, raccoons, long-tailed weasel) reptiles, and amphibians.

Uplands

Uplands areas including grasslands and ruderal areas adjacent to tidal and managed wetlands serve as important habitat for reptiles, amphibians, and small and large mammals. Uplands also provide foraging and high tide refugia for mammals that would otherwise use tidal habitats such as salt marsh harvest mouse. Uplands are also used by western pond turtles as potential nesting habitat (USBR et al. 2010).

Seasonal Pools and Vernal Pools

Ephemeral pools are used by several species of vernal pool invertebrates as well as by the California tiger salamander. These areas may also be used by other reptilian and amphibian species including the fence lizard, gopher snake, garter snake, and western toad.

Table 6 provides a summary of special-status wildlife and species of concern which occur within Suisun Marsh. Following is an overview of these species and their distribution in the Marsh.

Table 6. Special-Status Wildlife and Associated Habitats within Suisun Marsh

	Species		Listing Status		Tidal Aquatic					
	Common Name	Species Name	Federal	State	Bays	Major Sloughs	Minor Sloughs	Sloughs w/in Tidal Marsh	Tidal Marsh	Upland Transition
MAMMALS										
	American beaver	*Castor canadensis*				F	F	F		Lo/B
	California sea lion	*Zalophus californianus*			F	F				
	Harbor seal	*Phoca vitulina*			F	F				
	Muskrat	*Ondatra zibethicus*				F	F	F		Lo/B
	Mink					F	F	F		Lo/B
	North American river otter	*Lutra canadensis*				F	F	F		
	Salt marsh harvest mouse	*Reithrodontomys raviventris*	E	E					A/F,J/F, R	A/F,J/F
	Suisun shrew	*Sorex ornatus sinuosus*		SC					A/F,J/F, R	
	Tule Elk	*Cervus elaphus nannodes*								A/F,J/F, R
REPTILES and AMPHIBIANS										
	Northwestern pond turtle	*Actinemys marmorata*		SC		A/F,J/F, R	A/F,J/F, R			R,B

Life Stage:
(A) = Adult, (J) = Juvenile
Habitat Function:
(B) = Breeding, (R) = Rearing, (F) = Foraging, (M) = Migrating, (Lo) = Loafing
Listing Status
(E) = Listed as Endangered under Endangered Species Act, (SC) = Species of Special Concern

*** = Non-native species**

10.1.1 Special Status Species

Salt marsh harvest mouse

The northern subspecies of SMHM inhabits Suisun Marsh and San Pablo Bay regions; within Suisun Marsh there are thirteen areas totaling over 2,500 acres on state lands that have been set-aside to conserve habitat for this species. This species is commonly associated with areas consisting of dense cover of pickleweed or non-pickleweed-dominated mixed wetland

vegetation. The Suisun Marsh has been extensively surveyed for salt marsh harvest mice since 1997 by DFG and DWR. Four tidal areas (Peytonia Slough, Rush Ranch, Hill Slough, Joice Island, Lower Joice Island That's five areas) in Suisun have averaged a capture efficiency of which is much higher than any other surveys conducted in the salt marsh harvest mouse's range. Salt marsh harvest mice have also been found in high numbers in areas dominated by *Schoenoplectus americanus* in Suisun (Barthman-Thompson pers. comm.). Predation on the salt marsh harvest mouse in Suisun is unknown. Recurrent but shallow flooding by tidal (saline) or brackish water is probably needed to maintain habitat that favors the salt marsh harvest mouse over sympatric rodents such as voles and house mice. Interactions between various rodent species (*Mus, Microtus, Rattus*) and the salt marsh harvest mouse do not appear to negatively impact the salt marsh harvest mouse (Suistatia et al. in prep). The impacts of non-native plant species, such as perennial pepperweed (*Lepidium latifolium*), need to be researched, as does the degree to which chemical contaminants, such as heavy metals, organochlorines, and PCBs affect the quality of the salt marsh harvest mouse habitat. Salt marsh harvest mice are dependent on the thick, perennial cover of salt marshes and move in the adjacent grasslands only in the spring and summer when the grasslands provide maximum cover (Fisler 1965).

Suisun shrew

Suisun shrew is found in tidal wetlands of Suisun Bay, Grizzly Island, and San Pablo Bay (Jameson 1988 in USBR et al. 2010). This species is commonly found in similar middle and high marsh zone habitats as SMHM, and is typically associated with driftwood and wrack debris above the high tide zone, which it uses for nesting and foraging. There have been six documented occurrences of Suisun Shrew as of 2008 (CNDDB). Historically, the Suisun Bay was lined with natural salt brackish marshes. Since diked marshes are not capable of supporting enough invertebrates, these shrews prefer tidal over diked marshes (WESCO 1986). There is evidence indicating that shrews may have home ranges and defend territories for at least part of the year (Hawes 1977; Hays 1990; Moraleva and Telitzina 1994). These dynamic territories can range from 360 to 1,700 square meters in area (3,875 to 18,300 square feet), or from 11 to 100 meters (36 to 328 feet) in length (Moraleva and Telitzina 1994), depending on sex, age, and season. In Suisun Marsh, dense breeding subpopulations of Suisun shrew exist in the fall (Hays 1990). Salt marsh shrews are susceptible to extreme tides and weather-induced stress and can die if their fur becomes wet or cold (Hays 1990). To avoid high tides, shrews will climb into dense foliage that is above the tidal level (Hays 1990). Nearby upland habitat 13.8 to 2.4 m above sea level provides critical refugia from flooding (Williams 1983).

Western pond turtle

The western pond turtle (*Actinemys marmorata*) is the only reptilian species of special concern known to occur in Suisun Marsh (California species of special concern). This species has been found in permanent to relatively permanent waters with little or no current and suitable salinity

levels (Behler and King 1998 in USBR et al. 2010). Within the Marsh, this species has been observed in the upper reaches of tidal sloughs and managed wetlands, in habitats with thick bank vegetation and available basking sites such as logs, boulders, or open banks. Nesting typically occurs in upland areas, on unshaded slopes (USBR et al. 2010).

10.1.2 Other Native Species

Mammals such as the harbor seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), North American river otter (*Lutra canadensis*), and American beaver (*Castor canadensis*) utilize subtidal habitat (**Table 2**) (DFG 2005 and Goals Project 1999).

Harbor seals

Harbor seals typically forage in subtidal habitat 20 meters or less in depth (subtidal depths are described in more detail in the Physical Resources description). Prey items include fish, crustaceans, cephalopods, and benthic and schooling fishes (DFG 2005).

California sea lions

This species utilizes deep subtidal habitat and feed on fish and cephalopods (DFG 2005).

River otters

River otters occur throughout the Marsh in subtidal habitats primarily associated with good river bank cover (Goals Project 2000). Scat analysis of river otters in the Marsh showed that crayfish were the most frequent prey item, followed by birds and fish which were the second most frequent prey items depending on season (Goals Project 2000).

American beavers

This species can be found in slough habitats and utilize aquatic vegetation, such as tules and cattails, as a portion of their diet. Beavers also use sloughs for reproduction and cover (Zeiner et al. 1990).

Tule elk

Tule elk in Suisun Marsh occur primarily on the Grizzly Island Wildlife Area where a combination of grasslands, eucalyptus groves, wetlands and emergent vegetation, and waterways provide habitat for water, grazing and browsing, as well as cover during hotter months (Interagency Ecological Program). Although diet varies according to geographic location, tule elk eat grasses, forbes, twigs and leaves, and aquatic vegetation (Zeiner et al. 1990). Tule elk are the smallest of the native North American elk, with adult males weighing 900+ pounds and adult cows weighing 375-425 pounds[6].

[6] Suisun Marsh Program, Interagency Ecological Program (IEP) www.iep.ca.gov

Other Species

Other mammalian species are widespread across Suisun Marsh terrestrial/upland habitats. Sixteen species of bat have been observed within the marsh in addition to a number of other land dwelling native species such as gray fox, mink, muskrat, raccoons, long-tailed weasel, and American badger.

10.2 Non-Native Invasive Species

Feral pigs

Feral pigs are aggressive mammals that pose significant threats to the plant communities and rare plant habitats in the Suisun Marsh. These animals, which are present in significant numbers in the region, trample and root up large areas of vegetation, spread weeds and contribute to erosion. They also scratch and dig in wet ground to form wallows. Feral pigs can destroy nests of ground nesting birds. They prey on a wide variety of vegetation, as well as crayfish, frogs, snakes, salamanders, mice, the eggs and young of ground-nesting birds and young rabbits. Wallows can affect ponds and wetlands by increasing turbidity, creating algal blooms and lowering water quality (WDNR 2010).

Hunting is the main method used for eradicating feral pigs in California. Feral pig hunting is legal and regulated through the California Department of Fish and Game (CDFG 2001). Habitat destruction by feral pigs was fairly severe in earlier years on Rush Ranch, especially in upper marsh zones. Feral pig hunting is currently conducted as an organized management program on the Rush Ranch (Cuff 2006). This has greatly reduced but not eliminated feral pigs from this area.

Other Species

Other introduced species include Virginia opossum, black rats, Norway rats, and feral cats.

10.3 Viability Assessment

Summary

Overall special status wildlife in Suisun Marsh are currently stable but will continue to be threatened by loss of habitat without further management and habitat protection. Salt marsh harvest mice are found in abundance in the majority of diked brackish marshes that have been surveyed and in significant numbers in grasslands at the upper edge of diked marshes around San Francisco Bay; however, how these habitats are used by this species remains unclear. Suisun shrew's genetic distinction could be impacted by habitat invasion by its upland cousin, *S. o. californicus* but the overall status of this species is unknown. Western pond turtles are present throughout Suisun Marsh and are likely currently stable.

10.3.1 Special Status Species

Salt marsh harvest mouse

The salt marsh harvest mouse is a Federal Endangered species and California state fully protected species. The US Fish and Wildlife Service released a five-year status review of the salt marsh harvest mouse in 2010. This report indicates that Suisun Marsh may contain the largest population of salt marsh harvest mice in its entire remaining range. Though opportunistic and inconsistent trapping efforts occurred even earlier, standardized annual surveys have been conducted in the Suisun Marsh since 1997 by CDFG and California Department of Water Resources (DWR). These efforts continue to find high numbers in both diked and tidal wetlands. Capture efficiencies from eight separate tidal and diked locations surveyed in 2008 and 2009 were considered high, averaging 10 percent (Barthman- Thompson, *in litt*. 2009). The longest and most consistent trapping data set is for the Crescent Unit at the Grizzly Island Wildlife Area which began in 2000.

Suisun marsh trapping has indicated that salt marsh harvest mouse populations may rebound relatively quickly from depressed population levels. In winter/spring of 2006, the Crescent Unit and the Hill Slough Wildlife Area, were flooded due to high tides and levee overtopping, but by 2007, salt marsh harvest mouse numbers had increased to pre-flood event levels. Also, trapping immediately following a 2004 fire at Peytonia Slough Ecological Reserve documented salt marsh harvest mice using the burned area in low numbers. The year after the burn, salt marsh harvest mouse numbers had dramatically increased from the early post-burn trapping (Barthman-Thompson, *in litt*. 2010). It is possible that a population's ability to rebound is dependent upon extent and quality of habitat available, as well as not being concentrated during high tide events such that predation is a significant threat to survivors.

Like the southern subspecies, many northern subspecies populations have been displaced from tidal marshes to more variable diked *Sarcocornia* marshes. Most of the populations in diked managed marshes of Suisun Marsh may depend on wetland management and vegetation colonization. Salt marsh harvest mice are found in abundance in the majority of diked brackish marshes that have been surveyed. The Suisun Marsh currently contains twelve "Conservation Areas" totaling over 2,500 acres (1,012 hectares). Diked wetlands in Suisun are vulnerable to catastrophic flooding which over time can lead to local extirpation. Salt marsh harvest mice have also been found in significant numbers in grasslands at the upper edge of diked marshes around San Francisco Bay (Zetterquist 1976; Shellhammer et al. 1982; Johnson and Shellhammer 1988) and in Suisun; however, the extent to which this habitat is utilized is not clear (USFWS 2010).

Suisun shrew

The Suisun shrew is a Federal Species of Concern and a California Species of Special Concern. Very little is known about the current distribution and abundance of this species in Suisun Marsh. However, it is assumed to be restricted to the ecotone between tidal wetlands and grassland uplands along Grizzly Island and the northern extremes of Suisun Marsh (WWR et al. 2010a). Adjacent upland habitats are utilized by a close relative, *Sorex ornatus californicus* (Brown and Rudd 1981, Williams 1983). Research by Hays and Lidicker (2000) indicated that the shrew has a unique ecology; it lives in distinct, rigid social groups comprised of a single adult male, multiple females, and subadults during the winter. Upon the arrival of the breeding season, these groups are invaded by numerous adult males, completely changing the social makeup of the groups. In additional, individuals also lose 30-40% of their body mass over the course of the breeding season, a phenomenon known as the Dehnel effect that is rare in temperate habitats such as those in Suisun Marsh (Hays and Lidicker 2000). These unique behaviors may indicate that the Suisun shrew's genetic distinction could be impacted by habitat invasion by its upland cousin, *S. o. californicus* (WWR et al. 2010a).

Western pond turtle

The western pond turtle is a Federal Species of Concern and a California Species of Special Concern. Systematic boat surveys of sensitive species habitat have been conducted by DWR and DFG staff throughout Suisun Marsh since 1991. These surveys have focused on the detection of sensitive plant and bird species. The presence or absence of western pond turtles has been incidental to these specialized surveys, but observations of pond turtles have been reported by the Department of Water Resources.

Western pond turtles are present throughout Suisun Marsh. Pond turtles bask along the channel banks of tidal sloughs adjacent to emergent tidal marshes. Pond turtles bask on the banks with sunlight exposure at low tide. Western pond turtles have been observed basking on mud banks adjacent to the emergent wetlands of eastern Hill Slough, Nurse Slough, Cutoff Slough, First Mallard Branch, Second Mallard Branch, Boynton Slough, Peytonia Slough, Frank Horan Slough, and Cordelia Slough. Systematic surveys for pond turtles have not been conducted in diked, managed marshes. However, pond turtles have been observed from public roadways along internal water distribution systems which are cut off from natural tidal hydrology. The turtles have been observed along Roaring River, Grizzly Ditch, and Steve's Ditch of Grizzly Island. They have also been observed along Joice Island ponds, distribution ditches, and the Volanti Slough reservoir. It is assumed that western pond turtles are present at other pond and ditch systems within Suisun Marsh (Suisun Marsh Program DWR, www.iep.ca.gov).

10.3.2 Other Wildlife

River otters (*Lontra Canadensis*) were once widely distributed throughout California and North America but began declining significantly due to trapping, which became illegal in 1961. The number of river otters in Suisun Marsh is currently unknown, but this species is known to occur within channels and ponds throughout the Marsh. Tule elk within Suisun Marsh have no natural predators in the area, as such, the Grizzly Island tule elk population quickly expanded from its initial 8 reintroduced individuals in 1977 to over 100 individuals by 1997 (California Department of Fish and Game unpublished data www.dfg.ca.gov). Currently, the objective to maintain the Grizzly Island tule elk herd at 65-85 animals is primarily achieved by limited hunting managed by the CDFG (Interagency Ecological Program www.iep.ca.gov). Mink (*Mustela vison*) are believed to be increasing in number in Suisun Marsh based on observations made by Department of Fish and Game staff; however, DFG has indicated that muskrats may be affected by negative impacts from flood and drought conditions.

10.4 Threat Assessment

10.4.1 Special Status Species

Salt marsh harvest mouse

The most significant historical and present threat to salt marsh harvest house is the destruction and alteration of its habitat due to filling, diking, changes to water salinity, non-native species invasions, and sea level rise (USFWS 2010). Viable populations of salt marsh harvest mice also appear to be limited by the distribution of high tide cover and escape habitat (tidal refugia).

Predation on the salt marsh harvest mouse in Suisun is unknown. Recurrent but shallow flooding by tidal restoration or brackish water is probably needed to maintain habitat that favors the salt marsh harvest mouse over sympatric rodents such as voles and house mice. Interactions between various rodent species (*Mus, Microtus, Rattus*). The impacts of non-native plant species, such as perennial pepperweed (*Lepidium latifolium*), need to be researched, as does the degree to which chemical contaminants, such as heavy metals, organochlorines, and PCBs affect the quality of the salt marsh harvest mouse habitat.

Suisun shrew

The greatest current threats are the consequences of past reduction in the extent, quality, and continuity of tidal marsh habitat and resident shrew populations. The remaining populations are vulnerable to extreme tidal flooding events and erosion along wave-exposed shorelines. The isolated populations render dispersal difficult, if not impossible, across large distances which may limit genetic variability within the Suisun marsh. Adequate connectivity between middle marsh, high marsh, and upland habitats is scarce within the Suisun marsh. In addition,

current management within the marsh favors the establishment of bulrush and threatens to decrease habitat suitability for the remnant shrew populations.

The effect of contaminants in estuarine sediments may pose risks for recovery of tidal marsh shrews. Shrews have very high rates of metabolism and consume large quantities of invertebrates. Contaminants, such as PCBs, PNCs, heavy metals, and pesticides, may concentrate in the invertebrate species present in the marsh (WESCO 1986). These factors may make shrews more vulnerable to the effects of toxic substances in the estuarine environment. Diffuse, non-point sources of contaminants in the estuary may increase as urban development around the region intensifies. Pankakoski et al. (1994) demonstrated that heavy metal pollution could adversely affect the developmental stability of shrew populations. Sublethal effects of contaminants, such as reduced fecundity of adults or reduced viability of young, are probably the most significant potential population-level threats associated with estuarine contaminants. Specific studies relevant to the effects of contaminants on tidal marsh shrews are needed.

Several studies seem to indicate that shrews are seldom preyed upon (Pearson 1946; Crowcroft 1957). Predatory birds, such as owls and other raptors, are possible culprits to shrew predation, yet no shrew remains were found in pellets (Newman 1970). It is plausible that some mortality can be attributed to rats. More studies are needed on shrew predation.

The affects of non-native invasive plant or wildlife species has not been studied in regards to Suisun shrew habitat use/suitability and competition. However, it is likely that non-native species have some deleterious effects on shrews. Non-native invasive plants are known to out-compete native species and result in an altered vegetation community and structure, thereby possibly altering invertebrate communities shrews depend on. Non-native wildlife species may increase predation risk and competition for suitable foraging and nesting sites.

Western pond turtle

Habitat destruction, specifically wetland habitats, is the single greatest threat to western pond turtle. Development activities including urbanization, agriculture, flood control, and water diversion have reduced wetland habitats within the historic range for this species in California by over 90 percent. Introductions of non-native species has also likely significantly impacted western pond turtle populations in California; specifically, the introduction of red-eared sliders (*Trachemys scripta*) and painted turtles (*Chrysemys picta*) are believed to threatened western pond turtle though data supporting this claim is lacking (USGS no date). Bullfrogs, largemouth bass, and catfish are also significant predators on western pond turtle hatchlings and small juveniles (Contra Costa HCP/NCCP 2006).

10.4.2 Other Species

Though Tule elk within Suisun Marsh have no natural predators, 15 tule elk reportedly died during the mid 1980's from ingesting poison hemlock. Hemlock is prevalent throughout the marsh and may have been grazed on by the elk due to little rainfall during that fall and early winter, which limited alternate feed for the elk. As such, drought events and loss of upland grazing habitats are likely potential threats to this species. As mentioned above, muskrats are reportedly less common in Suisun Marsh, due potential in part to drought and flood conditions. Mink are also known to prey heavily on muskrats, which may account for their population control (SEW 2001). There are no documented threats to river otters in Suisun Marsh; however, it is likely that water pollution negatively affects this species.

10.5 Native Species Anticipated Responses to Restoration and No Action

Function supports native species. The general assumption, with some known exceptions, is that natural tidal marsh function supports native species recovery. It is acknowledged, however, that there are some species, such as salt marsh harvest mouse (*Reithrodontomys raviventris*), which may currently have greater recovery in managed marsh areas in Suisun Marsh due to this species' reliance on salt marsh rather than brackish marsh vegetation (which is more characteristic of Suisun) and the need for high tide refugia. This exception derives in part from Suisun Marsh's location at the edge of this species' geographic distribution.

Salt marsh harvest mouse

Salt marsh harvest mice occur in the tidal middle, high marsh zones and adjacent uplands. The basic habitat of the salt marsh harvest mouse is pickleweed-dominated vegetation (Fisler 1965), however in Suisun they have been found in mixed wetlands not dominated by pickleweed. Other highly important habitat considerations include high tide/flood refugia (both at the upper edge of the marsh and within mature marshes as areas of emergent gumplant or *Schoenoplectus americanus* even at the highest high tides), seasonal use of terrestrial grassland, exploitation of suboptimal habitats, and habitat selection in brackish marsh vegetation where pickleweed is a relatively minor component, as often is the case in Suisun Bay marshes.

Salt marsh harvest mice are dependent on the thick, perennial cover of salt marshes and move in the adjacent grasslands only in the spring and summer when the grasslands provide maximum cover (Fisler 1965). Restoration of managed marsh may temporarily result in the loss of salt marsh harvest mouse habitat due to initial flooding, but over time will create viable long-term habitat. When selecting sites for tidal marsh restoration, sites containing an area of high marsh and upland transition are necessary for the salt marsh harvest mouse. Sea-level rise makes this upland transition component even more important.

Suisun shrew

Suisun shrews use the middle and high marsh. Restoration that improves the structure of both remnant and restored tidal marshes at the appropriate mid and high marsh elevations will likely benefit tidal marsh shrews. It is important to restore areas to the appropriate vegetation structure over species composition, as structure seems to play an important role in habitat suitability. Variations in vegetation density and height will allow for appropriate foraging and nesting sites, as well as provide refugia from high tidal events. Connections between marsh and upland habitat are essential as uplands also provide refugia and nesting habitat. The construction or evolution of shallow sloping banks and extensive high marsh edges of well-vegetated tidal marsh plains is most likely to provide habitat that will be used by shrews. Natural tidal regimes provide higher prey availability then diked wetlands, so all efforts should be made to maximize natural tidal marsh restoration. Restoring marsh complexity by adding driftwood, wood planks, and other litter can further augment foraging and nesting sites.

The ability of tidal marsh restoration projects to compensate for past habitat loss is limited by the rate at which restored tidal marshes mature and form marsh plains near the elevation of mean high water. Earlier stages of marsh succession appear unlikely to benefit recovery of the shrew. The rate at which the marsh becomes fully functional for Suisun marsh will depend on several factors including tidal action, sedimentation rate, and contaminants.

Western pond turtle

Western pond turtles occur in the upper reaches of tidal sloughs, managed wetlands, brackish habitats, permanently flooded water supply ditches, and other areas throughout the study area where there is permanent or nearly permanent water. Planned restoration activities have the potential to affect breeding and foraging habitat. However, the change in magnitude of the currently implemented managed wetland activities would not result in a substantial temporary or permanent change in habitat, and activities are and will be conducted when the managed wetlands are dry.

Marsh management activities also would contribute to maintaining western pond turtle habitat. Restoration and management activities would be implemented on individual parcels throughout the 30-year implementation period and would improve flood and drain capabilities and levee stability in the Marsh. The improvement of flood and drain capabilities could result in the creation or enhancement of suitable habitat in the managed wetlands. Improved water quality (i.e., water that is less saline) will also benefit western pond turtles. Providing levee stability would minimize the potential for catastrophic loss of western pond turtle habitat in managed wetlands.

Other Species

There is little information regarding habitat use by mink in Suisun Marsh but this species is known to use habitats with relatively permanent sources of water with adjacent upland habitats. Managed wetlands and diked marsh likely provide optimal habitat for mink, while tidal areas are not expected to improve available habitat. Muskrats are typically found in marsh habitats associated with constant waters; as with mink, muskrats likely would likely not gain habitat following tidal marsh restoration.

10.6 Scientific Uncertainties and Testable Hypotheses

1. How will conversion of subsided managed wetlands to tidal marsh impact populations of salt marsh harvest mouse and Suisun shrew?

- **Hypothesis 1.** Restoration of subsided managed wetlands will result in short term losses of habitat for salt marsh harvest mouse and Suisun Shrew resulting in decreased populations within these sites.
- **Hypothesis 2.** Restoration of subsided managed wetlands will result in long term expansion of suitable tidal marsh habitat for these species, resulting in expanded populations.

11 Other Ecosystem Functions

Wetlands provide many ecosystem functions and services in addition to habitat for vegetation, fish, and wildlife. Some of the most important from a human perspective include flood attenuation, water quality improvement, mosquito control, carbon sequestration, and recreation.

11.1 Flood attenuation

It has been well established that wetlands provide regional flood protection benefits by intercepting and storing flood waters, thereby reducing peak discharge during a given event (Mitsch and Gosselink 2000). Under historic conditions, large expanses of Suisun Marsh would become inundated during flood events, providing storage of flood waters and reducing the volume of water moving through the estuary. Reduction in the Suisun Marsh tidal prism as a result of diking and conversion of much of the marsh to agriculture and managed wetlands has resulted in a loss of this flood attenuation capability. The loss of flood storage capacity within Suisun Marsh means that a greater volume of water will be transported through the estuary in a given event, resulting in greater severity of flood-related impacts to areas downstream.

11.2 Water quality improvement

Wetlands are commonly referred to as “nature’s kidneys” due to their ability to remove pollutants from the water column. The removal often occurs through the settling of contaminant-laden sediments, biological uptake by plants and subsequent burial of dead material, and bio-geochemical transformations (Mitsch and Gosselink 2000). Under historic conditions, the large expanses of tidal marshes in Suisun provided these cleansing functions to a large volume of water with each tidal cycle. The removal of much of the wetland area in Suisun Marsh from daily tidal action due to diking and conversion to managed wetlands, means that this important ecological function is less realized under current conditions. Managed wetlands still provide water quality improvement functions in the same way that tidal marshes do, but they are much less connected to source waters and their hydrologic exchange rates are regulated by human operators. Since the managed wetlands are primarily managed for waterfowl habitat, their hydroperiod and exchange rate varies throughout the year and many clubs are dry throughout the entire summer.

11.3 Mosquito production

Mosquitoes reproduce readily in quiescent water with standing vegetation. The greatest numbers of mosquitoes are produced in water bodies with poor circulation, high temperatures, and high organic content (Collins and Resh 1989). Typically, greater numbers of mosquitoes are produced in water bodies with water levels that slowly increase or recede, and fewer numbers

of mosquitoes are produced in water bodies with rapidly fluctuating water levels (Jones & Stokes Associates 1995). Tidal marshes often have relatively low mosquito production rates due to the regular inflow and outflow of water with the tidal cycle and general lack of permanent standing water (PWA and Faber 2004). This regular movement of water makes conditions less than ideal for mosquito egg deposition and has the effect of flushing deposited eggs and larvae from the wetland. However, tidal marshes that have areas which routinely pond water in depressions for multiple days after extreme high tides can still produce significant quantities of mosquitoes (USBR et al. 2010). Therefore the hydrology and geomorphology of individual tidal wetlands will dictate mosquito production potential.

Permanent (i.e. managed) wetlands generally exhibit the characteristics necessary for mosquito reproduction (poor circulation, high temperatures, high organic matter content, slow rise and fall in water levels, etc) to a greater degree than tidal marshes and are therefore more prone producing mosquitoes (USBR et al. 2010). The conversion of most of the tidal marshes in Suisun Marsh into managed wetlands has therefore likely led to an increase in mosquito production rates within the ecosystem over historical conditions. The Solano County Mosquito and Vector Control District regularly monitors and treats the managed wetlands in Suisun Marsh with pesticides to reduce mosquito production when the wetlands are flooded. These treatments can be costly and represent a significant financial burden on wetland managers.

11.4 Carbon Sequestration Wetlands

Another possible opportunity for Suisun Marsh is to sequester atmospheric carbon through emergent wetland vegetation on subsided lands. Such efforts have the potential to yield net reductions in greenhouse gases and, if regulatory-based carbon offset markets are established and protocols are in place for wetlands carbon sequestration, lands in Suisun might be able to generate a new source of economic revenue (Merrill et al. 2010). Integrated with restoring diked wetlands in Suisun to tidal marsh, the basic concept is to operate diked wetlands to maximize the soil-based retention of old and newly fixed atmospheric carbon and minimize the release of other greenhouse gases such as methane and nitrous oxide. Over time the accumulating biomass reverses subsidence and when at desired elevations, the wetlands are then opened to tidal action. At present, neither the regulatory-based carbon markets are in place (though they may be so in 2011 in California) and a wetland protocol is a few years out at the earliest. Key considerations in effective wetlands carbon sequestration efforts are minimizing production and transport of methylmercury into the food web and managing sites to minimize mosquito production (Merrill et al. 2010).

11.5 Recreation

Suisun Marsh's proximity to major highways and urban areas makes the Marsh accessible to many people. Duck hunting is the major recreational activity in the Marsh occurring from late October until January. Fishing accounts for nearly as much recreational use in the Marsh as duck hunting. In addition, several other recreation activities such as water sports, upland game hunting, hiking, and wildlife observation are popular in the Marsh (Solano County 2008). Much of the recreation associated with Suisun Marsh is water-dependent (boating and fishing) or water-enhanced (picnicking, hiking, hunting, and scenic/wildlife viewing). Recreation is a multimillion-dollar industry in the state. The demand for recreational resources in California is expected to increase with future population growth. Increasing demand is expected to put additional pressure on limited recreation resources and potentially contribute to deterioration of the quality of recreation experiences.

Fishing occurs year-round in the Marsh. In 2009, there were 6,600 visitors to the Grizzly Island Wildlife Area for fishing (Grizzly Island Wildlife Area Recreation User Survey 2009), and over the last several years, use of Belden's Landing for visitors for boat launching and pier fishing has ranged from 12,000 to 16,000 (Solano County Parks and Recreation 2009).

Duck hunting occurs from late October until January. Approximately 158 private duck clubs are located in the Marsh (California Department of Water Resources 2010). Private duck clubs compose approximately 37,500 acres of the Marsh and provide 41,000 waterfowl hunter days each year (Solano County Planning Department 1982). In addition to private clubs, DFG manages 15,300 acres of wildlife habitat for hunting and fishing opportunities and other public uses in the Grizzly Island Wildlife Area. Over the last several years, approximately 6,200 hunters visited Grizzly Island Wildlife Area during each hunting season (California Department of Fish and Game no date). Wildlife observation, photography, nature study, canoeing, kayaking, and motor boating are also popular recreational activities within the Marsh and occur year-a-round. The two major navigable waterways are Montezuma and Suisun Sloughs. Suisun Slough runs from Grizzly Bay to the northern portion of the Marsh, and Montezuma Slough runs from the eastern side of Grizzly Bay to the western side, with several smaller channels diverging from it. Other navigable waterways are Cordelia, Denverton, Nurse, and Hill Sloughs.

Most of the Marsh is navigable by small boats, and some channels, such as Montezuma and Suisun Sloughs, are navigable by much larger boats. A major navigation channel, the Suisun Bay channel, connects to the Carquinez Strait. Ability to navigate or access smaller channels and outer edges of the bay is influenced by the tides and type of watercraft used (USBR et al. 2010).

11.6 Restoration Impacts

The Suisun Marsh Restoration Plan does not propose construction or change of existing recreation facilities that would be considered under CEQA but does affect certain restoration activities. Recreation areas that could be affected by restoration activities would be Belden's Landing, Peytonia Slough Ecological Preserve, Hill Slough Wildlife Area, Grizzly Island Wildlife Area, Rush Ranch, and some private duck clubs. Most land-based activities would be unaffected by actions relating to implementing the SMP or its alternatives. Non-motorized recreational boating (e.g., kayaking and canoeing) would be the most affected if velocity changes were substantial in sloughs where breaching occurred.

Over the 30-year SMP implementation, up to 7,000 acres of diked wetlands would be restored to tidal wetlands. This represents a potential loss of up to 10% of existing managed wetlands. Some of these restored tidal wetlands within public ownership should continue to provide waterfowl and other hunting opportunities. These new areas should be accessible via navigable sloughs or existing public access areas. Remaining private duck clubs within the Marsh would continue their operations. The conversion to tidal wetlands may alter use patterns of these areas by dabbling ducks which are favored by local Marsh hunters and clubs. This waterfowl guild includes mallard, gadwall, northern shoveler, northern pintail, green-winged teal, and Canada goose. Additionally, the shift from managed to tidal wetlands as a result of the club owners willful sale of their property, may reduce the total number of private hunters allowed in the Marsh on busy days, such as opening day of the hunting season, due to the reduction in acres of managed wetlands. It is expected however, that existing and newly restored public lands and the remaining duck clubs would provide plenty of hunting opportunities during most days of the year. Additionally, the threatened and endangered species, and numerous dabbling and diving ducks.

Fishing opportunities may increase due to the increase in tidal wetland and openwater habitats via navigable waters. Although there would be some displacement of dabbling duck habitat through tidal marsh restoration, other forms of wildlife habitat will be created. Hunting and other recreational activities still would occur on the public lands and public opportunity may increase as a result of the tidal restoration (USBR et al. 2010).

12 Levee Integrity and Maintenance

Where possible, levees were constructed on existing channel berms to take advantage of the existing natural topography throughout the Marsh. Levee configurations throughout the Marsh vary considerably in material composition, cross-sectional geometry, strength, and stability (USBR et al. 2010). Since the early 1800s levees were constructed primarily with dredged material removed from the adjacent channels and now range in height from 4 to 8 feet. As levees have been maintained, some of the longstanding levees have increased in size as additional dredged material has been placed on the crown, seaward side, and landside. Due to regulatory constraints, options for maintaining Marsh levees are limited to the use of materials from within the managed wetlands or by very limited importation. Landowners maintain the external levees, subject to strict provisions of USACE Regional General Maintenance Permit. No maintenance activity is permitted that may adversely affect listed species or their critical habitat. Meeting this criterion requires that SRCD work with the resource agencies in obtaining necessary permits for levee work in Suisun Marsh (Brown 2004).

Subsidence requires additional placement of material to raise and reinforce the levees. Levee failures can result in flooding that can affect the regional salinity of the adjacent waterways, tidally restored sites, and managed wetlands. Historical flooding, including the flooding in 1998, prompted DWR to complete a levee breach analysis study to determine whether there was a correlation between levee failures in Suisun Marsh and salinity increases in the Delta. The study concluded that portions of the exterior levee system in Suisun Marsh may be important to controlling salinity. The August 1999 breach at the Sunrise Club on Chadbourne Slough (280 acres) is an example of a small breach (180 feet in width) that had localized impacts on salinity for adjacent landowners. Larger, region-wide breaches and flooding in the Marsh, as in 1998, can have water quality effects in the Delta that can affect SWP and CVP operations.

Though levee failure mechanisms are well understood, mechanisms causing sudden failures are rarely able to be determined. Therefore, inspection and maintenance is important to prevent failure. In Suisun Marsh, levee overtopping has been the historical failure mechanism (Chappell pers. comm.). (Overtopping is a systematic design failure which causes erosion that then breaches the levee as opposed to a breach caused by an internal structural failure of the levee.) As levees subside, the available freeboard (the distance between the high tide or flood elevation and the top of the levee) is reduced and the potential for overtopping is increased. Wave action and sea level rise also can reduce the effective freeboard. Over time, without maintenance all levees eventually will fail. Most if not all of the proposed restoration activities will require some amount of levee improvements to ensure that adjacent properties are

adequately protected from flooding. These upgrades will likely include levee raises and contouring, brush boxes, riprap, or other wave and wind protection (USBR et al. 2010).

The CALFED Levee Investigation Team (1999-2001) concluded that ongoing subsidence in Suisun Marsh requires an active levee maintenance program to avoid large scale flooding and conversion to vast open water areas. Increasing hydrostatic pressure can result from continuing subsidence on managed wetlands combined with projected sea level rise. Although tidal restoration can provide a beneficial effect by reducing tidal heights, funding for both maintenance and improvements of levees are necessary to protect water quality in both Suisun Marsh and the Delta (Brown 2004).

12.1 Suisun Levees – Exterior, Interior, Exposed, Protected

The Suisun Marsh is protected from tidal action and high water events by 200 miles of exterior levees. Several miles of interior levees are also maintained to separate land with differing uses and management practices. Exterior levees provide the Marsh with necessary flood protection and vehicle access. They also play a role in maintaining channels in the Marsh and thus have the potential to influence salinity in the Marsh and as far as the south Delta CWP and SWP diversions. Levees in the Marsh have not been constructed to an engineered standard nor have they been maintained to the standard of an urban or an agricultural levee.

The majority of Suisun Marsh, including wildlife habitat, is situated at or below mean tide elevation. Levees serve as the primary flood protection for Suisun Marsh lands, infrastructure, and natural resources. Exterior levees are used in conjunction with interior levees, ditches, and water control structures to retain, exclude, and direct water.

12.2 Range of Levee Measures Restoration May Entail

The No Action Alternative under the AMP EIR would rely on the existing level of maintenance activities to inspect, assess, and maintain the exterior levee system. The inability to obtain permits for managed wetland activities, including levee maintenance, would further reduce the level of maintenance activities. Currently, maintenance efforts are not able to keep up with the current rate of levee degradation. Suisun Marsh is already susceptible to flooding during major flood events, and continued wave erosion (fetch-generated and boat traffic) rates are putting several miles of exterior levees at risk for failure during less frequent flood events and potential "summer failure" (e.g., Jones Tract).

Under the proposed restoration of 5,000-7,000 acres of tidal marsh, the impacts to levees from restoration activities include: 1) a potential increase in levee failure and flooding, 2) a change in flood state and flow capacity in the marsh (beneficial), and 3) a temporary decrease in levee

stability. As a result of levee breaches and other actions that may be implemented as part of SMP tidal wetland restoration actions, interior levees may become exterior levees, thus increasing their exposure to tidal action for which they were not intended. To reduce the potential risk for failure of these levees, they would be improved to meet exterior levee standards. Under the plan, levee profile and crown surveys will be completed to determine compliance with the standard and identify areas needing improvements.

Beneficial impacts will result through breaching of existing exterior levees, which will increase the acreage of land available to draw tidal flows overland and increase flood storage capacity during storm events. This additional area would have varying effects on the adjacent waters that would supply flow to the tidal wetland areas. Preliminary hydraulic modeling suggests that the addition of tidal prism through the breaching of levees and restoration of tidal wetlands would reduce tidal stages in the adjacent channels and bays, which would vary based on the location within the Marsh.

With restoration off fewer acres (2,000-4,000), there would be less need to bolster interior levees to meet exterior levee standards and there would be fewer changes in tidal stage and muting. With greater acres of restored tidal marsh (7,000-9,000), there would be a reduced need for some exterior levee maintenance but the reduced application of management wetland activities would not increase the overall flood protection improvements as described above. There would be more change in tidal stage and muting (USBR et al. 2010).

13 Contaminants

13.1 Methyl Mercury

Methylmercury (CH_3Hg, commonly annotated MeHg) is a potent human and wildlife neurotoxin (U.S. EPA 2001). The primary route of exposure is from consumption of MeHg-contaminated fish. The San Francisco Estuary has been listed on the California 303(d) list as an impaired water body because of elevated methylmercury concentrations in fish. In addition, health advisories have been issued for the San Francisco Estuary and several of its tributaries cautioning people to limit their consumption of mercury-contaminated fish. The few studies that have been conducted in Suisun Bay and Marsh found some fish had high levels of methylmercury. Seven of eight striped bass from Suisun Bay were above the EPA screening level for protection of human health (Slotton et al. 2003). Two of five inland silverside fish (a small forage fish abundant in the Marsh) collected in Suisun Marsh were above the EPA screening level for protection of human health (Slotton et al. 2003). A discussion of the state of knowledge of mercury cycling processes in Suisun Marsh can be found in the Suisun Marsh Water Quality Conceptual Model: Mercury.

Mercury (Hg) originates in the San Francisco Estuary from a number of historic and current sources. Historically, the region supported several cinnabar mines, and some mines still cause legacy loading to the estuary. Beginning in the 19^{th} century, gold mining in the Sierra Nevada used mercury to isolate gold from ore. The downstream transport of hydraulic mining debris from these activities eventually spread mercury throughout the estuary and into the Pacific Ocean. Tailings from hydraulic mining still contribute mercury to the estuary each year during spring flooding. Modern mercury sources include industrial and wastewater and atmospheric deposition (Davis et al. 2002).

Though Cinnabar mercury from the Coastal Range occurs in a stable mercury sulfide (HgS) form, mercury from hydraulic mining in the Sierra Nevada enters the estuary as elemental mercury. Conversion from elemental mercury requires reduction to Hg^{2+} before it can bond with other molecules such as sulfide or methane (CH_3). This process takes place within the aerobic/ anaerobic interface in wetlands and the substrates of bays and rivers. The anoxic conditions often found in tidal and managed wetlands can provide very suitable conditions for mercury methylation, with distinct periods of wetting and drying increasing methylation capacity. Data available for Suisun Marsh indicate that the managed wetlands can produce significantly higher methylmercury concentrations than those found in its tidal marshes (Mark Stephenson, in-progress research). Understanding the relative contributions from and controlling factors for methylmercury production in Suisun is essential to making informed decisions for management and restoration.

The scientific understanding of the processes that affect methylmercury production and cycling is relatively limited at this time. Several research efforts are underway throughout the region that examine factors influencing mercury methylation and demethylation, transport, organismal uptake, ecotoxicological effects, and ecosystem effects. These studies and efforts include, but are not limited to, the following projects:

- Transport, cycling and fate of mercury and monomethyl mercury in the San Francisco Delta and tributaries, an integrated mass balance assessment approach – San Jose State University Foundation: Moss Landing Marine Labs (CALFED)
- Mercury and methylmercury processes in North San Francisco Bay tidal wetland ecosystems – San Francisco Estuary Institute (CALFED)
- Measurement of mercury release from Delta wetlands: amounts, alterations, and implications – U.S. Geological Survey (CALFED)
- Methylmercury Conceptual Model for the Delta (CALFED DRERIP; Alpers et al. 2008)
- Regional Monitoring Program Methylmercury Annual Meetings (http://www.sfei.org/rmp)
- The Suisun Marsh Low Dissolved Oxygen and Methylmercury Study currently underway (SWRCB)

13.2 Organic compounds

Marshes are often a sink for organic contaminants, especially hydrophobic compounds associated with sediments. Organic contaminants of greatest concern regionally can be generalized into three categories: polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and organophosphate pesticides. Recent studies evaluating the relative contribution of different sources into Suisun Marsh (agricultural inputs from the Delta and upstream throughout the Central Valley, municipal wastewater, and industrial activities) indicate that the Delta is a major source for agricultural products and the Bay and the Delta may be major sources for PCBs and PAHs (Leatherbarrow et al. 2005). Within Suisun Marsh, organic contaminants can be bioavailable, move into the food web, and ultimately cause adverse ecological effects. The fate of organic contaminants depends on the individual physiochemical properties of each compound and the overall effect of ecosystem processes on transport, partitioning, and uptake by organisms. Knowledge about the occurrence of organic contaminants in the Marsh is critical for undertaking any restoration effort. This knowledge, coupled with an understanding of how the hydrologic, biochemical, geomorphic, and ecological processes influence the bioavailability of these contaminants, would provide information necessary for management and restoration decisions.

Contaminants from upland sources originate from a variety of anthropogenic activities. Residential, commercial, and industrial discharges are treated at the Fairfield-Suisun Treatment Plant (Fairfield-Suisun Sewer District 2006) and enter the Marsh via a pipeline to Boynton Slough on the northwestern edge of the Marsh. Stormwater discharges untreated to the Marsh and can include pesticides applied in urban and agricultural settings in Suisun Marsh uplands. The growing urban area around Fairfield is a source of pesticides used around homes and businesses that enters Suisun Marsh via untreated storm drains. Two creeks that drain into Suisun Marsh, Laurel and Ledgewood creeks, and Suisun Slough are on the US EPA 303(d) list for impairment by diazinon from urban runoff and storm sewers. Pyrethroid insecticides are replacing diazinon and chlorpyrifos and could become a problem in the future. In the adjacent agricultural areas, a variety of pesticides are applied to vineyards, orchards, and ornamental turf farms. Applications of pyrethroid and organophosphate insecticides for mosquito control are likely to increase as West Nile virus and Avian Flu become more of a concern in Northern California. Another upland source of contaminants is Travis Air Force Base. Hydrophobic organochlorine compounds, including legacy pesticides, from contaminated facilities at Travis Air Force Base (San Francisco Bay Regional Water Quality Control Board Adopted Order #99-072) are present in ground waters and surface waters adjacent to the marsh. Contaminants detected at the highest concentrations include alpha-chlordane, dieldrin, heptachlor epoxide, and PCBs. Herbicides and insecticides have been detected in water and sediments near the mouth of Montezuma Slough throughout much of the year (Domagalski and Kuivila 1993; Kuivila and Foe 1995; Kuivila and Moon 2004).

13.3 Copper

Copper is a toxin that can be lethal in aquatic environments to fish, invertebrates and amphibians, can reduce growth rates, and has been proven detrimental to embryonic development (USEPA 1993). Although bioaccumulation has not been demonstrated in fish, phytoplankton are highly sensitive to copper toxicity and therefore copper exposure could compromise the base of the food chain and higher trophic levels. Copper exposure could also reduce the efficiency of photosynthesis in phytoplankton and cyanobacteria (Brand et al. 1986). The toxicity of copper to aquatic autotrophs is demonstrated by its frequent use as an anti-fouling agent in marine coatings and as an anti-algal agent in pools, ornamental ponds, and drinking water reservoirs. Other copper sources include agricultural runoff (copper is used as a topical anti-fungal for horses and cattle), municipal wastewater plant discharges (from copper pipes used in many households), and runoff from road/paved areas (which contain particulate copper from brake pads).

The US EPA has placed elemental copper on the 303(d) Watch List for the San Francisco Estuary (SFEI 2005) and has published a draft document, 2003 Draft Update of Ambient Water Quality

Criteria for Copper (EPA-822-R-03-026), which describes new criteria for aquatic life in both freshwater and saltwater (USEPA 2004). Currently, no regulatory standard for dissolved copper concentrations has been implemented for any region of the San Francisco Bay other than Lower South San Francisco Bay (SFRWQCB 2004). However, recent collaborations between the San Francisco Bay RWQCB and the Clean Estuary Project and others have made significant progress in addressing the State Implementation Policy. These efforts include the publication of a series of documents outlining recent results, applied methodologies, and conclusions relating specifically to water north of the Dumbarton Bridge (further separating the North Bay to include San Pablo Bay, Suisun Bay, and the Delta) and concluded impairment of beneficial uses in the Bay due to copper is unlikely (EOA 2005a-d).

13.4 Industrial and Commercial Activities/Sources

Suisun Marsh and Bay are susceptible to pollution from a suite of industrial and commercial activities that may degrade the quality and quantity of a broad range of habitats. Removal of substrate from the bay floor for dredging and mining purposes leads to a direct physical loss of subtidal habitat. Sand mining is currently allowed within 107 acres around Middle Ground shoal and adjacent shoals in Suisun Bay. The mined sand is used as aggregate in concrete for commercial construction within the greater San Francisco Bay area. Although mining operations can significantly impact benthic infauna and epifauna, it generally has a low likelihood of entraining macro-invertebrates and fish (MEC 1993). Dredging in order to maintain navigation channels also occurs in portions of Suisun Bay. The “Suisun Bay Channel” extends from the Carquinez Strait at Martinez to Pittsburg and is dredged annually to maintain its 300’ wide and 35’ deep profile. The “New York Slough” continues upstream from Pittsburg to Antioch and is dredged every four years to maintain its 250’ wide and 20’ deep channel (GS 2005).

Two power generating stations along the Contra Costa shoreline create a potential stressor on Suisun subtidal systems. These power plants draw as much as 3,240 cubic feet per second of water from Suisun Bay through unscreened pipes to cool their turbines. As a result, fish and invertebrate species are impinged and entrained by the plants’ cooling system. Biological surveys in 1979 estimated as much as 86 million Delta smelt (*Hypomesus transpacificus*) and their larvae were being impinged or entrained annually; though it is likely that this number has decreased since then due to the fish’s recent population crash (Taugher 2006). Moreover, thermal discharges from the plants into Suisun Bay can create lethal conditions for aquatic life, especially species’ larval stages. Elevated temperatures can alter the biochemical processes of the environment and the behavior (e.g., migration) and physiology (e.g., metabolism) of marine organisms (Hanson et al. 2003).

The Suisun Bay shoreline along Benicia in Solano County and along much of Contra Costa County is home to numerous industrial enterprises including oil refineries, chemical plants, steel plants, boatyards, and the like. These industries as well as toxic hot spots contribute organic and inorganic pollutants into Suisun Bay waters which can have deleterious effects on aquatic organisms. Suisun Bay is also home to the U.S. Navy's Ready Reserve Fleet (the "mothball fleet"), a collection of retired naval ships anchored semi-permanently. This fleet may contribute small quantities of organic and inorganic pollutants into Suisun Bay via exterior paint deterioration and bilge pump discharge water.

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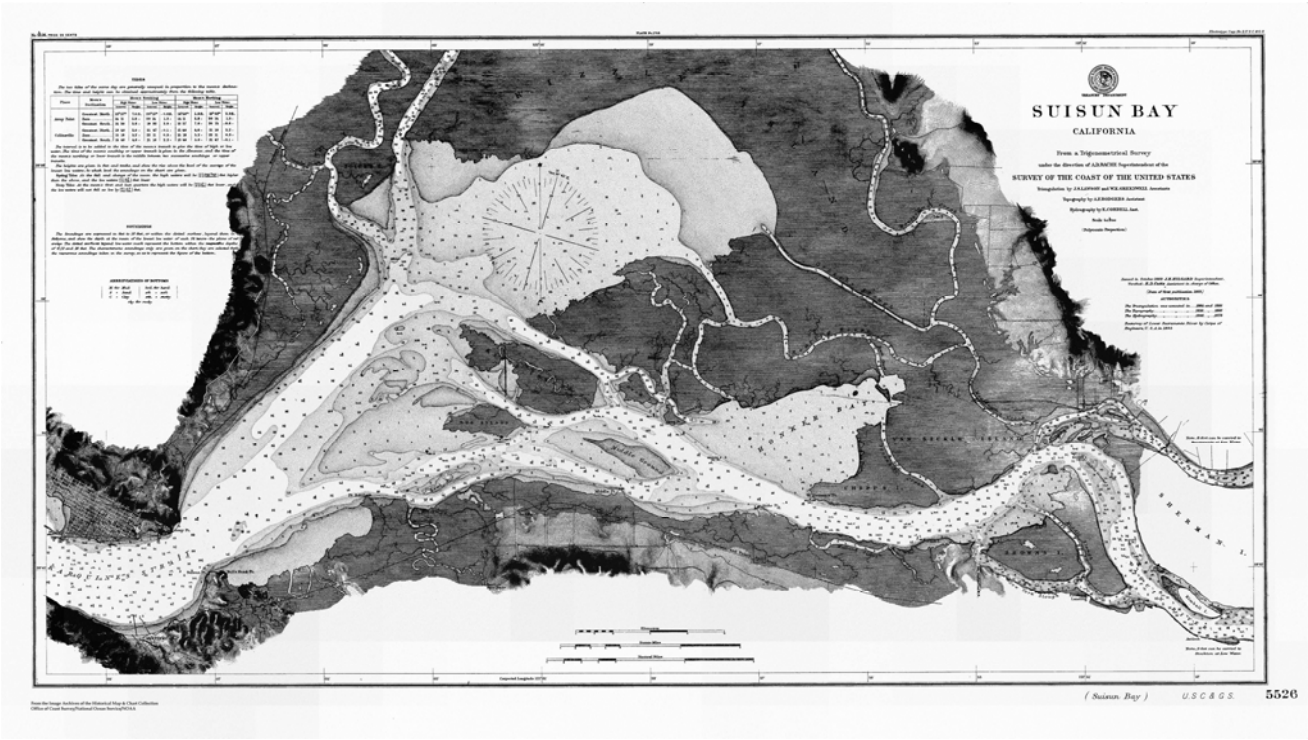

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WETLANDS AND WATER RESOURCES

Prepared for:
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Suisun Marsh Conservation Assessment
Volume II: Tidal Marsh Restoration Strategic Plan

1 Introduction

This *Suisun Marsh Tidal Marsh Restoration Strategic Plan* is intended to provide a thorough scientific foundation for actively pursuing tidal restoration efforts in Suisun. This Strategic Plan is built upon conceptual models: (1) the suite of models prepared for the Suisun Marsh Plan[1] with a strong focus on tidal restoration, and (2) the suite of DRERIP conceptual models[2] that cover a broad range of ecosystem processes and stressors. This Strategic Plan distills the earlier work into a landscape scale conceptual model intended to constitute a coherent strategic tidal restoration plan for Suisun Marsh. It represents the current best understanding of historical landscape function and the influence of landscape patterns and scales on native species life history behaviors. It should be viewed as "version one" of a living landscape scale conceptual model of how tidal restoration in Suisun Marsh meets goals for conservation native species, communities, and natural processes.

The policy context for large-scale tidal restoration in Suisun is moderately well established at this point in time. The Suisun Marsh Plan Draft EIR/EIS (USBR et al. 2010) identifies alternatives that include up to 7,000 acres of tidal restoration. The Delta Plan, currently in preparation, is drawing in part upon the in-progress Bay Delta Conservation Plan (BDCP 2010), the Ecosystem Restoration Program Stage 2 Conservation Strategy (CDFG 2008), and the Delta Vision Strategic Plan (Delta Vision 2008), all of which call for tens of thousands of acres of tidal restoration in the Delta and Suisun. The U.S. Fish and Wildlife Service Biological Opinion for Delta Smelt (USFWS 2008) and the National Marine Fisheries Service Biological Opinion for Salmonids (and other species) (NMFS 2009) both require 8,000 acres of tidal restoration in Suisun and/or the Delta. Lastly, the four-year effort that produced the Baylands Habitat Goals Report (Goals Project 1999) identified a tidal restoration target for Suisun Marsh of 17,500-22,500 acres.

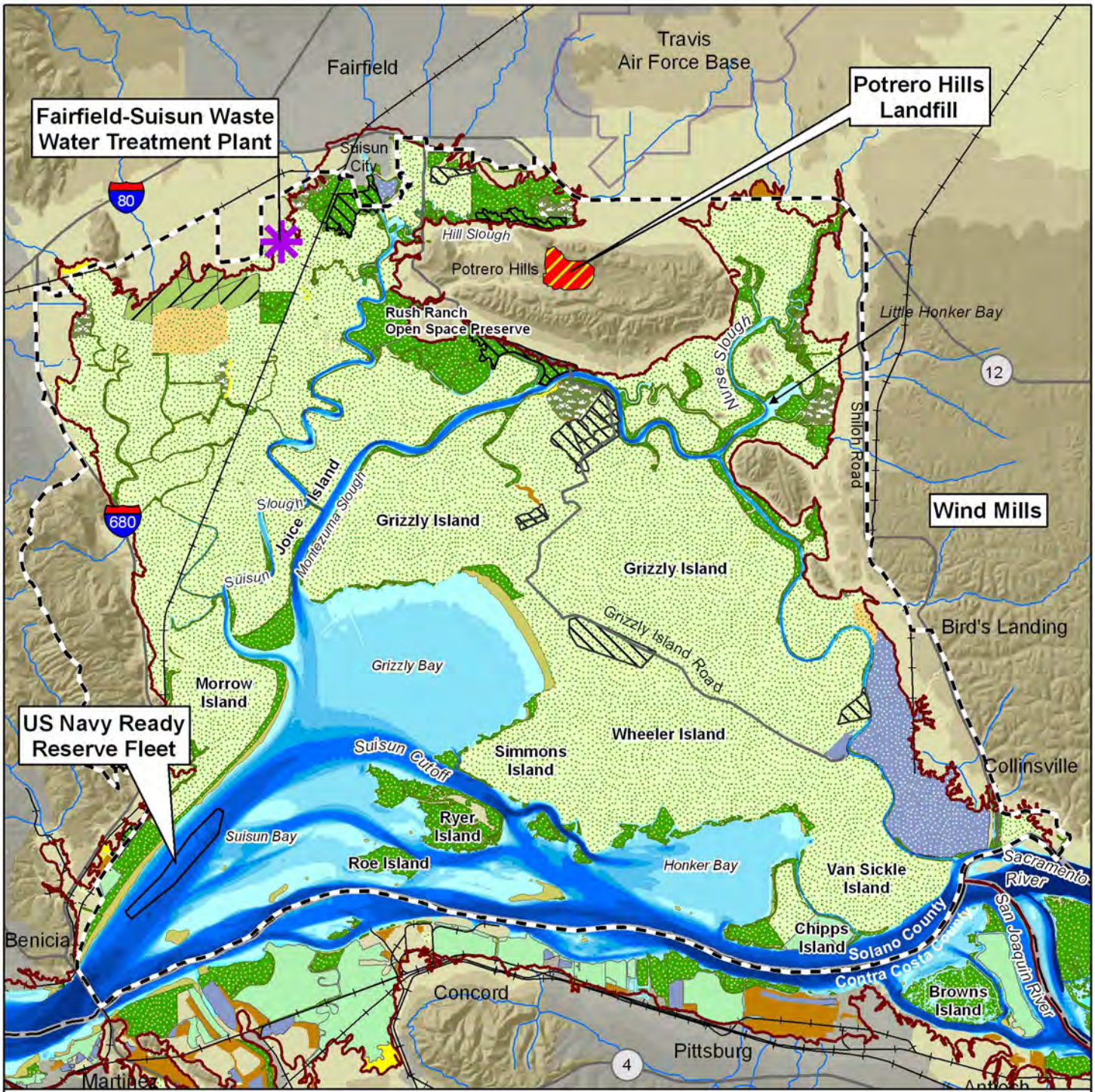
[1] The suite of six Suisun Marsh Plan conceptual models can be downloaded at http://www.fws.gov/sacramento/ea/news_releases/2010_News_Releases/SuisunMP_EIS-EIR_DraftRelease.htm. These models cover tidal marsh and aquatic (Siegel 2010), methylmercury (Enos 2007), managed wetlands (DFG 2005), levees (DWR 2005), organic carbon (Mueller-Solger and Bergamaschi 2005).

[2] The suite of 11 DRERIP conceptual models can be downloaded at http://science.calwater.ca.gov/drerip/drerip_index.html and http://www.dfg.ca.gov/ERP/conceptual_models.asp. Unfortunately, neither site has all the models; ERP has all but the aquatic food web model on the Science Program web site.

This Plan includes the following chapters:

- **Chapter 1, Introduction**
- **Chapter 2, Strategic Vision** – presents overarching goals for tidal restoration in Suisun Marsh
- **Chapter 3, Restoration Hypotheses and Strategies** – frames strategies through a suite of hypotheses based on regional conceptual models
- **Chapter 4, Key Principles Guiding Development of the Strategic Plan** – informs approaching restoration planning at a regional scale
- **Chapter 5, Landscape-Level Restoration Conceptual Model** – the key drivers influencing the design and evolution of tidal restoration efforts
- **Chapter 6, Measures of Success** – tied to our hypotheses, performance measures and indicators that yield clear assessment of forward progress
- **Chapter 7, Comparison to Other Regional Plans** – a look at how the recommendations contained in this Strategic Plan stack up relative to earlier recommendations
- **References**

This report is ***Volume II*** of the ***Suisun Marsh Conservation Assessment***. ***Volume I, Characterization Report*** (WWR 2011) provides an in-depth examination of the physical and biological setting of Suisun Marsh, viability and threat assessments for the biological resource of Suisun, other ecosystem functions, and future drivers of change.



Diked Baylands

- Managed Marsh
- Diked Marsh
- Farmed Bayland
- Grazed Bayland
- Ruderal
- Pheasant Club
- Dredged Material Basin
- Other

Tidal Baylands

- Tidal Marsh
- Muted Tidal Marsh
- Mudflat

Salt Marsh Harvest Mouse Conservation Areas

- DFG Diked Lands
- DFG Tidal Lands

Reference Features

- Historic Baylands Margin
- Suisun Marsh Protection Plan Boundary
- Urban Area

Bathymetry (ft NAVD 88)

Shallow		Deep
1		-20
-20		-140

N W E S

1:150,000 (1" = 12,500' at letter layout)

0 1 2 mi

0 2 4 km

Data sources: USGS (2004), TIGER (2000), GAP (1998), Eco Atlas (1998 with updates by WWR: 2009, 2011), CDFG (2006-2007)
Produced by WWR, September 2011
map file: land-use_Suisun_AP_1151_2011-0912mdl.mxd

WETLANDS AND WATER RESOURCES

SUISUN LAND USES

Suisun Marsh
Solano County, California

September 2011 | Project No. 1151 | **Figure 1**

2 Strategic Vision

Suisun Marsh supports the Estuary's most diverse tidal marshes and a great richness of fish and wildlife species. The strong salinity gradients from the Delta to San Pablo Bay drive enormous geographic variability in tidal marsh plant communities as well as tremendous species richness due to overlapping tolerances of freshwater and saline plants. From the nearly freshwater tule/cattail marshes in the southeast to the nearly saline pickleweed/salt grass/bulrush marshes around the northwestern edges and the brackish bulrush/tule/pickleweed marshes between, Suisun restoration offers high potential for conservation of several native species and natural communities as well as creating resiliency to climate change. Its 88,000 acres of baylands were historically tidal marshes, bays and sloughs. Today there is only about 9,000 acres of tidal marsh, 53,000 acres of diked marsh managed largely for waterfowl hunting, and about 25,000 acres of tidal bays and sloughs. Much of Suisun has subsided on average to about low tide yet Suisun also retains much of its natural upland transition, a rarity in the Estuary. Restoration has the potential to yield a wide range of shallow aquatic, low marsh, high marsh, and marsh-upland transition natural communities, also a rarity in the Estuary. And through Jepson Prairie to its immediate northeast, there exists a reasonably natural uplands and vernal pool/seasonal wetland corridor to Cache Slough and the northwest Delta, again a rarity in the Estuary. This truly unique setting and vast scale make Suisun Marsh a critical region of the Estuary for large-scale tidal restoration.

Fundamental conceptual model and restoration context. Native species are native species because populations adapted to the historical climate, hydrology, community ecology, and landscape pattern of the Sacramento-San Joaquin Valley and San Francisco estuary (Moyle and Bennett 2010). Prior to European contact and reclamation, the physical system of Suisun Marsh was very different than the modern configuration. The interface between land and water was historically far more diffuse, permeable, and variable at a variety of scales allowing flows of energy and materials to occur in diverse ways. Within these habitats, native species encountered diverse options for meeting survival, growth and reproduction needs. On balance, native populations persisted despite enormous variability because they could spread "risk" by exercising different life-history strategies among the population (Chesson 1986, Chesson and Case 1986.

Therefore, a fundamental hypothesis, put forward as the Strategic Vision for Suisun Marsh restoration, is that *conservation of native species is best promoted by restoration of physical landscape components, flows, connections, and processes at scales that allow for full expression of native species life history strategies.*

The primary method to achieve this strategic vision is deceptively simple: **re-establish connectivity between open water bays and sloughs and former tidal marshlands.** That simplicity flows from a few key strategies:

- **Conserve and restore estuarine natural communities**
- **Conserve and restore estuarine ecosystem processes and functions**
- **Maximize the potential for resiliency in face of future changes**

Conserve and Restore Estuarine Natural Communities

Suisun Marsh harbors several categories of natural communities that support native species. From a landscape perspective, native species derive resources both directly and indirectly from each of the following community types. Indeed, it is often the r*elationships* between communities that native species are adapted to exploit for food, refuge, ontogeny (growth or development), and transit (Simenstad et al. 2000).

The estuarine natural communities listed here represent priorities for conservation and restoration in the Suisun Marsh. While these communities are identified by their dominant plants or physiographic features, it is important to note that we recommend conservation of all plants and animals that comprise these community types, including phytoplankton, aquatic and emergent vegetation, zooplankton, invertebrates and vertebrates. In addition, it is essential that native species be prioritized for conservation and restoration. In some cases, such as among fishes, non-native species are more common in term of biomass and species richness compared to native species. Some, such as striped bass, have a well established sport fishery; striped bass may be unique in that its introduction occurred so early in the transformation of the estuary that perhaps it could be considered a 'naturalized' species (Bruce Herbold, pers. comm.). Invasive species represent a problem and a challenge for future conservation and restoration in the Suisun Marsh.

The natural communities of Suisun Marsh are:

- Freshwater tidal marsh (tule/cattail) (*less common in Suisun*)
- Brackish tidal marsh (bulrush/tule/rush/pickleweed) (*most common tidal marsh in Suisun*)
- Saline tidal marsh (pickleweed/salt grass/bulrush) (*less common in Suisun*)
- Marsh-upland transition (high marsh/grasses/forbs) (*rare throughout Estuary*)
- Tidal slough aquatic systems (aquatic food web including vertebrates such as fishes and birds)
- Shallow bay aquatic systems (conserve existing, restore additional that may be incidental or interim to tidal marsh restoration)

Conserve and Restore Estuarine Ecosystem Processes and Functions

Estuarine processes link drivers to ecosystem outcomes. The drivers are the energetic inputs to the estuary including sun energy, tides, river flows, and meteorology. Processes are the expression of driver energy as recognizable estuarine characteristics like moving water (hydrodynamic processes), landforms (sedimentation and vegetation processes), and salinity (transport processes). Estuarine functions are the emergent outcomes of natural processes that species use to get their needs met (Kneib et al. 2008). Ecosystem restoration in Suisun Marsh and elsewhere in the estuary amounts to re-establishing processes so that the functional outcomes that support native species can occur.

Here we identify major categories of ecosystem processes that must be incorporated into future conservation and restoration on the Suisun Marsh. While not an exhaustive list, it does seek to capture the essential biotic and abiotic linkages between drivers and functional outcomes at work in the Suisun. Some ecosystem processes such as natural fire regimes, or natural grazing regimes by large herbivores such as tule elk, are less dominant processes and are not explicitly considered at this phase of analysis.

Three primary process categories include:

Hydrodynamics and transport: tidal exchange, salinity gradients, temperature gradients, flood attenuation, water quality enhancement, residence time variability, corridor connectivity to uplands and watersheds

Geomorphology: sediment transport, sediment deposition, marsh building interactions of sedimentation and vegetation

Biology: food web dynamics and productivity, nutrient and detritus exchange, aquatic organisms exchange (phytoplankton, zooplankton, invertebrates, fish), carbon sequestration, migration, reproduction, herbivory, predation, competition, and mutualisms.

Maximize Potential for Resiliency in Face of Future Change

Ecological resilience is defined as a measure of how far the system can be perturbed without shifting to a different regime (Holling 1973). Native species adapted to the historical climate, hydrology, geomorphology, and community ecology of the Sacramento-San Joaquin Valley and San Francisco estuary. The regime of natural ecosystem processes and functions prior to European contact and reclamation was far more complex and variable than can be supported by the modern domesticated landscape (Moyle et al. 2010). As a result, species that once navigated a spatially complex estuary that afforded multiple options for food, forage, and

physiological adaptation, now have far fewer options. Many believe that a regime shift has occurred in the Delta and Suisun Marsh that puts several native species in danger of extinction (Moyle et al. 2010, Baxter et al. 2010).

Climate change and sea level rise are perhaps the most well publicized drivers of future change, though numerous other changes are expected to have significant impacts on ecosystem processes and native species composition in the Suisun Marsh in the future. Restoration planning must be cognizant of these long-term changes and promote resiliency in the face of such changes. An example of this principle is the identification of gradients in slope and upland transition areas for tidal restoration areas so that tidal marsh habitat is retained as climate changes and sea level rises.

Restoring complex ecosystem interactions is essential in Suisun Marsh because present and future drivers of change are at play including:

- **Climate change**—hydrologic inputs to the Delta are shifting to earlier periods with Delta outflows (in absence of changes in water management) projected to increase by 20% during the October-February period and decrease by 20% during the March-September period (Cayan et al. 2008)
- **Sea level rise**—Glacier melt and thermal expansion of the ocean will increase mean sea level and the frequency of very high tides (Cayan et al. 2008)
- **Reduced sediment supply**—sediment transport to the Delta has declined with the passing of placer mining sediments and the inception of reservoirs (Ganju and Schoellhamer 2010; Schoellhamer et al. 2008)
- **Delta water operations**—Reliable water supply depends on passing water collected in the northern part of the state through the Delta.
- **Salinity increases**—More variable climate means that droughts could be more frequent and intense making salinity intrusion into the Delta a high likelihood.
- **Invasive species**—Non-native species continue to colonize the Delta (cite)
- **Land use**—development with the local watershed has been extensive in the 35 years since the Suisun Marsh Protection Act and is projected to continue well into the future (ABAG 2009)

3 Restoration Hypotheses and Associated Response Strategies

The purpose of defining hypotheses and their associated conservation strategies is to provide a long-term, durable foundation for undertaking a range of actions in Suisun Marsh geared toward ecosystem enhancement and recovery. This section covers several overarching categories of hypotheses and strategies that will be the primary focus of scientific investigation as restoration takes place. Ecosystem restoration in Suisun Marsh would be designed to improve ecosystem food webs and habitats, address stressors and landscape scaling, and provide resilience to future threats. The hypotheses for each of these ecosystem improvement categories reflect the key findings for causes of the pelagic organism decline (Baxter et al. 2010) though these hypotheses are not limited in their scope only to fishes. The following hypotheses, while overarching, are broadly testable by application of the scientific method on Suisun Marsh-wide scales as well as invoking principles of landscape ecology and conservation biology. This "learning by doing" also provides the scientific foundation for adaptive management decisions.

Food Web

Hypothesis 1, Food Web: Low estuarine food web productivity and altered food web composition is an important limiting factor in aquatic species abundance in Suisun Marsh and the Delta. Restoration of tidal marsh and connectivity with tidal aquatic habitats can contribute positively toward improving food web productivity and composition.

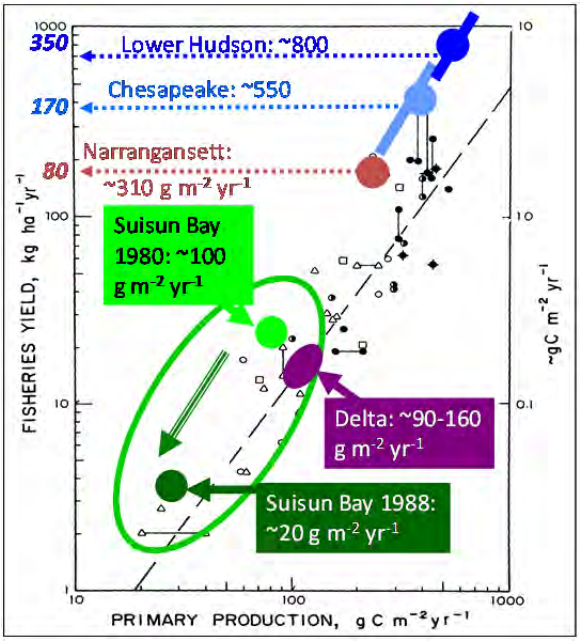


Figure 2. Estuarine Productivity Comparisons
Source: Jassby 2008 as shown in Baxter et al. 2010

Background: One of the key identified issues for aquatic species in the Estuary is limited food web productivity and a food web species composition that is less useful and available to, and in some cases toxic to, native species (Jassby 2008). Productivity levels in Suisun and the Delta are well documented to be much lower than in many estuaries around the world (see **Figure 2**).Food web stressors include reduced volume and extent of estuarine habitats in which primary production occurs, invasive filter-feeding invertebrates (mainly overbite and Asian clams), nutrient imbalances, low residence times, loss to water diversions, low

variability of X2 position, and limited tidal mixing from more productive areas (Durand 2008).

Tidal marshlands and shallow tidal aquatic habitats in general are well established as being very productive estuarine environments helping to fuel aquatic and terrestrial fish and wildlife communities (Kneib et al. 2008; Siegel 2010). What is less clear, however, are the specific relationships between particular tidal restoration approaches and the resulting contributions to food webs and benefits to particular focal species such as Delta smelt (NRC 2010).

Strategy 1: Increase the abundance, diversity, and availability of food for aquatic organisms generated within the Suisun Marsh-Suisun Bay complex by restoring lands to tidal action and restoring connectivity between tidal marsh and tidal sloughs and bays.

Habitats

Hypothesis 2, Habitats: The reduction in spatial extent and habitat quality of tidal marshes and tidally influenced marsh-edge communities plays an important role in limiting population abundances, compared to natural conditions, of the following species that utilize these Suisun habitats:

- **Fish:** Central Valley steelhead, Central Coast steelhead, Central Valley spring-run Chinook salmon, Sacramento River winter-run Chinook salmon, Central Valley fall/late fall-run Chinook salmon, starry flounder, green sturgeon, white sturgeon, longfin smelt, Delta smelt, Sacramento splittail
- **Small mammals:** salt marsh harvest mouse, Suisun shrew
- **Birds:** California clapper rail, California black rail, California least tern, great blue heron, northern harrier, salt marsh common yellowthroat, short-eared owl, snowy egret, Suisun song sparrow, tricolored blackbird, white-tailed kite
- **Plants:** Suisun Marsh aster, Suisun thistle, soft bird's beak, marsh gumplant, Delta tule pea, Mason's lilaeopsis, Delta mudwort
- **Reptiles and amphibians:** western pond turtle

Background: The Suisun Marsh Plan Draft EIR/EIS (USBR et al. 2010) lists the above special status species that utilize Suisun Marsh environments at some stage in their life histories. Some species are very dependent on Suisun (e.g., Suisun shrew) while other species have more dispersed dependencies and factors limiting their abundances (e.g., salmonids). Many plants, fish and wildlife have specific habitat requirements in relation

to soil, elevation, natural-community type, plant-species composition, salinity, and level of tidal inundation. Additional fine-scale analysis is required to determine the habitat parameters for each species, in relation to an array of proposed restoration projects.

Strategy 2: Increase amount, geographic distribution, connectivity, and diversity of tidal marshlands and tidally influenced marsh-upland edge communities and improve the functioning of their regulating processes.

Stressors

Hypothesis 3, Stressors: Three primary types of strategies exist to reduce or eliminate the effects of the many stressors affecting Suisun that impair ecosystem functions and open water, tidal marsh, and marsh-upland edge communities: tidal marsh restoration, modified management of diked managed wetlands in and other factors internal to Suisun Marsh, and modified management of external processes and conditions that influence Suisun. These stressors are often interactive and in some cases have cumulative impacts upon native species and communities. Some stressors may not be possible to reduce or eliminate.

Strategy 3: Remedy stressors where possible to increase ecosystem function and native species richness and abundance. In Table 1 below, "Suisun Tidal Restoration" consists of modifying or removing levees and allowing tidal flows to move across marshlands. "Suisun Management Actions" consists of on-the-ground management actions and interventions across managed and tidal marshlands of Suisun and of associated infrastructure. "Regional Planning Efforts" consist of large-scale actions in the Bay Delta or Suisun Marsh that have the potential to influence many miles of tidal sloughs and thousands of acres of managed or tidal marshlands. "Presumed no available approach" refers to those stressors for which we are not aware of any possible intervention or abatement strategy that is logistically or economically feasible.

1 **Table 1. Possible Intervention Approaches to Stressors**
2

Stressor	Intervention Approaches			
	Suisun Tidal Restoration	Suisun Management Actions	Regional Planning Efforts	Presumed no available approach
Habitats				
Poor connectivity between tidal marsh and aquatic habitats	X			
Low density of habitat patches and poor connectivity between patches	X			
Little high tide refuge	X	X		
Water quality				
Low dissolved oxygen	X	X		
Methylmercury	X	X	X	
Nutrient loadings	X	X	X	
Urban, industrial, agricultural contaminants		X	X	
Salinity variability		X	X	
Elevated water temperature				X
Invasive species				
Plants (*Lepidium, Phragmites, Arundo*)	X	X		X?
Invertebrates (*Corbicula*, many other)				X
Fish (warm water centrarchids, catfish)			X	X?
Mammals (feral pigs, feral cats, red fox, Norway rats, raccoons)		X		X?
Birds (brown-headed cowbirds)				X
Reptiles and amphibians (bullfrogs, red-eared sliders, painted turtles)				X?
Hydrology				
Salinity control gates			X	
Delta outflow			X	
Reduced sediment supply				X
Water diversions within Suisun		X	X	
Sea level rise, storm intensity increase	X			X
Channel bank erosion	X?	X?		X
Land Use				
Grazing pressure		X		
Wind power avian mortality			X	X?

3

4 ## *Scale*

5 **Hypothesis 4, Scale:** Conservation of native species and natural communities is promoted by
6 restoration of physical landscape components, connections, and processes at scales that
7 allow for full expression of native species life history strategies.

Background: Scale matters. First and foremost, the identified restoration regions should offer restoration potential that is relevant to adapted native species life history strategies. In general, this means providing for a wide range of geomorphic structures and connections between landscape components at adequate scales so that physical/chemical/biological processes can generate gradients of ecosystem outcomes (food, temperature, residence time, morphology, vegetation, nutrients etc.). A primary attribute of this criterion is that it favors spans of connected landscape that provide continuous corridors for species movement and diverse habitat access. For example, corridors long enough to scale with regional tidal excursion lengths promote full expression of native tidal energy dissipation, sedimentation/erosion, and vegetation processes. Alternatively, a future Suisun Marsh with a random collection of landscape pieces at the scale of property boundaries will likely be energetically miss-matched to native processes with unknown consequences.

Strategy 4: Use principles of landscape ecology to assure connectivity, energy flows, and migration pathways between tidal marshes by restoring lands in sufficiently large, connected blocks to yield the scales necessary to support target ecosystem functions.

Resiliency to Future Threats

Hypothesis 5, Future Threats: Resiliency to expected future challenges like (e.g., sea level rise) is promoted through tidally restoring lands in large, contiguous areas across gradients of baseline elevations, salinity regimes, sediment supply, tidal mixing, and upland edges.

Background: Future threats will challenge the resiliency of aquatic, wetland, and terrestrial food webs, tidal marshlands, marsh-upland edge communities, and the ecosystem functions that support these communities. Resiliency is the ability of these natural communities to adapt and to retain native species and ecosystem functions into the future. External agents of change include climate change, sea level rise, storm intensity increases, Delta water management, salinity increases, new invasive species, sediment supply reductions, and land use changes Climate change is a major threat that will alter sea level, storm intensity, water temperatures, freshwater inflows, salinity, sediment supply, and tidal patterns in Suisun Marsh. Numerous other threats are increasing such as invasive species and intensification of land and water use by humans. It is important that we pursue restoration of tidal marsh in Suisun with an implicit objective to promote resiliency and adaptability in natural communities in the face of these many changes.

Strategy 5: Distribute large restoration clusters across the geographic and chemical gradients present in Suisun Marsh including incorporation of lands with broad upland transitions.

4 Key Principles Guiding Development of the Strategic Plan

Underlying this Strategic Plan is a set of key principles that inform how subregions are identified for restoration and how site selection criteria are derived.

Restoration of native species, communities, and process will take time

Most restoration actions in Suisun Marsh begin with degraded (primarily subsided) landscape. We understand that early restoration outcomes are directed at rehabilitation of physical and geomorphological processes and that initial tidal habitats may be sub-optimal for native species. We consider this setting a necessary investment in time that will eventually yield self-sustaining landscape processes and attributes that give native species competitive advantage. It took time to mess it up; it will take time for nature to fix it. Apropos of that:

Work with nature, let nature do the work

The natural landscape, as modified by humans over the past 150 years or so, still holds strong guidance for how we proceed with restoration. The historical landscape pattern provided the template for natural selection that shaped the particular adaptations of native and endemic species. Understanding historical spatial habitat patterns tell us what processes and functions the landscape has a tendency to support. Key landscape features that guide restoration planning include: topography and elevation, bathymetry, geomorphology, human infrastructure, waterways, land uses, potential for connectivity, and geography at scales from restoration site to subregion to estuary. These features inform ease (and cost) of restoration, ecologically relevant scale, the potential to achieve target outcomes, the opportunity to use natural processes to minimize risk of problems such as invasive species, and resiliency to future change such as sea level rise. By letting nature do the work encourages natural self-repair processes and minimizes inputs of materials and expense. Apropos of that:

Be guided by principles of the historical landscape ecology

We should be guided by our best understanding of historical landscape ecology. Despite its degraded condition, the Bay-Delta landscape contains clues about its former morphology, connectivity, and functioning. We can leverage remnant features at appropriate scales to improve the landscape's own self-repair capability. Native species are more likely to gain competitive advantages from the results.

Natural ecosystems seldom conform with political boundaries or land ownership patterns

Ecosystem restoration for conservation of native species requires consideration of whole-landscape attributes and connectivity at natural spatial and temporal scales, regardless of

political or ownership boundaries. Doing so promotes native species resilience by allowing full expression of population life history strategies for survival, growth, and reproduction (Simenstad 2000, Peterson 2005 etc). Properly scaled and located restoration actions would leverage historical landscape features, minimize the need for costly flood control levees, and create persistent overlaps within and between aquatic, wetland, and terrestrial physical/chemical attributes and landscape morphologies that provide access, forage, cover, and physiological adaptation opportunities during all life-history phases. Land acquisition strategies for restoration of native species should consider ecological relationships and connectivity that leverage historical landscape features and consider whole landscape functioning at ecologically relevant scales.

Levees are anathema to ecological functions

Levees simplify the land-water interface. They create mismatches of tidal energy with the dissipation capacity of restoration sites. They are abrupt topographic ecotones that may aid non-native predator foraging (e.g., foxes). They are vectors for invasive plants like pepper weed (*Lepidium latifolium*) and star thistle (*Centaurea solstitialis)*. And, they are financial and human resource sinks because they require expensive upgrade and maintenance that further requires difficult environmental permitting. Almost all property boundaries in Suisun Marsh have levees that would require upgrading if restorations were implemented on a property line basis. Minimizing levee involvement in restorations will require very clever strategies including buying and holding, land swaps, easements, and otherwise innovative agreements with adjacent landowners.

A corollary to this principle is that restoration projects developed in absence of a landscape perspective and instead focusing on individual properties as restoration opportunities have a lower likelihood of avoiding this levee issue. For example, commercial mitigation banks in many cases acquire individual properties and seek their restoration in absence of how those properties link to adjacent lands.

Learning is central; conceptual models drive approaches

Though we possess a remarkable knowledge-base across many facets important to advance ecosystem recovery in the San Francisco Estuary, there is much yet to learn to assure conservation success. Consequently, restoration efforts must be guided by strong science (via conceptual models) and they must incorporate 'experiments' to foster learning geared specifically at addressing uncertainties and knowledge gaps. Contributions to the peer reviewed scientific literature are the most effective way to assure that synthetic knowledge guides future conservation actions.

Outcomes of our best efforts are difficult to predict

Natural ecological systems constantly change. Predicting or guiding the course of change is extraordinarily difficult if not impossible because the ecological outcomes are "emergent" phenomena. That is, tides, rivers, and solar energy drive a cascade of interacting processes that control estuarine water motions and transport and transformation of biotic and abiotic materials. The functional outcomes we will attempt to influence with landscape restoration and more natural flow regimes are subject to thresholds or "tipping points", non-linear interactions, feedbacks, and human decisions. Therefore, trajectories of change will usually not follow our predictions. The intended ecological outcomes may take time to be realized and they may even exhibit 'negative' trajectories initially. As we attempt to observe population and natural community responses at the landscape scale, these outcomes may be both challenging to detect (signal-to-noise ratio) and they may take time to be realized.

5 Understanding the Restoration Capacity of Suisun Marsh: a Landscape-Level Conceptual Model

The next topic in our line of inquiry into establishing a Strategic Plan for restoration of tidal marshlands in Suisun is to examine what controls tidal restoration outcomes and how these drivers are at play in Suisun Marsh – i.e., a landscape-level conceptual model of tidal marsh and tidal aquatic (open water) restoration in Suisun. With these conceptual models in hand we then have the tools to construct a geographically-based restoration strategy for Suisun, which is the subject of the following Chapter 1.

This chapter presents the following information: definition of 'landscape', the landscape-level conceptual models for tidal restoration evolution and tidal marsh and tidal aquatic ecological functions, and a discussion of the four major drivers of those conceptual models (hydrology and hydrodynamics, sediment supply, initial elevations, and vegetation community composition in relation to salinity).

Definition of 'Landscape'

The "landscape perspective" deals with the influence of spatial pattern on ecological processes (Weins 2002). It fundamentally implies *relationships* between terrestrial and aquatic components and processes at multiple scales. It considers the patterns of landscape components and how they interact as well as the scales of those patterns and how much space it takes for patterns to repeat. For example, estuaries often exhibit a pattern of tidal channels connecting to dendritic marshes that in turn connect to upland grasslands. The spatial scale of the pattern depends on drivers like tides and river flow as well as vegetation, salinity, and substrate. Relationships between landscape components are manifested as flows of energy and materials between ecosystem components via ecotone-spanning corridors that can be used and traversed by species. For example, diverse connections between upland grasslands, freshwater creeks, alluvial fans, and ephemeral lakes adjacent to tidal marshes allow exchanges of detritus and insects and provide corridors for birds and land predators. In turn, tidal marshes are extremely proficient at fixing carbon into ecosystems that can then be transported back to uplands or exported to the deeper channel habitats that are otherwise light limited (e.g., by trophic relay). Then in turn, channel habitats regenerate system nutrients that are dispersed back to marsh habitats by tidal currents. Native species populations developed competitive advantages by successfully navigating the diversity and variability of these relationships to obtain resources including food, refuge, and physiological adaptation space. Restoration that promotes native species conservation should be directed toward restoring native physical landscape patterns and attributes along with the connections and energy flows between them

The "landscape perspective" is meant to consider all of these components, connections, and exchanges. Native species are adapted to these landscape processes.

The Landscape-Level Conceptual Model of Tidal Restoration Evolution

These conceptual models are adapted from the Suisun Marsh Tidal Marsh and Aquatic Habitats Conceptual Model (Siegel 2010). **Figure 3** illustrates the processes that affect the rate at which tidal marsh restoration sites evolve upward toward 'high elevation equilibrium marsh'. The interactions of these processes and the resulting rates of marsh accretion control the range of ecological functions provided by restoration efforts. **Figure 4** then illustrates the general relationships between the many physical and biological processes and characteristics and the ecological functions provided by tidal marshlands. **Figure 5** provides the comparable illustration for tidal aquatic habitats. Together these conceptual models inform the nature of how restoration efforts will evolve as geomorphic elements of Suisun Marsh and how they will provide a range of ecological functions as they evolve.

Tidal marsh restoration is an evolutionary process. The 'initial conditions' reflect the baseline site elevation, substrate characteristics, and composition of emergent vegetation and open substrate (Siegel 2010). Once diked lands are restored to tidal action, the many physical and biological processes controlling site evolution take over. Ecological functions are tied very strongly to the position of the marsh along this evolutionary trajectory (Siegel 2010). **Figure 6** shows the relationship between marsh elevation and inundation regime which exerts a major influence over all aspects of the site ecology. The rate of evolution is controlled predominantly by the relative influence and magnitudes of the four major drivers of restoration outcome discussed later in this chapter. **Table 2** summarizes the directionality of that each of these four drivers exerts upon tidal marsh restoration evolution.

Table 2. Factors Controlling Rate of Tidal Marsh Restoration Evolution

Driver	How Magnitude of Driver Affects Rate of Restoration Evolution	
	High Magnitude	Low Magnitude
Sediment Supply	More sediment = faster	Less sediment = slower
Hydrodynamic Energy	More energy = slower	Less energy = faster
Initial Elevation	Higher elevation = faster	Lower elevation = slower
Salinity and Vegetation	Higher salinity = slower	Lower salinity = higher

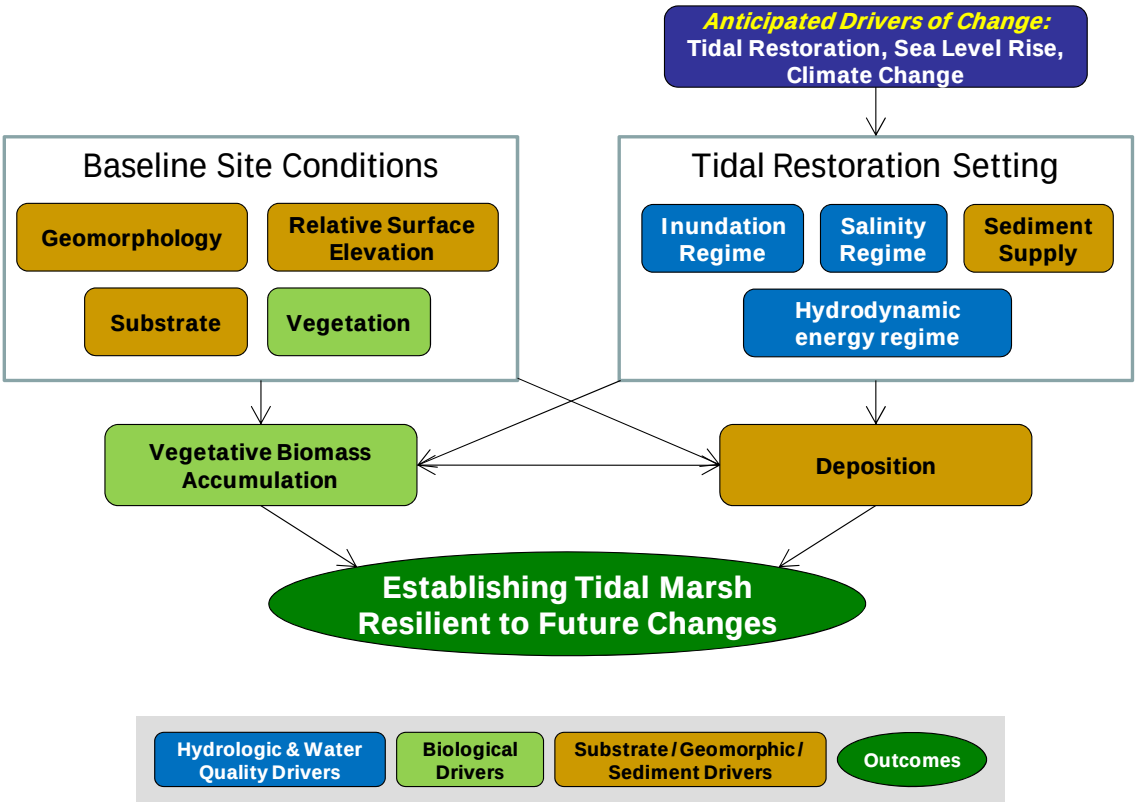


Figure 3. Conceptual Model: Factors Influencing Tidal Marsh Restoration Evolution

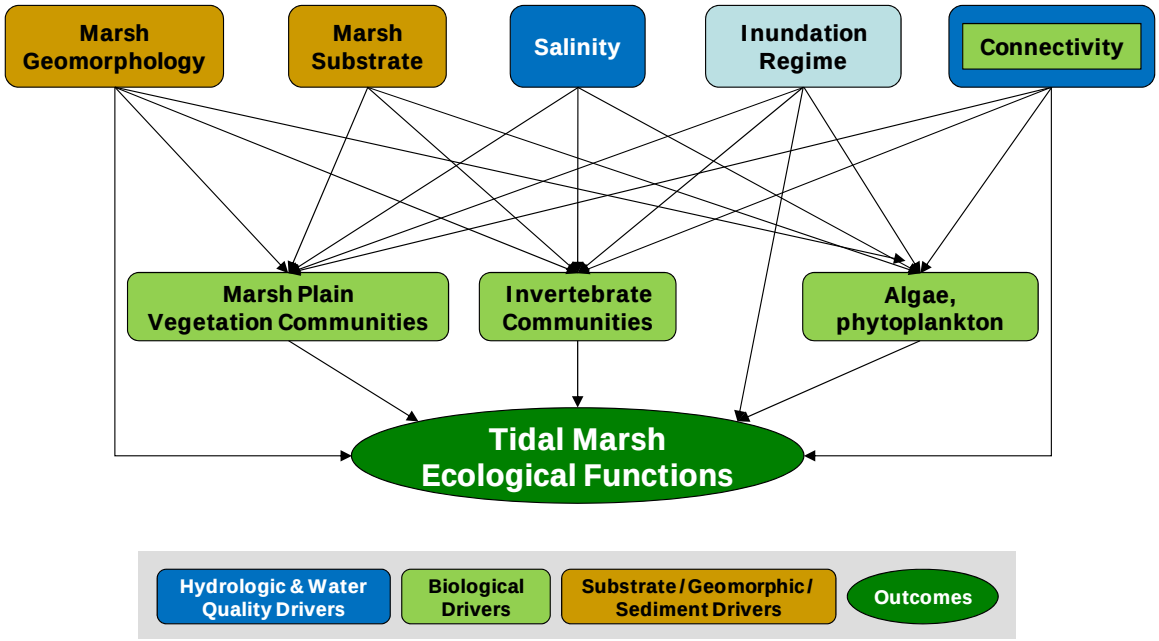


Figure 4. Conceptual Model: Factors Influencing Tidal Marshes Providing Ecological Functions

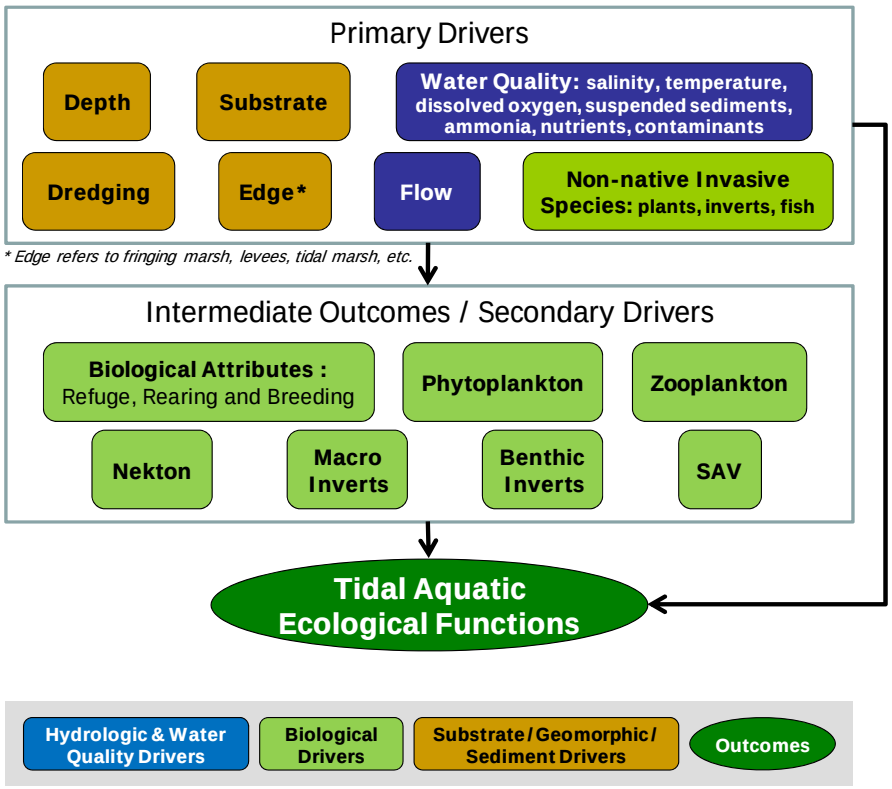


Figure 5. Conceptual Model: Factors Influencing Tidal Aquatic Providing Ecological Functions

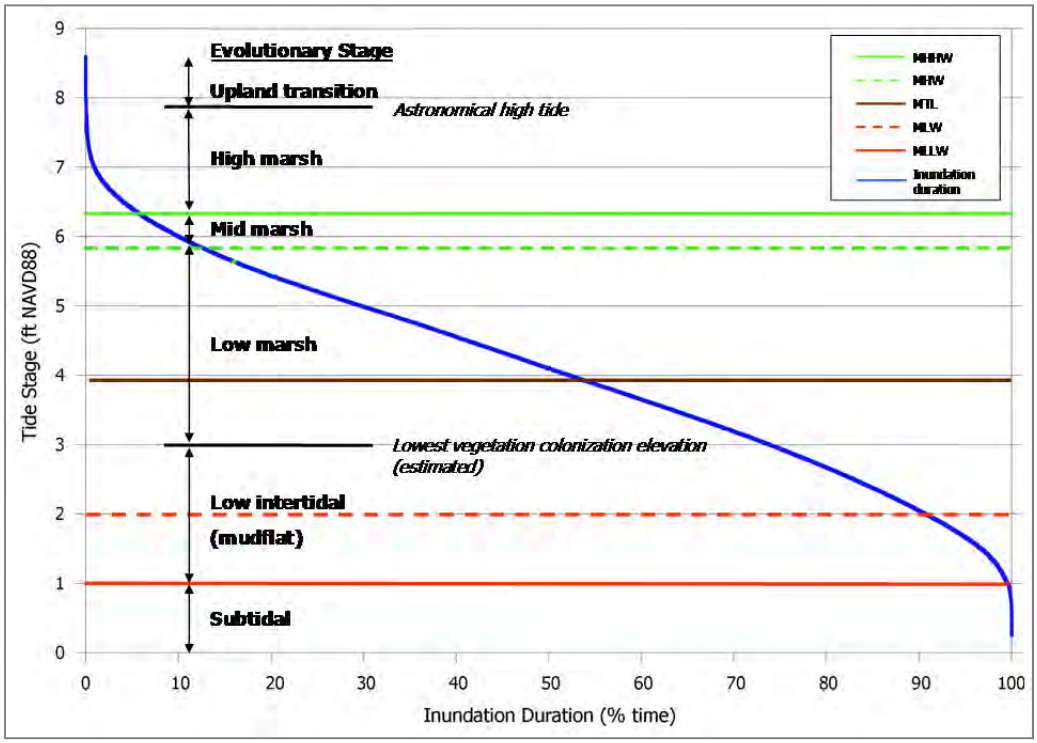


Figure 6. Inundation Regime, Marsh Elevation, and Restoration Evolution Trajectories
Source: Wetlands and Water Resources

The Major Landscape-Scale Processes and Characteristics Influencing the Long-Term Outcomes of Tidal Marsh and Tidal Aquatic Restoration in Suisun

The four major landscape-scale processes and characteristics that influence what takes place once lands are restored to tidal action and thus resulting ecological functions are: (1) hydrology and hydrodynamics, (2) sediment supply, (3) initial elevations, and (4) upland transitions.

Hydrology and Hydrodynamics

The spatial scales of hydrodynamic and transport complexity in Suisun marsh are illustrated in **Figure 7**. Suisun Marsh exhibits strong salinity gradients in both the east-to-west and north-to-south directions by different mechanisms. The estuarine salinity gradient is a balance between freshwater river flow (advection) and mixing of ocean salinity by tidal currents (dispersion) (Fischer et al. 1979). Located in the geographic center of the northern reach of the San Francisco estuary, Suisun Bay generally experiences the strongest east-to-west salinity gradient. This gradient is partially responsible for net currents driven by the east-to-west density difference, especially during slack tides. These density currents, called “gravitational circulation,” are thought to be important for upstream transport of salinity and sediment, as well as being used by some organisms to move and maintain position in the estuary (Monismith et al. 1998). Inputs of freshwater from northern Suisun Marsh creeks generate a persistent salinity gradient from north-to-south. The inset chart on **Figure 7** shows a salinity time series between April and August 2004 showing progressively increasing salinity along Suisun Slough toward the south.

The larger channels crossing Suisun Marsh are unique features both because of their size and because their lengths are longer than the excursion of the tide. Therefore, while channels are tidally energetic, they significantly contain the full tidal excursion or tidal “slosh” within their length. Another feature of tidal channels in Suisun Marsh is that several of them form "loops" either naturally or because of historical channel cutting. Propagating tidal waves enter each of these loops from both ends with variable timing and come together in "convergence zones." **Figure 7** shows the general location of convergence zones in Cutoff Slough, the Nurse Slough complex, and eastern Montezuma Slough. The speed of tide propagation depends on water depth; therefore convergence zone locations are variable. However, in the region where convergences occur, we generally observe lower overall current velocities and shallow depths because sediment is more likely to be deposited in these areas.

Suisun Marsh is connected at three primary locations to Suisun Bay. To the extent that Suisun Marsh is a net producer of energy to the Suisun Bay food web, the key water mass exchanges are made here. The details of these exchanges are not well understood at this time. **Figure 7**

shows how a volume of water that is exported from Suisun Marsh through the mouth of Suisun Slough and Western Montezuma Slough can be replaced on the following flood tide partly by that same water, and partly by other water that had been resident in Grizzly Bay. This partial "exchange" is also affected by the strong wind shear in Grizzly Bay as well as by the dynamics of variable ebb and flood tide strength (Schoellhamer 2008). Finally, dark green arrows show the nominal length of the 6.2 hour tidal excursion in various places within Suisun Marsh and Suisun Bay. Considerations of restoration scale adequacy should be guided by these lengths and the potential geographic habitat area that is therefore available to aquatic species and tidally mixed relative to productivity exchange.

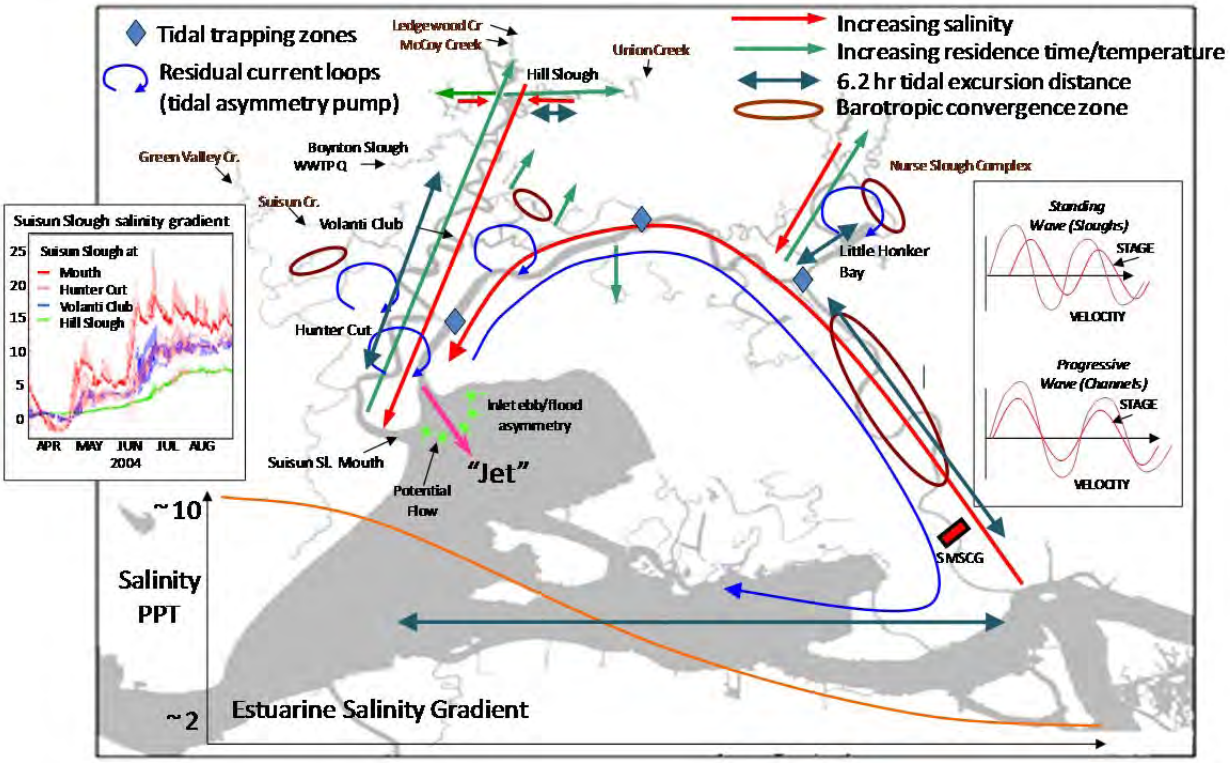


Figure 7. Conceptual model of hydrodynamic complexity due to landscape connectivity among various parts of Suisun Marsh

This model highlights the spatial variability in salinity, residence time, and the locations of barotropic convergence zones, residual current loops, and tidal trapping zones. Also shown are the locations of inflowing creeks and the ebb/flood asymmetry of flow at the western end of Montezuma Slough. SMSCG is the Suisun Marsh Salinity Control Gate. Source: Chris Enright, DWR

Sediment Supply

Understanding the availability of sediment for rebuilding subsided landscapes is an important element for restoration planning. Tidal marsh accretion rates are a function primarily of sediment supply and its grain size characteristics (mass for deposition and settling velocities), time period of inundation (opportunity for deposition), and sufficiently low water velocities to avoid resuspension (keeping deposition in place). Regional-scale processes control available

sediment supply and grain size characteristics; restoration planning can at most control for this variable through site selection. Site elevations, tide ranges, and extent of tidal connections control time period of inundation; restoration planning can control for this variable mainly through levee breach designs and pre-restoration subsidence reversal efforts. See *Volume I: Suisun Characterization Report* (WWR 2011) for more information on processes affecting sediment supply and sediment accretion in wetland restoration sites.

Figure 8 illustrates the very broad pattern of sediment supply and key controlling factors in Suisun that are explained later in this section. Taking the landscape perspective the generalized suspended sediment gradient is lower in the north at the margins of Suisun Marsh and higher in the south in Suisun Bay. Little Honker Bay in the northeast locally has high SSC levels from wind and tidal resuspension from the shallow bay floor. Tidal transport from the large shallow bays in the south and some within-slough resuspension can make locally higher SSC concentrations in many sloughs. The main Suisun Bay channel SSC levels are driven by Delta inputs, some tidal inputs from San Pablo Bay, and resuspension from the shallows of Grizzly, Honker and Suisun bays.

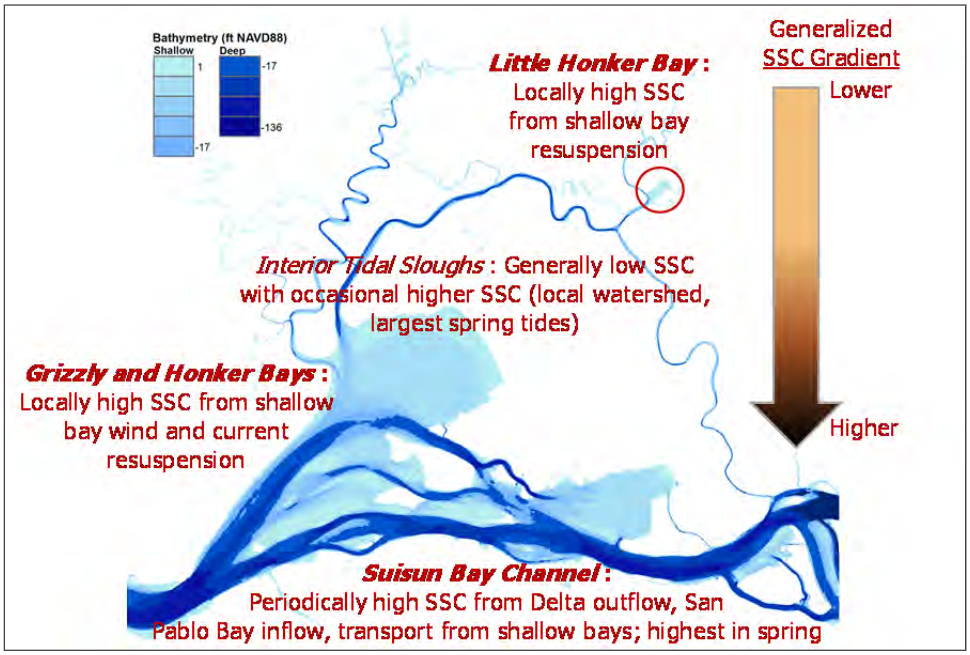


Figure 8. Suspended Sediment Gradients
Source: Developed in collaboration with Schoellhamer, pers. comm.

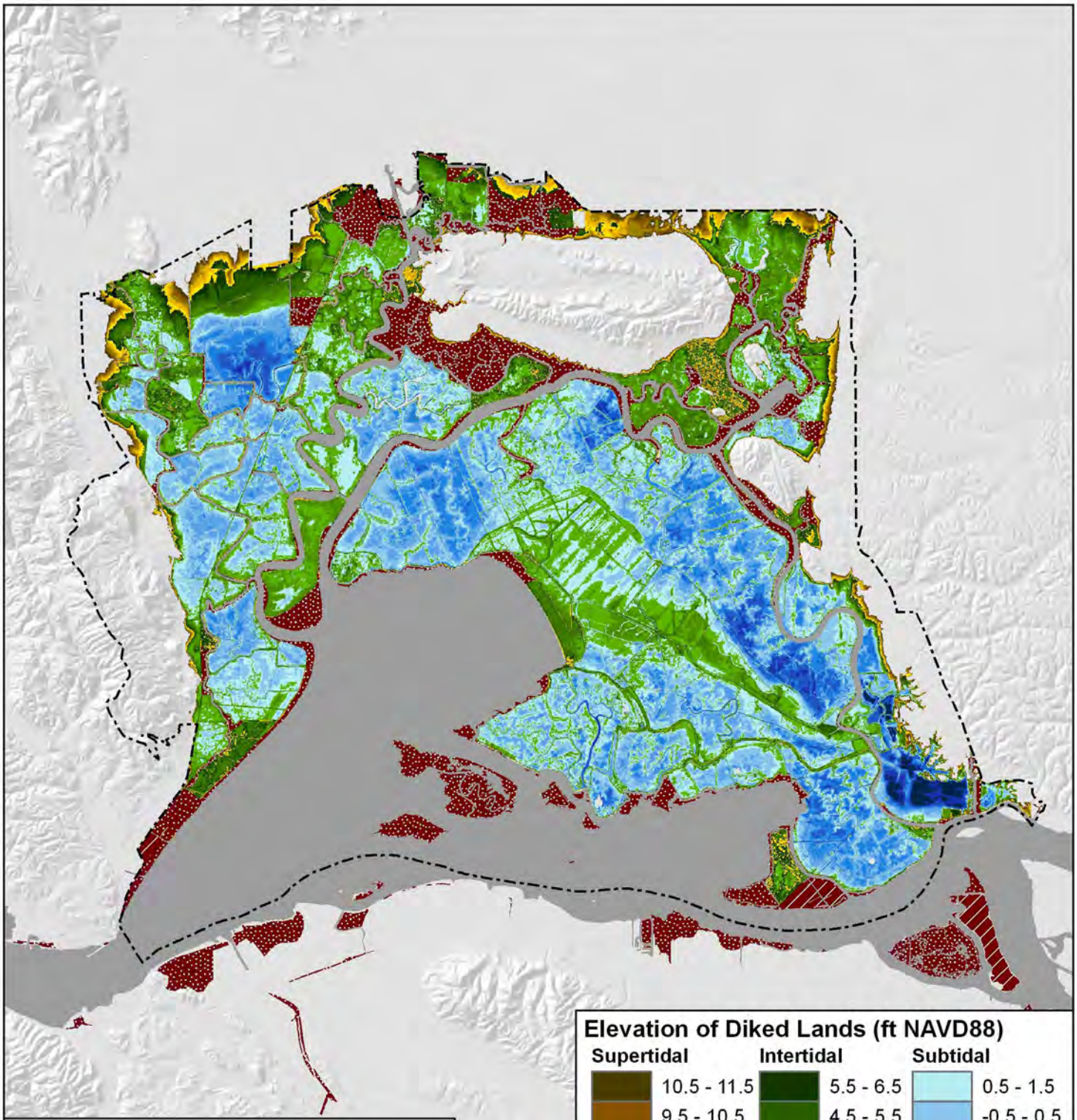
Recent work by the USGS (Schoellhamer 2011) hypothesizes that the San Francisco Estuary cross a threshold in 1999 wherein the erodible sediment pool on the estuary's bottom is depleted. These pools are resupplied by watershed contributions, both local and from Delta outflow. The decline in those sources along with prior resuspension, transport, and deposition

in areas that do not readily erode (e.g., tidal marsh restoration sites) translates into the crossing of this threshold. The ramification of this recent hypothesis is that the estuary will have reduced suspended sediment concentrations, which translates into lower rates of marsh accretion and increased potential for wind-wave resuspension to keep restoration sites from accreting at all or accreting far more slowly.

Subsidence and Baseline Topography

Diked former tidelands are the opportunity for tidal restoration in Suisun Marsh. Land use since tidal marshland reclamation in the 19th and early 20th century has resulted in subsidence throughout much of Suisun Marsh (**Figure 9**). Consequently, the resulting ecosystems from tidal restoration will reflect those subsided elevations (i.e., baseline elevations). Sediment placement (e.g., dredged material) and carbon sequestration (emergent wetland vegetation) prior to restoration are options for raising baseline elevations. Sediment accretion and emergent wetland vegetation will carry on after restoration and their rates largely dictate the pace at which site 'evolution' takes place.

The varied subsidence in Suisun (**Figure 9**) offers the opportunity to create a matrix of restoration areas with varied initial conditions and thus varied ecological functions. When combined with spatially variable physical processes controlling the rates of marsh restoration evolution, the result would be a geographically diverse suite of associated ecological functions that evolves over time. This diversity would be expected to support a wide range of target species and natural communities and provide greater resiliency for those targets.



Suisun Marsh Protection Plan Boundary
Existing Tidal Marsh
Muted Tidal Marsh

NOTE: Diked lands topography shows 1.5 ft downward adjustment by DWR to account for vegetation interference with LiDAR

Elevation of Diked Lands (ft NAVD88)

Supertidal	Intertidal	Subtidal
10.5 - 11.5	5.5 - 6.5	0.5 - 1.5
9.5 - 10.5	4.5 - 5.5	-0.5 - 0.5
8.5 - 9.5	3.5 - 4.5	-1.5 - -0.5
7.5 - 8.5	2.5 - 3.5	-2.5 - -1.5
6.5 - 7.5	1.5 - 2.5	-3.5 - -2.5
		-4.5 - -3.5
		< -4.5

N W E S

1:158,400
(1" = 2.5 mi' at letter layout)

0 1.25 2.5 mi
0 2 4 km

Elevation Data Source: DWR 2005 LiDAR, SFEI 1998 (updated by WWR, 2011)
Produced by WWR, September 2011
map file: topo-1ft-diked-LiDAR05_Suisun_AP_1149_2011-0914mdl.mxd

WETLANDS AND WATER RESOURCES

DIKED LANDS TOPOGRAPHY 1 FT CONTOUR, 2005 LIDAR

Suisun Marsh
Solano County, California

September 2011

Figure 9

Salinity-Moderated Vegetation Community Composition

Emergent vegetation plays an important role in controlling site evolution through its contribution to promoting sediment accretion and through its biomass accumulation. Vegetation communities present at time of restoration ('pre-vegetation' or carbon sequestration) may die off initially due to the new tidal inundation regime but they will still affect sediment accretion processes. The relationship between site elevation and new vegetation growth is tied directly to the strong salinity gradients of Suisun Marsh, with saline-tolerant species being more sensitive to prolonged inundation and freshwater species having greater inundation tolerance (**Figure 10**). Consequently, the more productive and lower-growing vegetation community composition in the fresher southeast region of Suisun Marsh will play a more important role in guiding restoration evolution than would the less productive and higher-growing species in the more saline northern and western regions of Suisun.

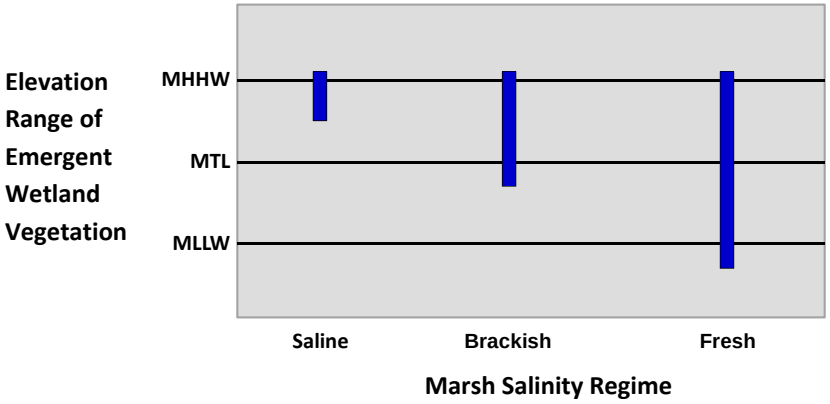


Figure 10. Tidal Marsh Vegetation Vertical Range with Salinity
Source: Wetlands and Water Resources. Ranges are approximations.

Sea Level Rise Resiliency and the Upland Transition

Tidal marshes can respond geomorphically to sea level rise in one or more of three possible paths: estuarine transgression (move laterally into the adjacent uplands), marsh vertical building (keep up with sea level rise), or marsh drowning (lose the battle and convert to open water). Which path(s) a given natural or restored tidal marsh follows in Suisun is about its location relative to upland edge (transgression accommodation), salinity regime (plant community productivity), and sediment supply (accretion). It is possible that different parts of a marsh may respond in multiple ways. The preceding sections discussed salinity regime and sediment supply; here we discuss the upland edge both in terms of its role in facilitating estuarine transgression. It also key to note that from an ecological perspective, the marsh-upland transition zone supports unique vegetation communities and associated ecological functions that are very rare today throughout the San Francisco Estuary. Due to the history of development and land use change, Suisun Marsh has one of the very few remaining large

extents of natural estuarine-upland edge in the Estuary and much of it could be restored together with tidal restoration efforts.

Estuarine Transgression

Estuarine transgression is the lateral advancement of the marsh into the adjacent uplands. This mechanism occurred on a massive scale over the past several thousand years as Holocene sea level rise flooded inland to create the San Francisco Estuary. Modern estuarine transgression is highly constrained by hardened shorelines that protect developed areas (**Figure 11**).

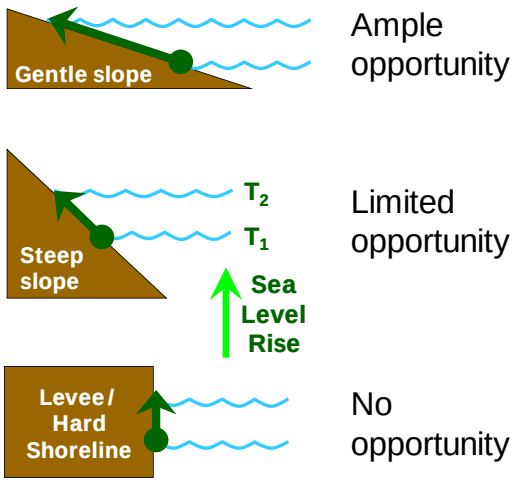
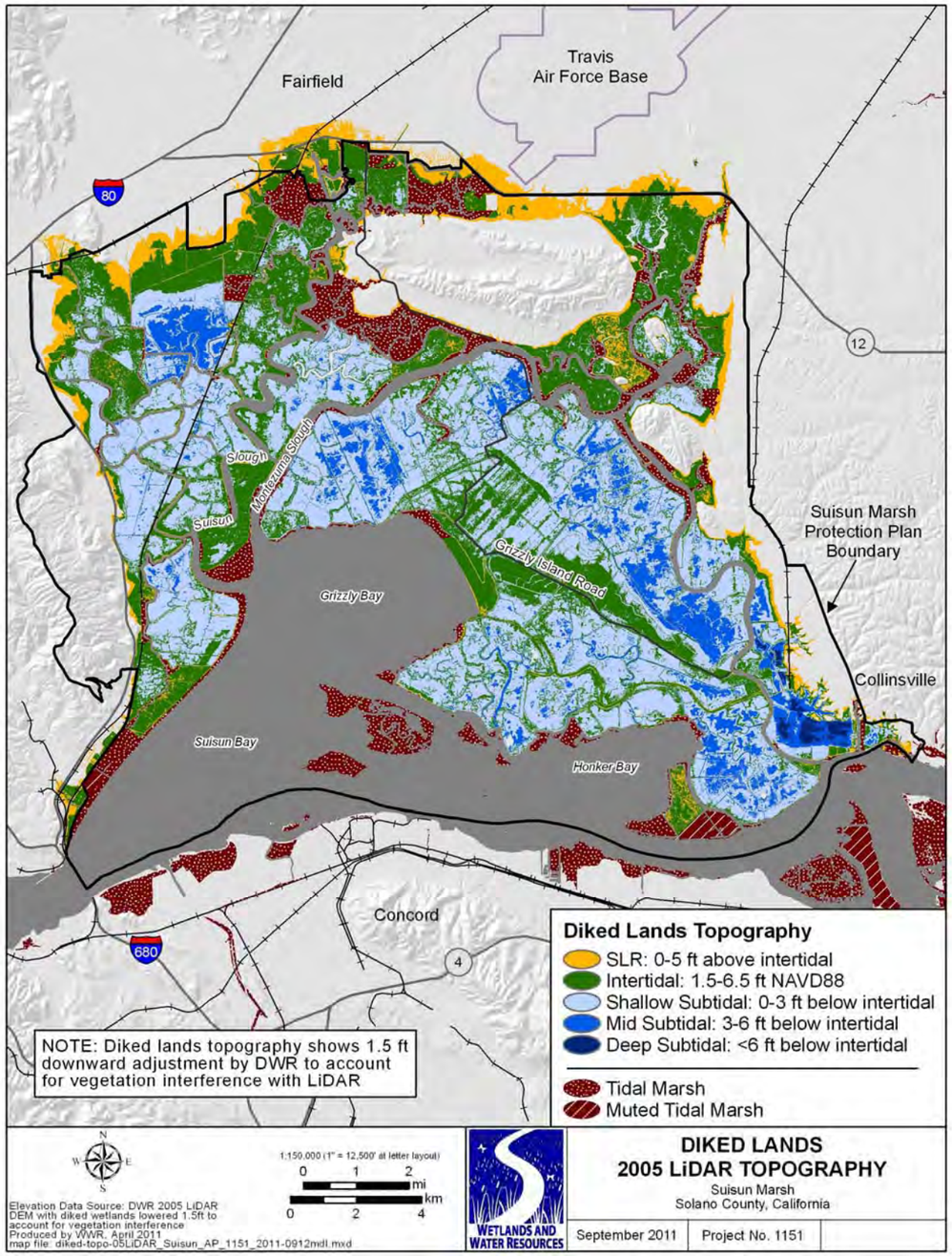


Figure 11. Conceptual Diagram of Potential for Continued Tidal Marsh Estuarine Transgression

Source: Wetlands and Water Resources

Sea Level Rise Accommodation Space – now and in 2100

Suisun exhibits mixed 'sea level rise accommodation space' opportunities; generally the northern Marsh has the broadest slopes whereas the east and west Marsh rise relatively comparatively steeply. Some regions of the Marsh abut hillsides that would allow marsh continuance but at a very small magnitude; the edges of Potrero Hills and the steeper small hills at Rush Ranch exemplify this setting. Some areas are very low-gradient offering significant opportunity; the Nurse-Denverton Slough area in the northeast, the Cordelia area in the northwest, and much of the northern boundary of Suisun, all south of Highway 12. Expansion north of Highway 12 around Denverton Slough may be possible depending on bridges and culverts under Highway 12 and road elevations.



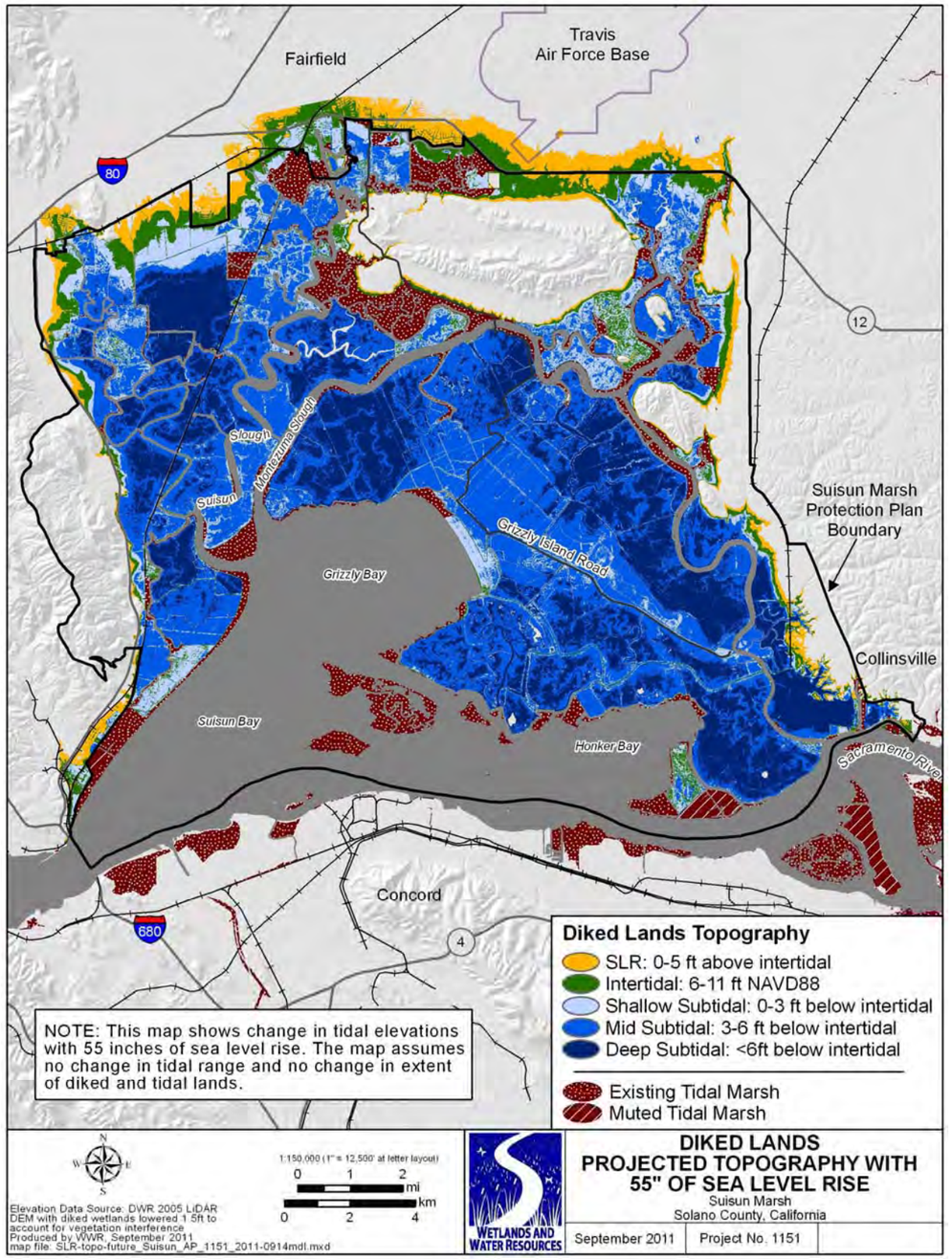


Figure 12. Sea Level Rise Accommodation Space in Suisun: Today and in 2100

6 Measures of Success

Determining whether ecosystem recovery efforts are "successful", especially at the landscape scale, is a long-standing challenge for every restoration effort. CALFED spent years working on performance measures. Delta Vision had great challenges in reaching a suite of meaningful and agreeable performance measures. Here we acknowledge that the hard work of the past reflects the complexity of the task and thus what follows below is stab at what yield effective information about the effectiveness of large-scale tidal restoration efforts in Suisun Marsh. The key element of the measures below is that they link directly to the five hypotheses in Chapter 3 that we defined explicitly to provide a foundation for taking restoration actions in Suisun.

Table 3 shows a sample of the sort of physical, chemical, biological, and morphological metrics that should be observed to assess restoration success. The first column is metrics that may take the form of a ratio, rate, flux, index, or abundance. Column two is a brief conceptual model and/or hypothesis about how the metric functions to improve native species health, community composition, or reduce stressors. Column three is the indicator of success which may include the method by which one would determine success. Assessment of restoration success requires comparison to nearby undisturbed reference sites, comparison of "treatments," comparison to the pre-project condition, or process modeling. The five remaining columns indicate the metric's linkage to the five hypotheses.

Table 3. Success Measures

Metrics of Ecosystem Function[1]	Conceptual Model/Hypothesis	Indicator of Success[2]	Relation to Key Restoration Hypotheses				
			Food Web	Habitats	Stressors	Scale	Resilience
1. PHYSICAL PROCESSES							
A. Landscape scale structure and connectivity							
Habitat matrix heterogeneity as patch quality, patch context, edge permeability, connectivity, scale.	Native species integrate a matrix of habitat choices in their life history. Provides competitive advantage.	Increase- compare refs or treatments	X	X	X	X	X
Dendritic channel complexity e.g. bifurcation ratio, edge/drain area ratio, sinuosity, channel density	Native species evolved life history strategies in response to natural structural diversity.	Increase- compare refs or treatments		X	X	X	X
disturbance frequency and intensity (e.g. extreme tide, storm, seismic events)	Irregular disturbances at various timescales reset the system state(e.g. storm surge w/ wind & wave attack on shorlines can step-change and complexify morphology). Native species are adapted.	Compare to reference	X	X	X	X	X
Sedimentation rate and elevation recovery	Subsided marshes will be net sinks for allocthanous mineral sediment depending on hydrodynamics, proximate transportable sediment, wind, fetch, initial vegetation structure and pattern and morphology.	Rate of elevation increase- compare treatments		X	X	X	X
B. Levee breach scale dynamics metrics							
Ratio of ebb and flood tidal energy	Tidal dynamics controls net sedimentation.	Flood dominance- use modeling		X	X		
Velocity gradient structure	May influence predator behavior	Minimize		X	X		
Scalar flux decompositions (data log for temperature, Chl a, pH, salinity; discrete samples for phyto/zoop species, toxics, OM)	Net and tidal material transports constitute primary wetland functions	Compare ref. treatments, or modeling	X		X		
C. Regional hydrodynamics and transport dynamics e.g.:							
Tidal range, flow, cross-section average current	Fundamental data and driver of several processes and functions. On subsided lands, controls aspects of habitat quality and competitive advantage for native species.	Increase native competitive advantage		X	X	X	X
Tidal energy dissipation/tidal datum	Exanding wetted area dissipates tidal energy and influences regional tide range and current energy	Minimize- Use modeling		X		X	
Residence time gradient	Gradient of water residence time influences PP and chemical variability	Increase- Use modeling	X	X	X		
D. Sea-level rise accomodation							
Upland transition ecotone complexity and potential fore sea-level rise accomodation	Marsh upland transition is the leading edge of estuarine transgression and key terrestrial landscape gradient.	Increase- Use modeling/GIS		X	X	X	X

Table 3. Success Measures

Metrics of Ecosystem Function[1]	Conceptual Model/Hypothesis	Indicator of Success[2]	Relation to Key Restoration Hypotheses				
			Food Web	Habitats	Stressors	Scale	Resilience
Ratio of marsh plain accretion rate to sea-level rise rate	Ratio determines trajectory of tidal marsh structure and function	Increase- compare treatments		X	X	X	X
2. VEGETATION							
Vegetation and bio-accretion for elevation recovery	Elevatio recovery is essential for long-term functional restoration	Rate of elevation increase		X	X		X
Area of emergent vegetation by species	System state information; emergent veg is an indicator of elevation, salinity, and habitat association	Compare ref. or treatments	X	X		X	
Area of SAV and FAV by species and season	System state information; native SAV/FAV provide invertebrate food and structural fish habitat.	Compare ref. or treatments	X	X			
Composition (ID, density, height, richness, aboveground biomass, stem density, proportion flowering)	Restored marshes are on trajectory of change toward native plant species, pattern, and richness	Compare reference or treatments	X	X			X
Low, intermediate and high intertidal associated plant community composition	System state information; plant community composition and pattern	Compare to reference	X	X			X
Patch quality, context, permeability, and connectivity	Native species integrate a matrix of habitat choices in their life history.	Compare ref. or treatments		X			X
3. FOOD WEB (in-situ)							
Primary productivity	Marshes are light and nutrient rich and produce ecosystem food web energy in excess.	Compare ref. or treatments	X	X			
Phytoplankton species	System state/census	Compare ref. or treatments	X	X			
Zooplankton and benthos species/density and habitat associations	System state/census; Primary consumers are produced in excess in tidal marshes and represent the primary trophic pathway to pelagic productivity	Compare reference or treatments	X	X			
Drift species and density	Aquatic insects are produced in excess in tidal marshes and can subsidize the near pelagic region.	Compare ref. or treatments	X			X	XX
Stable isotopes (C/N)	C/N ratios will show primary producers are acquiring energy for in-situ primary production.	Compare ref. or treatments	X	X			
4. PROCESSES							
Exchange between autotrophic and heterotrophic landscape elements (e.g. net or tidal channel-bay exchange)	Shallow water habitats are largely autotrophic and will produce an excess of carbon material that may provide energy subsidied to adjacent pelagic habitats. Regional system productivity is increased when different tidal marsh elements exchange material (e.g. DOM, POM, nutrients, detritus, organisms) at various time and space scales.	Increase	X	X		X	X

Table 3. Success Measures

Metrics of Ecosystem Function[1]	Conceptual Model/Hypothesis	Indicator of Success[2]	Relation to Key Restoration Hypotheses				
			Food Web	Habitats	Stressors	Scale	Resilience
Loading of MeHg	Wetting and drying cycles activate production of MeHg	Decrease			X		
Restoration area flux of temperature, turbidity, DO, pH, NH3, NH4, NO3, toxics (e.g. transport at levee breach)	Restored lands will be sources and sinks for scalar quantities. Marshs will be sources for PON and sinks for DIN.	Compare to reference or treatments	X	X			
Soil profiles for OM content, redox potential, Hg methylation, pore water sulfide, microbial community composition	Soil quality controls plant community composition and buffers channel water quality	Compare to reference or treatments	X	X	X		
Rate of burial of elemental mercury by accretion processes	Reconnected subsided marshes will be sinks for tide transported mineral sediment and loci of organic sediment production. Elevation gains bury elemental mercury and reduces MeHg production and cycling.	Increase			X		
5. FISH							
A. Fish community							
Fish abundance by species	System state/census	Compare to ref	X				
Fish diet	System state/census	Compare to ref	X				
Seasonal percent alien	System state/census	Compare to ref	X		X		
Sub-habitat associations of larvae, juveniles, and adult fish by species, life-stage, and abiotic conditions (e.g. fish may be found in tidal creek outlets, undercut banks, or open shallow water depending on light, wind, flow, turbidity, food availability etc.).	Native fishes integrate a mosaic of marsh structural habitats for food, refuge, and physiological adaptation according to life-stage and abiotic conditions	Compare to reference or treatments	X	X	X	X	X
B. Landscape scale indices							
"Structural habitat heterogeneity index": For ex., within a tidal excursion, score the availability of structural habitat attributes (e.g., patch diversity: under cut banks, channel bifurcations ("hot spots"), slump blocks, mudflats, shoals, eddies, vegetation)	Native species integrate a matrix of structural habitat choices in their life history. They navigate diverse habitats margially "better" than non-natives.	Compare to reference, treatments, or pre-project condition		X		X	X
"Connectivity richness index" e.g., the relative ease that material/energy can move between different patch types (e.g. native morphometric relationships like channel density, and hydrodynamics like velocity gradient.	Native species use currents and behavior to find chemical habitat, then to find structural habitat for access to food and cover. So, *What is the quality of access to structure via currents?* …	Compare to reference, treatments, or pre-project condition		X		X	X
Residence time heterogeneity index	RT diversity generates interplay of production and transport while limiting opportunities for non-native dominance.	Compare ref. or treatments	X	X	X	X	X

Table 3. Success Measures

Metrics of Ecosystem Function[1]	Conceptual Model/Hypothesis	Indicator of Success[2]	Relation to Key Restoration Hypotheses				
			Food Web	Habitats	Stressors	Scale	Resilience
Capacity-Access index	production = capacity x access (fish production depends on habitat capacity to produce food and access to the food)	Compare ref., treatments, pre-project condition	X	X		X	

Notes:

1. These metrics are generalized and high level. Most require a particular set of what could be called "indicators" that role up into a metric. For example, a metric could be a ratio of channel edge to marsh plain area.

2. Assessment of restoration progress toward species conservation or abiotic process rehabilitation is aided by comparisons to a standard. One or more comparison options is available depending on the metric. Nearby undisturbed "reference" wetlands are most useful but not always available. "Treatments" allow comparison between experimental alternative like size of levee breach. "Pre-project" comparison requires full characterization of landscape structure and function prior to restoration. Finally, modeling is useful for extrapolating hydrodynamic and transport changes to their full range of propagation.

7 Comparison to Other Regional Plans

The final analysis of this Strategic Plan is a short discussion of how it compares to several regional plans that address tidal restoration in Suisun Marsh. Specifically, this analysis will examine the priority restoration subregions (Chapter 5) relative to recommendations of these other plans.

These plans are:

1) U.S. Fish and Wildlife Service Tidal Marsh Recovery Plan (Draft, 2010)
2) Ecosystem Restoration Program Stage 2 Conservation Strategy (Final, 2010)
3) Suisun Marsh Plan (Draft, 2010)
4) Delta Vision Strategic Plan (Final, 2008)
5) Baylands Habitat Goals Project (Final, 1999)

USFWS Draft Tidal Marsh Recovery Plan

This Strategic Plan is very consistent with the USFWS Draft Tidal Marsh Recovery Plan (USFWS 2010). That Plan identifies the same three geographic regions as highest priority for restoration (see written descriptions on page 204 and Figures III-7 and III-8 on pages 251 and 252 of USFWS 2010).

There are two differences in restoration priorities between this Strategic Plan and the USFWS Plan. First is that USFWS identifies lands between Suisun Slough and the railroad as high priority. Here we have not included these lands as high priority because of the possibility of costly erosion protection requirements for the railroad and we acknowledged that if UPRR does not require such protection then these lands would be fairly well suited for restoration. Second is that USFWS identifies some lands west of the railroad that have a natural upland edge as a secondary priority. Here, we recognize the value of this upland edge but determined that the problems of restoration west of the railroad will be difficult to overcome. In addition, the lands identified by USFWS are the most subsided of all the lands west of the railroad, suggesting they would remain as shallow open water for a long time; due to limited tidal exchange those lands would also run the risk of generating water quality problems with harmful algal blooms and the like.

ERP Stage 2 Conservation Strategy

The most recent version of the ERP Stage 2 Conservation Strategy (DFG et al. 2010) removed discussion of specific restoration actions in Suisun Marsh and instead deferred to the Suisun Marsh Habitat Management, Preservation, and Restoration Plan that is currently under revision from its October 2010 draft (see below).

Suisun Marsh Plan

The Suisun Marsh Charter Agencies (USFWS, USBR, NMFS, DFG, DWR, CALFED, and SRCD) released the Draft Suisun Marsh Habitat Management, Preservation, and Restoration Plan in October 2010 (USBR et al. 2010). It calls for restoration of 5,000 to 7,000 acres of tidal marsh over its 30-year period. It segregates Suisun Marsh into four geographic regions (**Figure 13**) and assigns ranges of restoration extent to each of the four regions based on "different habitat conditions within each region to provide the range of environmental gradients necessary to contribute to the recovery of listed species" (see **Table 3**).

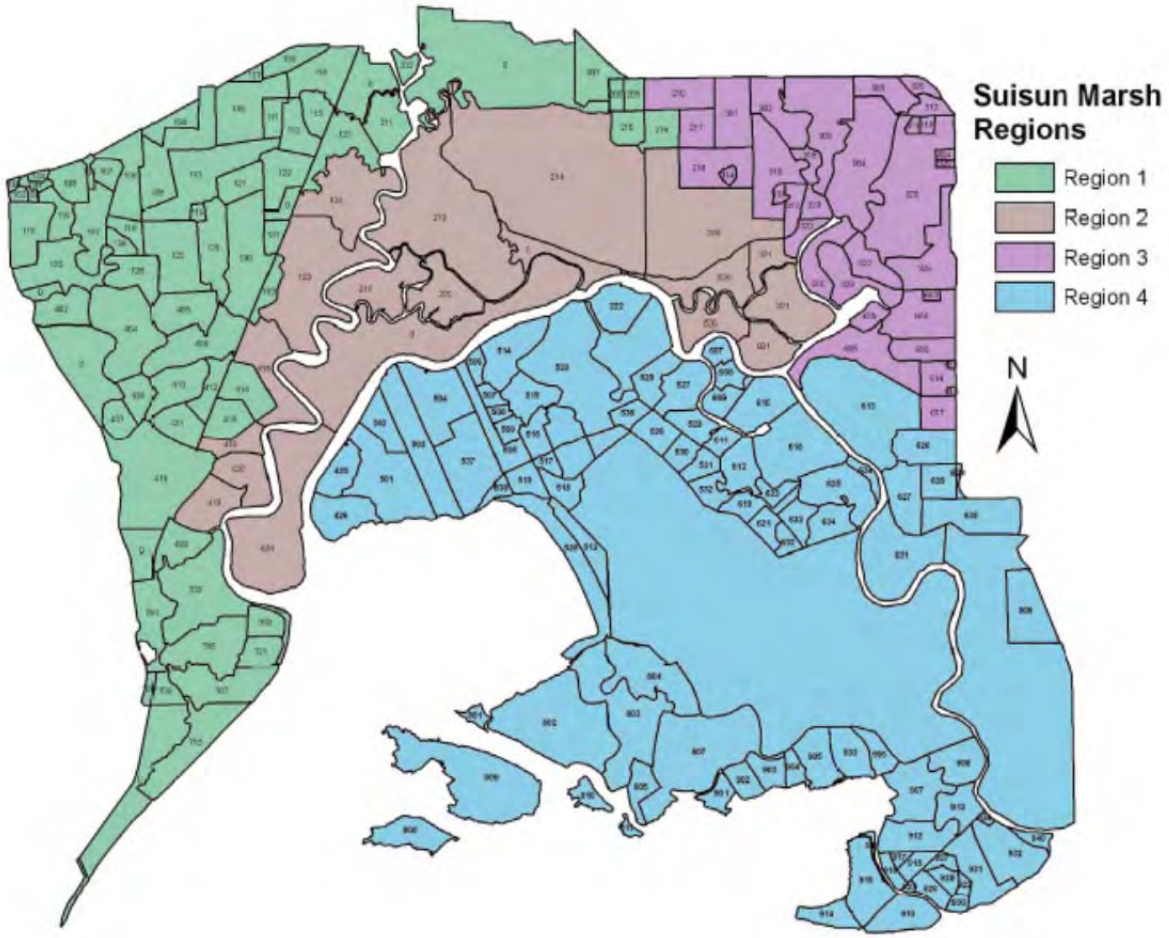


Figure 13. Suisun Regions in the Suisun Marsh Plan
Source: USBR et al. 2010, Figure ES-2

Table 4. Tidal Marsh Restoration Target Acreages by Region in the Suisun Marsh Plan

Region	Acreage Targets for Tidal Restoration
Region 1	1,000-1,500
Region 2	920-1,380
Region 3	360-540
Region 4	1,720-2,580

Source: USBR et al. 2010, Table ES-3

The Suisun Marsh Plan does not make more detailed geographic recommendations for tidal restoration beyond what is shown in **Figure 13** and **Table 3**. The recommendations of this Strategic Plan can be aligned entirely with these more general SMP recommendations. The key consideration is the SMP acreage target for its Region 1 (1,000-1,500 acres), which consists of lands west of the railroad plus Morrow Island. Restoration would have to take place entirely within Morrow Island lands (which total about 3,200 acres), as we have concluded in this Plan that restoration west of the railroad will be very challenging to carry out and achieve desired ecological outcomes.

Delta Vision Strategic Plan

The Delta Vision Strategic Plan included the following recommendations for Suisun tidal restoration (see Action 3.1.2 in Delta Vision 2008): (1) restore 12,500 acres by 2020, (2) restore another 12,500 acres by 2040, and (3) add more acreage as lands become available, if adaptive management monitoring indicates prior restoration and other activities have not yet accomplished ecosystem goals.

This Strategic Plan is inherently consistent with these general recommendations of Delta Vision. Here we have not specified specific acreage targets The strategic vision in this Strategic Plan is centered around ecological outcomes; the science does not exist to establish a quantitative linkage between acres restored and resulting ecological outcomes and, as discussed throughout this Strategic Plan, achieving desired outcomes involves more complexity than simple acreage targets.

Bayland Habitat Goals Project

The Baylands Habitat Goals Project (Monroe et al. 1999) recommended tidal restoration of between 17,000 and 22,000 acres in Suisun Marsh. It provides the following narrative recommendation for the geographic distribution of this restoration:

In Suisun Marsh, there should be a continuous band of restored tidal marsh from the confluence of Montezuma Slough and the Sacramento/San Joaquin rivers to the Marsh's western edge. This band of tidal marsh should extend in an arc around the northern edge of the Marsh and should blend naturally with the adjacent grasslands to provide maximum diversity of the upland ecotone, especially for plant communities. A broad band of tidal marsh also should be restored along the southern edge of Suisun Marsh and around Honker Bay, in large part to improve fish habitat.

Recommendations:

- *Restore tidal marsh at sites adjacent to Honker Bay, along the eastern side of Montezuma Slough, in the Nurse Slough area, and near Denverton Creek.*
- *Provide a tidal marsh corridor along the base of Potrero Hills between Nurse Slough and the marshes to the west.*
- *Provide natural transitions to adjacent uplands (with protective buffers wherever possible) for all existing and restored tidal marshes.*
- *Protect and enhance existing vernal pools and other seasonal wetlands adjacent to Montezuma Slough, in the Nurse Slough area, and north of Potrero Hills.*
- *Enhance managed marshes in the Grizzly Island area to improve and diversify managed wetlands.*
- *Restore large areas of tidal marsh in the Hill Slough and upper Suisun Slough areas, and on Morrow Island south of the confluence of Goodyear Slough and Suisun Slough.*
- *Connect these large areas of restored tidal marsh with a tidal marsh corridor. The location of this corridor is highly flexible, but establishing it along Cordelia Slough probably would facilitate water management on duck clubs in the area.*
- *Provide natural transitions to adjacent uplands, with protective buffers wherever possible.*
- *Enhance managed marsh areas that are not restored to tidal marsh to improve waterfowl habitat.*

These recommendations align well with this Strategic Plan. The primary point of divergence is with the Goals Report recommendation of a tidal marsh corridor along Cordelia Slough, which is predominantly west of the railroad which has a range of complications diminishing its restoration suitability.

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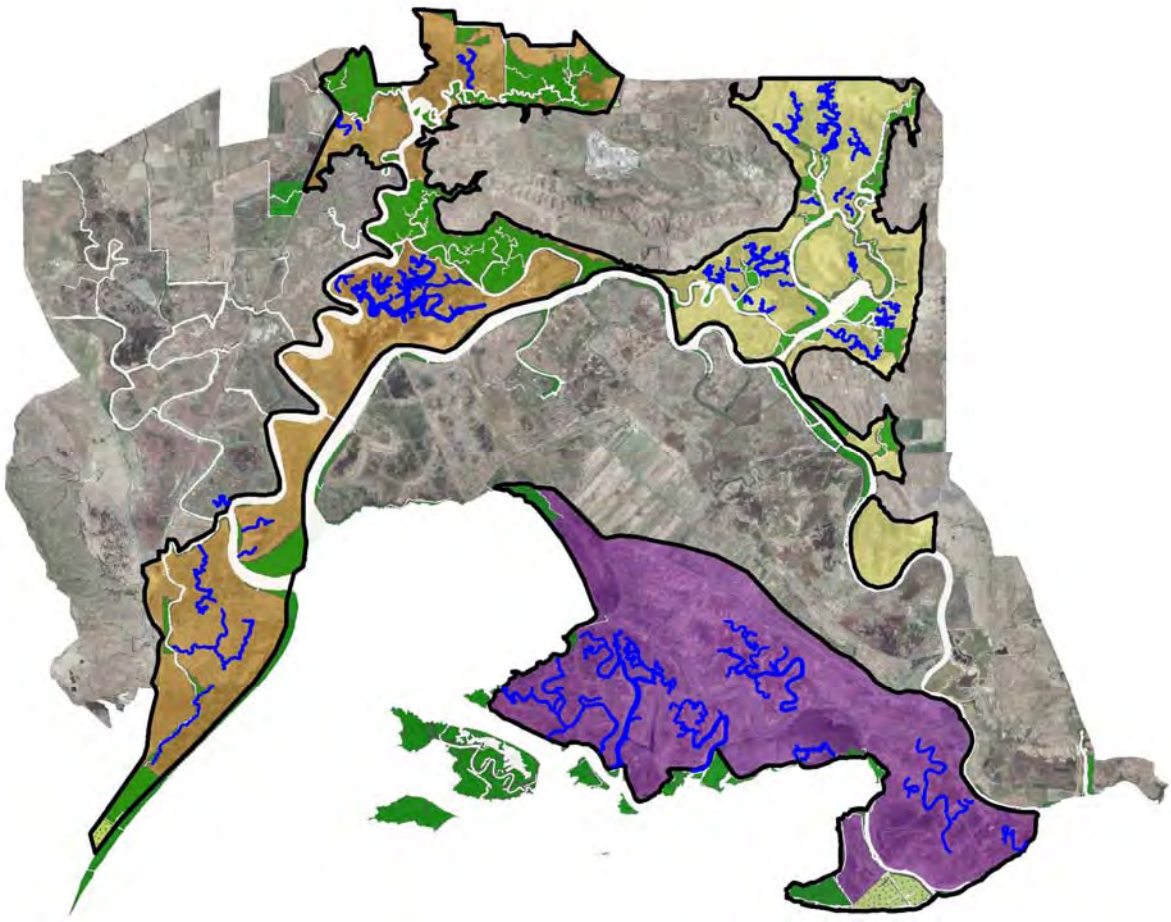
Suisun Marsh Conservation Assessment
Volume III: Conservation Strategy

September 2011



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WETLANDS AND WATER RESOURCES

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The Nature Conservancy, Delta Program

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Suisun Marsh Conservation Assessment
Volume III: Conservation Strategy

September 2011

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Project No. 1151

Suisun Marsh Conservation Assessment
Volume III: Conservation Strategy

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APPENDIX B. FEASIBILITY RANKINGS DATABASE

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Suisun Marsh Conservation Assessment
Volume III: Conservation Strategy

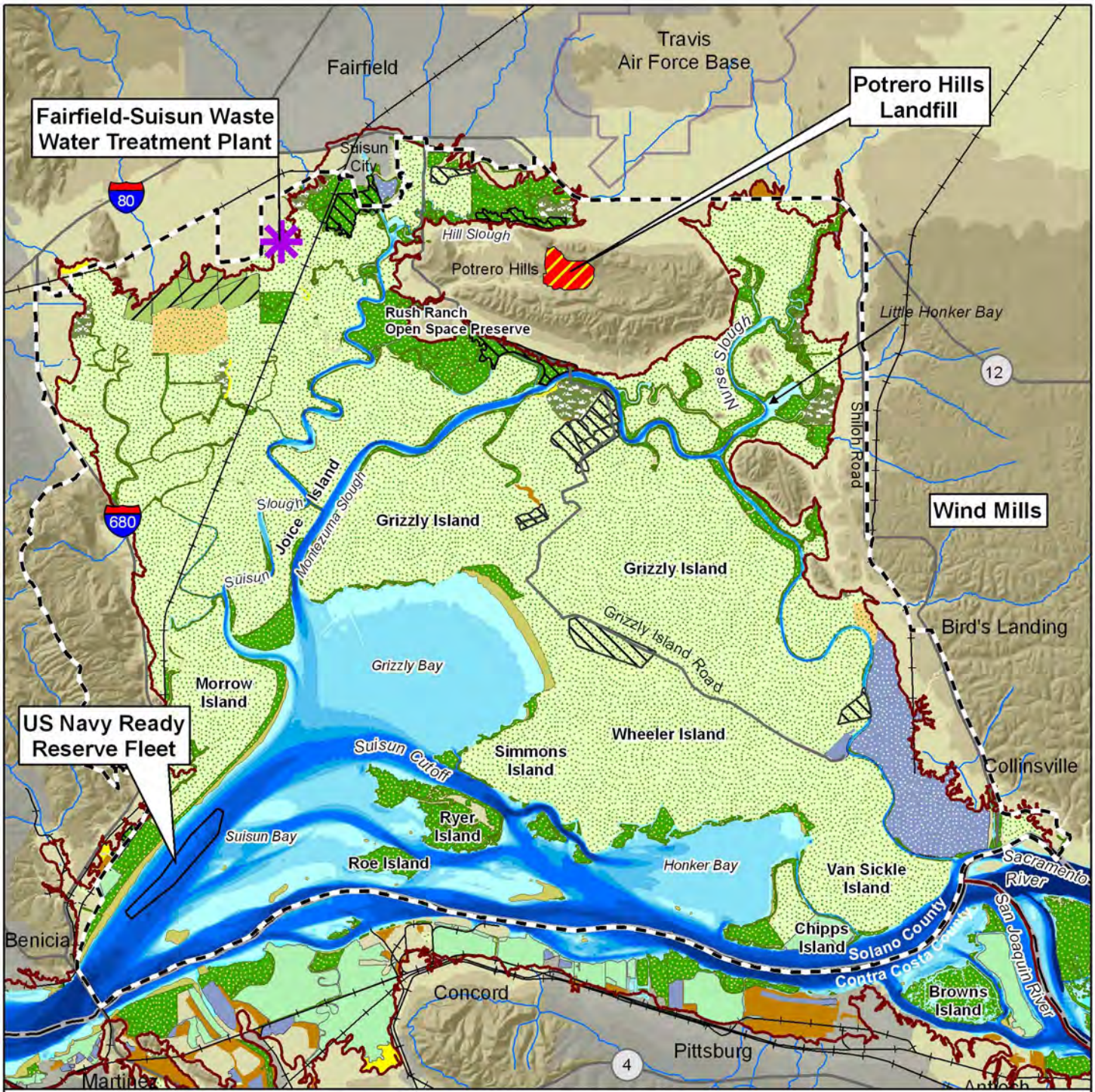
1 Introduction

This **Volume III, Conservation Strategy**, is the third and final volume of the **Suisun Marsh Conservation Assessment**. This Volume III performs two tasks. First, it lays out the details of what properties in Suisun Marsh to focus on for restoration through conducting a feasibility assessment of individual properties and of multi-property clusters against 13 feasibility criteria. Second, it describes strategies for working with landowners to bring target properties into restoration projects. ***Volume I, Characterization Report*** (WWR 2011a) provides an in-depth examination of the physical and biological setting of Suisun Marsh, viability and threat assessments for the biological resource of Suisun, other ecosystem functions, and future drivers of change. ***Volume II, Strategic Plan*** (WWR 2011b), describes the strategic vision for Suisun Marsh restoration, presents restoration hypotheses and associated response strategies, key principles guiding restoration, a review of the restoration capacity of Suisun Marsh, and a conclusion with the priority restoration regions for Suisun Marsh.

This Conservation Strategy includes the following chapters:

- **Chapter 1, Introduction**
- **Chapter 2, Summary of Volume II Strategic Plan**
- **Chapter 3, Priority Subregions for Suisun Restoration** – where in Suisun landscape-scale tidal restoration should be focused
- **Chapter 4, Properties and Restoration Clusters** – a brief description of the properties considered in the feasibility analyses including the identification of restoration clusters consisting of multiple contiguous properties
- **Chapter 5, Feasibility Assessment by Each Restoration Criterion** – examination of each property and restoration cluster in context of performance against 15 feasibility criteria
- **Chapter 6, Putting the Puzzle Together: Integrated Restoration Feasibility** – synthesizes findings of each of the 15 feasibility criteria into an overall restoration feasibility assessment by property considering it individually and as part of restoration clusters
- **Chapter 7, Conservation Strategy** – a suite of actions that collectively constitute a game plan for advancing restoration efforts in Suisun.

As with **Volume II, Strategic Plan**, this document should be considered as version one to be refined through a small implementation-oriented group.



Diked Baylands

- Managed Marsh
- Diked Marsh
- Farmed Bayland
- Grazed Bayland
- Ruderal
- Pheasant Club
- Dredged Material Basin
- Other

Tidal Baylands

- Tidal Marsh
- Muted Tidal Marsh
- Mudflat

Salt Marsh Harvest Mouse Conservation Areas

- DFG Diked Lands
- DFG Tidal Lands

Reference Features

- Historic Baylands Margin
- Suisun Marsh Protection Plan Boundary
- Urban Area

Bathymetry (ft NAVD 88)

Shallow		Deep
1		-20
-20		-140

N W E S

1:150,000 (1" = 12,500' at letter layout)

0 1 2 mi

0 2 4 km

Data sources: USGS (2004), TIGER (2000), GAP (1998), Eco Atlas (1998 with updates by WWR: 2009, 2011), CDFG (2006-2007)
Produced by WWR, September 2011
map file: land-use_Suisun_AP_1151_2011-0912mdl.mxd

WETLANDS AND WATER RESOURCES

SUISUN LAND USES

Suisun Marsh
Solano County, California

September 2011 | Project No. 1151 | **Figure 1**

2 Summary of Volume II Strategic Plan

This chapter provides a very brief summary of Volume II Strategic Plan in order to allow the reader of this Volume III to possess the key concepts and principles of that Strategic Plan as context for the restoration feasibility elements and consequent Conservation Strategy.

2.1 Strategic Vision

A fundamental hypothesis, put forward as the Strategic Vision for Suisun Marsh restoration, is that ***conservation of native species is best promoted by restoration of physical landscape components, flows, connections, and processes at scales that allow for full expression of native species life history strategies***.

The primary method to achieve this strategic vision is deceptively simple: re-establish connectivity between open water bays and sloughs and former tidal marshlands. That simplicity flows from a few key strategies:

- Conserve and restore estuarine natural communities
- Conserve and restore estuarine ecosystem processes and functions
- Maximize the potential for resiliency in face of future changes

2.2 Restoration Hypotheses and Associated Response Strategies

Food Web

Hypothesis 1, Food Web: Low estuarine food web productivity and altered food web composition is an important limiting factor in aquatic species abundance in Suisun Marsh and the Delta. Restoration of tidal marsh and connectivity with tidal aquatic habitats can contribute positively toward improving food web productivity and composition.

Strategy 1: Increase the abundance, diversity, and availability of food for aquatic organisms generated within the Suisun Marsh-Suisun Bay complex by restoring lands to tidal action and restoring connectivity between tidal marsh and tidal sloughs and bays.

Habitats

Hypothesis 2, Habitats: The reduction in spatial extent and habitat quality of tidal marshes and tidally influenced marsh-edge communities plays an important role in limiting population abundances, compared to natural conditions, of many species of fish, small mammals, birds, plants, reptiles, and amphibians that utilize Suisun habitats.

Strategy 2: Increase amount, geographic distribution, connectivity, and diversity of tidal marshlands and tidally influenced marsh-upland edge communities and improve the functioning of their regulating processes.

Stressors

Hypothesis 3, Stressors: Three primary types of strategies exist to reduce or eliminate the effects of the many stressors affecting Suisun that impair ecosystem functions and open water, tidal marsh, and marsh-upland edge communities: tidal marsh restoration, modified management of diked managed wetlands in and other factors internal to Suisun Marsh, and modified management of external processes and conditions that influence Suisun. These stressors are often interactive and in some cases have cumulative impacts upon native species and communities. Some stressors may not be possible to reduce or eliminate.

Strategy 3: Remedy stressors where possible to increase ecosystem function and native species richness and abundance, using one or more of the three approaches stated above. Recognize that some stressors may not be amenable to resolution regardless of approach.

Scale

Hypothesis 4, Scale: Conservation of native species and natural communities is promoted by restoration of physical landscape components, connections, and processes at scales that allow for full expression of native species life history strategies.

Strategy 4: Use principles of landscape ecology to assure connectivity, energy flows, and migration pathways between tidal marsh components by restoring lands in sufficiently large, connected blocks to yield the scales necessary to support target ecosystem functions.

Resiliency to Future Threats

Hypothesis 5, Future Threats: Resiliency to expected future challenges like climate change and sea level rise is promoted through tidally restoring lands in large, contiguous areas across gradients of baseline elevations, salinity regimes, sediment supply, tidal mixing, and upland edges.

Strategy 5: Distribute large clusters of restored lands actions across the geographic and chemical gradients present in Suisun Marsh including incorporation of lands with broad upland transitions.

2.3 Key Principles Guiding Strategic Plan

Underlying the Strategic Plan is a set of key principles that inform how subregions are identified for restoration and how site selection criteria are derived.

1) **Restoration of native species, communities, and process will take time.** We recognize that there exists a necessary investment in time that will eventually yield self-sustaining landscape processes and attributes that give native species competitive advantage. It took time to mess it up; it will take time for nature to fix it.

2) **Work with nature, let nature do the work.** Key landscape features that guide restoration planning include: topography and elevation, bathymetry, geomorphology, human infrastructure, waterways, land uses, potential for connectivity, and geography at scales from restoration site to subregion to estuary. These features inform ease (and cost) of restoration, ecologically relevant scale, the potential to achieve target outcomes, the opportunity to use natural processes to minimize risk of problems such as invasive species, and resiliency to future change such as sea level rise. By letting nature do the work encourages natural self-repair processes and minimizes inputs of materials and expense.

3) **Be guided by principles of the historical landscape ecology.** We should be guided by our best understanding of historical landscape ecology. Despite its degraded condition, the Bay-Delta landscape contains clues about its former morphology, connectivity, and functioning. We can leverage remnant features at appropriate scales to improve the landscape's own self-repair capability. Native species are more likely to gain competitive advantages from the results.

4) **Natural ecosystems seldom conform with political boundaries or land ownership patterns.** Ecosystem restoration for conservation of native species requires consideration of whole-landscape attributes and connectivity at natural spatial and temporal scales, regardless of political or ownership boundaries. Properly scaled and located restoration actions would leverage historical landscape features, minimize the need for costly flood control levees, and create persistent overlaps within and between aquatic, wetland, and terrestrial physical/chemical attributes and landscape morphologies that provide access, forage, cover, and physiological adaptation opportunities during all life-history phases.

5) **Levees are anathema to ecological functions.** Levees simplify the land-water interface. They create mismatches of tidal energy with the dissipation capacity of restoration sites. They are abrupt topographic ecotones that may aid non-native predator foraging. They are vectors for invasive plants. And they are financial and human resource sinks because they require expensive upgrade and maintenance that further requires difficult environmental permitting. Almost all property boundaries in Suisun Marsh have levees that would require upgrading if restorations were implemented on a property line basis. Minimizing levee involvement in restoration efforts therefore is of very high importance. Restoration without a landscape perspective and instead focusing on individual properties will have a far lower likelihood of avoiding this levee issue.

6) **Learning is central; conceptual models drive approaches.** Though we possess a remarkable knowledge-base across many facets important to advance ecosystem

recovery in the San Francisco Estuary, there is much yet to learn to assure conservation success. Consequently, restoration efforts must be guided by strong science (via conceptual models) and they must incorporate 'experiments' to foster learning geared specifically at addressing uncertainties and knowledge gaps.

7) **Outcomes of our best efforts are difficult to predict.** Natural ecological systems constantly change. Predicting or guiding the course of change is extraordinarily difficult if not impossible because the ecological outcomes are "emergent" phenomena. The functional outcomes we will attempt to influence with landscape restoration and more natural flow regimes are subject to thresholds or "tipping points", non-linear interactions, feedbacks, and human decisions. Therefore, trajectories of change will usually not follow our predictions.

2.4 Restoration Capacity of Suisun Marsh

The capacity of Suisun Marsh to support tidal restoration from a physical, chemical, and biological perspective is controlled by a suite of landscape-level processes influencing tidal marsh and tidal aquatic (open water) restoration in Suisun. The Strategic Plan presents these processes in the form of a landscape-level conceptual model the key elements of which are summarized here.

The four major landscape-scale processes and characteristics that influence what takes place once lands are restored to tidal action and thus resulting ecological functions are: (1) hydrology and hydrodynamics, (2) sediment supply, (3) initial elevations, and (4) upland transitions.

Hydrology and Hydrodynamics

The spatial scales of hydrodynamic and transport complexity in Suisun marsh are illustrated in **Figure 2**. Suisun Marsh exhibits strong salinity gradients in both the east-to-west and north-to-south directions by different mechanisms. The larger channels crossing Suisun Marsh are unique features both because of their size and because their lengths are longer than the excursion of the tide. Therefore, while channels are tidally energetic, they significantly contain the full tidal excursion or tidal "slosh" within their length. Another feature of tidal channels in Suisun Marsh is that several of them form "loops" either naturally or because of historical channel cutting. Propagating tidal waves enter each of these loops from both ends with variable timing and come together in "convergence zones." Suisun Marsh is connected at three primary locations to Suisun Bay. To the extent that Suisun Marsh is a net producer of energy to the Suisun Bay food web, the key water mass exchanges are made here. The details of these exchanges are not well understood at this time.

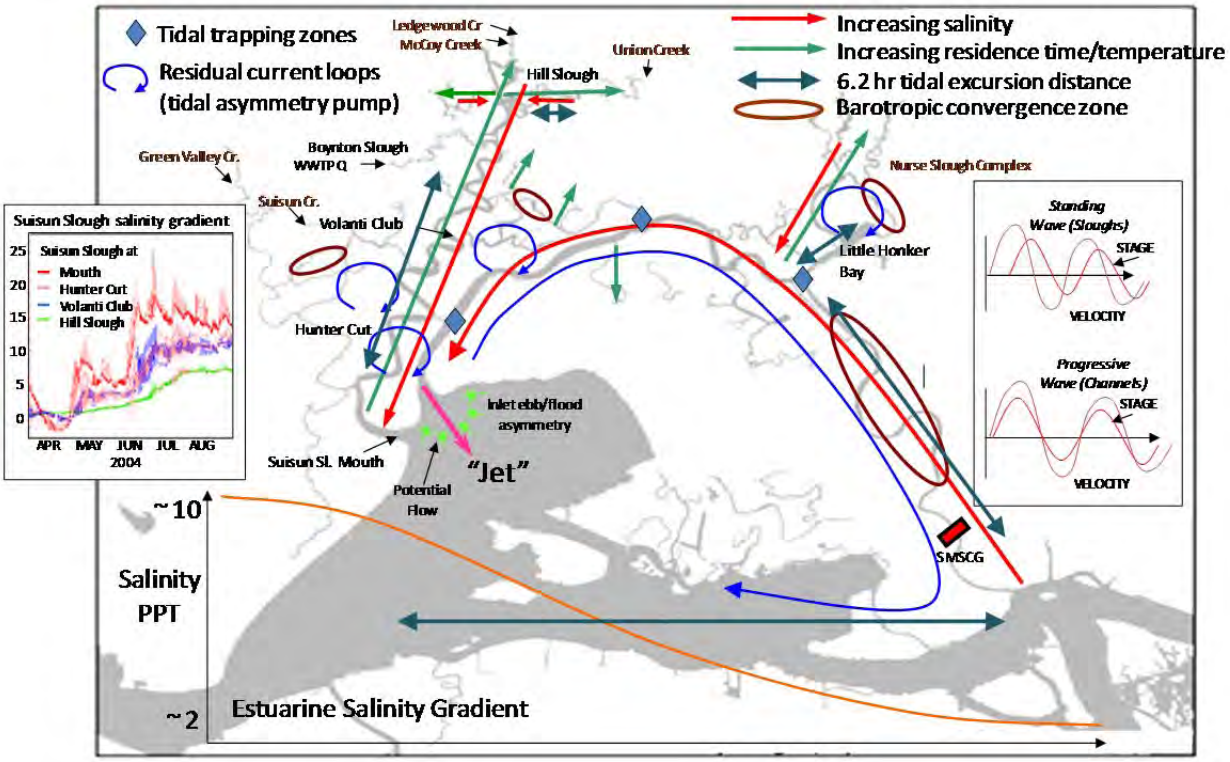


Figure 2. Conceptual model of hydrodynamic complexity due to landscape connectivity among various parts of Suisun Marsh

This model highlights the spatial variability in salinity, residence time, and the locations of barotropic convergence zones, residual current loops, and tidal trapping zones. Also shown are the locations of inflowing creeks and the ebb/flood asymmetry of flow at the western end of Montezuma Slough. SMSCG is the Suisun Marsh Salinity Control Gate. Source: Chris Enright, DWR

Sediment Supply

Understanding the availability of sediment for rebuilding subsided landscapes is an important element for restoration planning. Regional-scale processes control available sediment supply and grain size characteristics; restoration planning can at most control for this variable through site selection and certain design configurations. **Figure 3** illustrates the very broad pattern of sediment supply and key controlling factors in Suisun. The generalized suspended sediment gradient is lower in the north at the margins of Suisun and higher in the south in Suisun Bay. Little Honker Bay in the northeast locally has high SSC levels from wind and tidal resuspension from the shallow bay floor. Tidal transport from the large shallow bays in the south and some within-slough resuspension can make locally higher SSC concentrations in many sloughs. The main Suisun Bay channel SSC levels are driven by Delta inputs, some tidal inputs from San Pablo Bay, and resuspension from the shallows of Grizzly, Honker and Suisun bays.

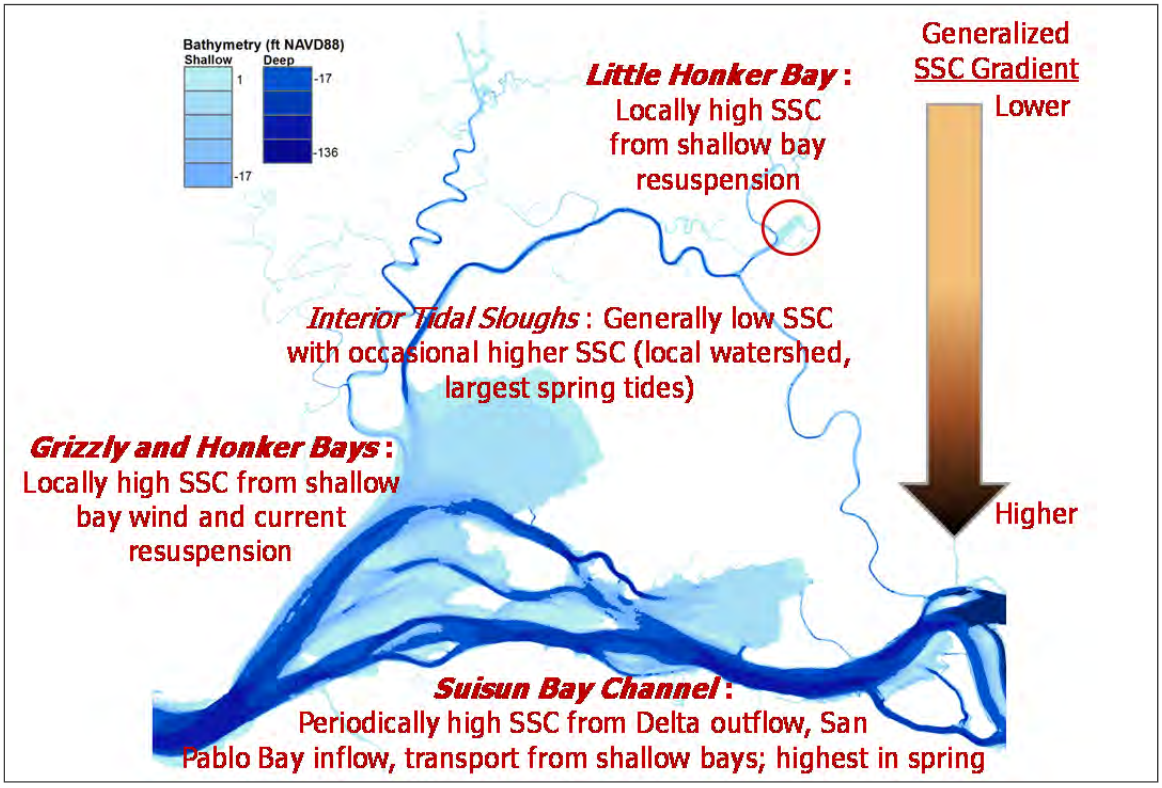


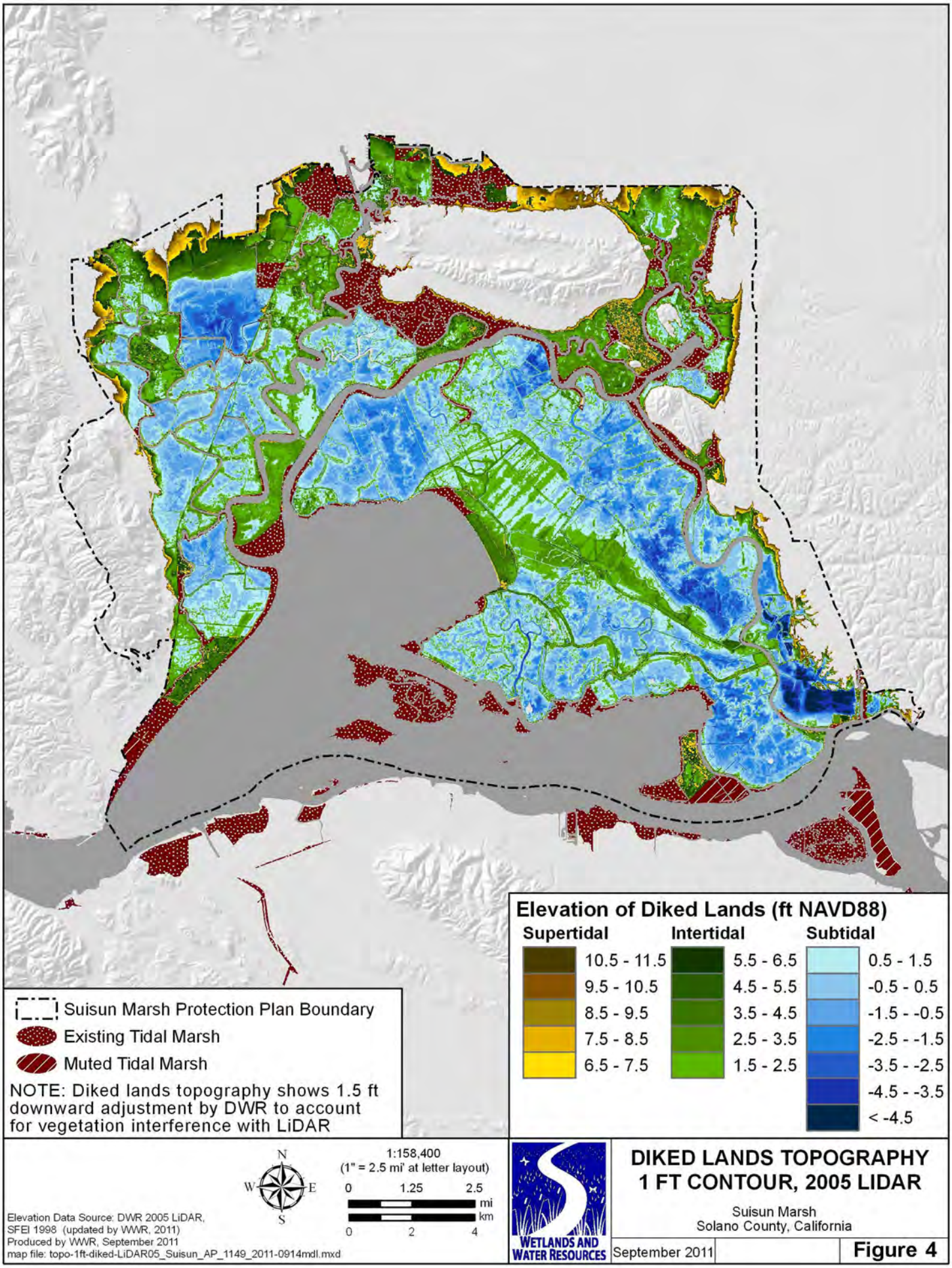
Figure 3. Suspended Sediment Gradients
Source: Developed in collaboration with Schoellhamer, pers. comm.

Recent work by the USGS (Schoellhamer 2011) hypothesizes that the San Francisco Estuary cross a threshold in 1999 wherein the erodible sediment pool on the estuary's bottom is depleted. These pools are resupplied by watershed contributions, both local and from Delta outflow. The decline in those sources along with prior resuspension, transport, and deposition

in areas that do not readily erode (e.g., tidal marsh restoration sites) translates into the crossing of this threshold. The ramification of this recent hypothesis is that the estuary will have reduced suspended sediment concentrations, which translates into lower rates of marsh accretion and increased potential for wind-wave resuspension to keep restoration sites from accreting at all or accreting far more slowly.

Subsidence and Baseline Topography

Diked former tidelands are the opportunity for tidal restoration in Suisun Marsh (**Figure 4**). The resulting ecosystems from tidal restoration will reflect those baseline subsided elevations, pre-restoration subsidence reversal efforts if any (sediment placement and carbon sequestration/ managing for emergent wetland vegetation), and sediment accretion and emergent wetland vegetation biomass after restoration. The varied subsidence in Suisun offers the opportunity to create a matrix of restoration areas with varied initial conditions and thus varied ecological functions. When combined with spatially variable physical processes controlling the rates of marsh restoration evolution, the result would be a geographically diverse suite of associated ecological functions that evolves over time that would be expected to support a wide range of target species and natural communities and provide greater resiliency for those targets.


Elevation of Diked Lands (ft NAVD88)
Supertidal
10.5 - 11.5
9.5 - 10.5
8.5 - 9.5
7.5 - 8.5
6.5 - 7.5
Intertidal
5.5 - 6.5
4.5 - 5.5
3.5 - 4.5
2.5 - 3.5
1.5 - 2.5
Subtidal
0.5 - 1.5
-0.5 - 0.5
-1.5 - -0.5
-2.5 - -1.5
-3.5 - -2.5
-4.5 - -3.5
< -4.5
Suisun Marsh Protection Plan Boundary
Existing Tidal Marsh
Muted Tidal Marsh
NOTE: Diked lands topography shows 1.5 ft downward adjustment by DWR to account for vegetation interference with LiDAR
N
W
E
S
1:158,400
(1" = 2.5 mi' at letter layout)
0 1.25 2.5
mi
km
0 2 4
Elevation Data Source: DWR 2005 LiDAR, SFEI 1998 (updated by WWR, 2011)
Produced by WWR, September 2011
map file: topo-1ft-diked-LiDAR05_Suisun_AP_1149_2011-0914mdl.mxd
WETLANDS AND WATER RESOURCES
DIKED LANDS TOPOGRAPHY
1 FT CONTOUR, 2005 LIDAR
Suisun Marsh
Solano County, California
September 2011
Figure 4

Salinity-Moderated Vegetation Community Composition

Emergent vegetation plays an important role in controlling site evolution through its contribution to promoting sediment accretion and through its biomass accumulation. The relationship between site elevation and new vegetation growth is tied directly to the strong salinity gradients of Suisun Marsh, with saline-tolerant species being more sensitive to prolonged inundation and freshwater species having greater inundation tolerance (**Figure 5**).

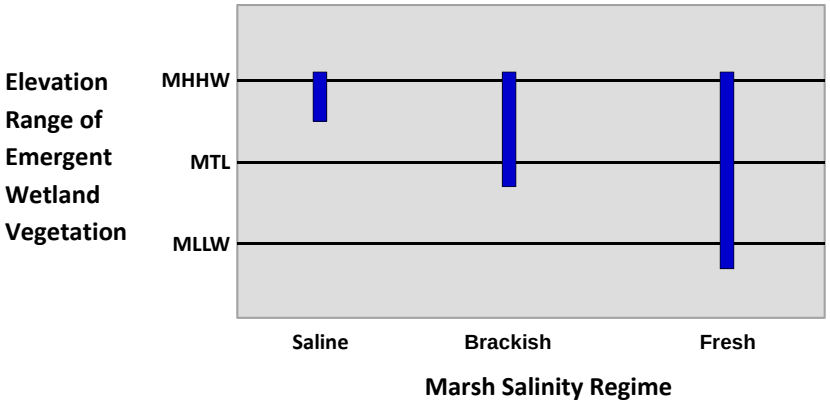


Figure 5. Tidal Marsh Vegetation Vertical Range with Salinity
Source: Wetlands and Water Resources. Ranges are approximations.

Sea Level Rise Resiliency and the Upland Transition

Tidal marshes can respond geomorphically to sea level rise in one or more of three possible paths: estuarine transgression (move laterally into the adjacent uplands), marsh vertical building (keep up with sea level rise), or marsh drowning (lose the battle and convert to open water). Which path(s) a given natural or restored tidal marsh follows in Suisun is about its location relative to upland edge (transgression accommodation), salinity regime (plant community productivity), and sediment supply (accretion). The marsh-upland transition zone supports unique vegetation communities and associated ecological functions that are very rare today throughout the San Francisco Estuary. Estuarine transgression is the lateral advancement of the marsh into the adjacent uplands. This mechanism occurred on a massive scale over the past several thousand years as Holocene sea level rise flooded inland to create the San Francisco Estuary. Modern estuarine transgression is highly constrained by hardened shorelines that protect developed areas (**Figure 6**).

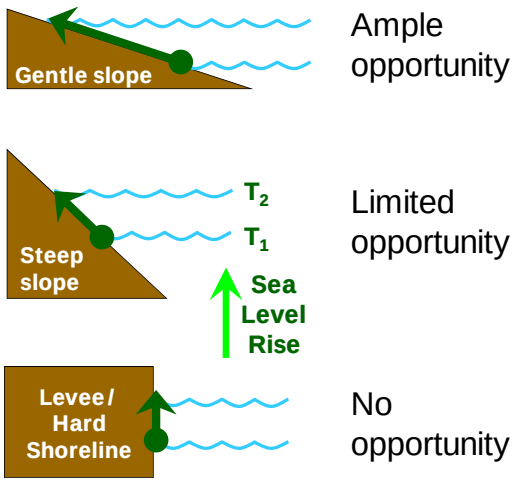


Figure 6. Conceptual Diagram of Potential for Continued Tidal Marsh Estuarine Transgression
Source: Wetlands and Water Resources

3 Priority Subregions for Suisun Restoration and Their Respective Landscape-Scale Conceptual Models

Where within Suisun Marsh should restoration efforts be directed? To address this question we need to establish a few premises. First, a substantial portion but by no means all of the 53,000 acres of diked lands will be restored so it will be important to focus restoration efforts expected to yield the greatest ecological benefits for the least possible cost. Second, Suisun Marsh exhibits strong gradients of all the key drivers influencing the outcomes of restoration and thus outcomes will be demonstrably different depending on where in the Marsh restoration is carried out. Third, the results of restoration will continuously change over time as restoration sites evolve at different rates from different starting conditions while at the same time the external drivers of change such as sea level rise and a changing sediment supply will exert their influence. Last and perhaps most importantly, we cannot predict with certainty the restoration-ecological response relationships especially at the individual species level because there are many facets we do not yet understand and nature is famous for handing us unexpected learning opportunities. This last point merely argues for approaching the task at hand very methodically and with a strong role for adaptive management science.

We have therefore developed the following suite of criteria to define priority restoration subregions within Suisun Marsh. These criteria originate in each chapter of Volume II, Strategic Plan (WWR 2011b).

Criteria to Achieve Strategic Vision (Volume II, Chapter 2)

These criteria reflect where we are trying to go:

1) Conserve and restore estuarine natural communities:
    a. Of sufficient scale to support range of natural communities
    b. Encompass key physical processes that support recovery of natural communities
2) Conserve and restore estuarine ecosystem processes and functions:
    a. Of sufficient scale and situated effectively relative to Suisun hydrodynamics and transport processes
    b. Of sufficient scale and situated geographically to take advantage of sediment transport, sediment deposition processes, and support marsh-building interactions of sedimentation and vegetation
3) Maximize the potential for resiliency in the face of future changes (note that these criteria are most applicable when applied to the suite of priority restoration subregions together rather than to each subregion alone):

a. Encompass mechanisms to maintain marsh plain elevations with sea level rise and reduced sediment supply, either through landward migration and/or marsh biophysical accretion
b. Encompass geographies that adapt to future changes in salinity regimes, invasive species, and land use changes

Criteria to Test Restoration Hypotheses (Volume II, Chapter 3)

These criteria use the specific characteristics of the natural environment that need to be addressed to move toward the strategic vision:

1) **Productivity:** Will restoration efforts improve aquatic and terrestrial food web productivity.
2) **Tidal marsh extent:** Will population abundances be increased through the increase in spatial extent and habitat quality of tidal marshes and tidally influenced marsh-edge communities.
3) **Stressors:** Will tidal marsh restoration, modified management of diked managed wetlands in and other factors internal to Suisun Marsh, and modified management of external processes and conditions that influence Suisun result in reducing or eliminating the effects of the many stressors affecting Suisun that impair ecosystem functions and open water, tidal marsh, and marsh-upland edge communities.
4) **Scale:** Will restoration of physical landscape components, connections, and processes at scales that allow for full expression of native species life history strategies result in conservation of native species and natural communities.
5) **Resiliency to future change:** Will tidally restoring lands in large, contiguous areas across gradients of baseline elevations, salinity regimes, sediment supply, tidal mixing, and upland edges promote resiliency to expected future change (e.g., sea level rise)

Criteria to Implement Key Restoration Principles (Volume II, Chapter 4)

These criteria give us a set of tools to apply at both the site and subregion scale so that we have the best chance of success:

1) Can the landscape support allowing the time necessary for natural processes to restore native species and natural communities without excessive ongoing human intervention.
2) Are natural processes as the primary control over evolution of restoration areas effectively integrated such that excessive ongoing human intervention is not necessary to achieve target restoration outcomes.
3) Are remnant features of historical landscape ecology being integrated effectively.

4) Are landscape-scale perspectives focusing on relationships and connectivity that leverage historical landscape features and consider whole landscape functioning at ecologically relevant scales and not being driven by political boundaries or land ownership patterns.
5) Are needs for maintaining, upgrading, and constructing tidal flood protection levees being minimized to the greatest extent possible.
6) Are landscape-scale conceptual models and incorporation of adaptive management science being incorporated.

Criteria to Conform with Restoration Capacity of the Landscape (Volume II, Chapter 5)

These criteria tell us what the major factors are that will control the outcomes of our restoration efforts, knowledge we can use to sift through the knowledge base of conditions in Suisun Marsh.

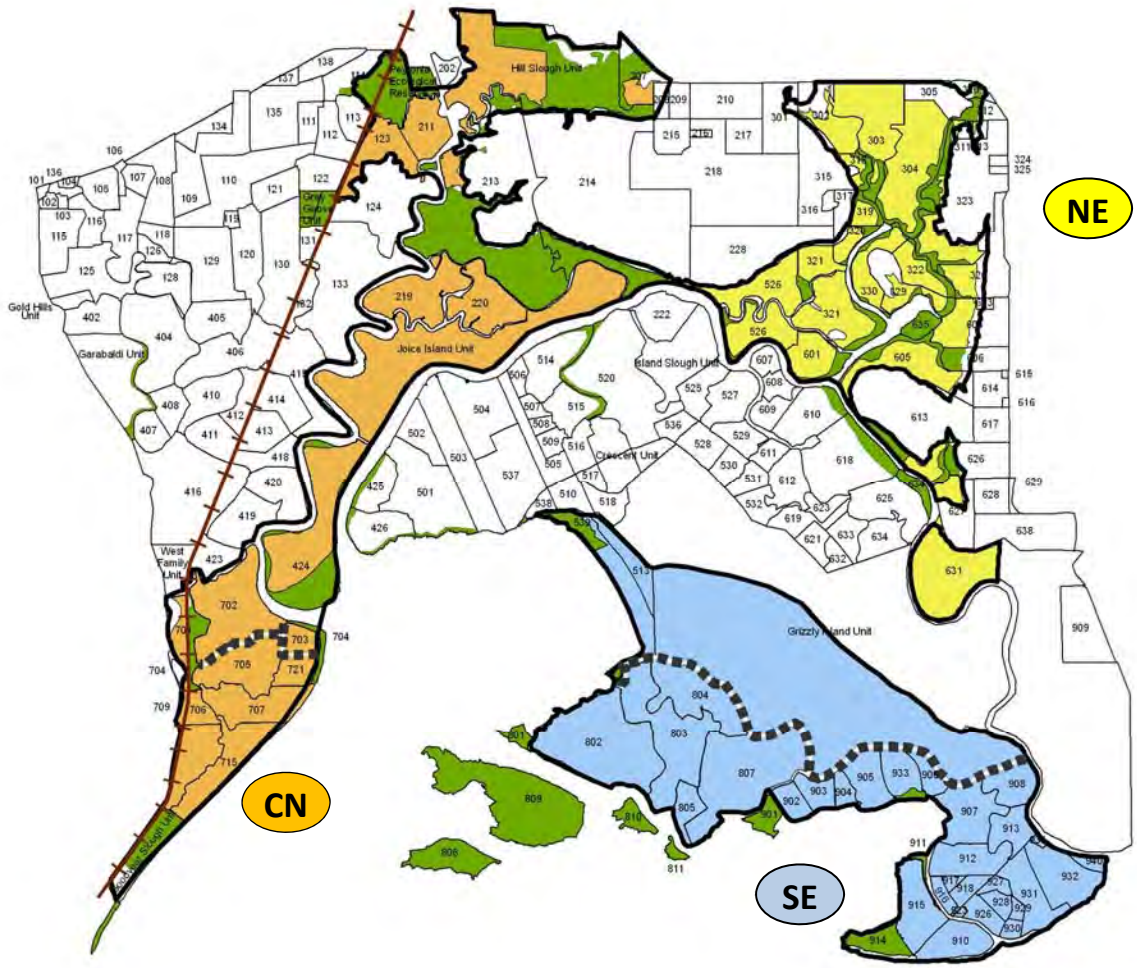
1) Do the regions align with the hydrologic and hydrodynamic processes that exert major control on ecological functions and outcomes of ecosystem restoration, including those supporting and those interfering with effective restoration.
2) Do the regions afford a range of conditions that would provide diverse outcomes given current sediment supplies and the predicted future declining supplies.
3) Do the regions provide a range of baseline topographic conditions conducive to restoring emergent tidal marsh, either upon restoration, through sedimentation, or through subsidence reversal strategies.
4) Do the regions offer a range of salinities to yield diverse wetland plant communities.
5) Are opportunities for accommodating sea level rise available, either through estuarine transgression and/or upward marsh building through sedimentation or plant biomass.

Figure 7 shows the proposed three priority restoration subregions of Suisun Marsh and **Table 1** presents the acreages of each subregion. The Suisun Marsh Plan (USBR et al. 2010) and the ERP Stage 2 Conservation Strategy call for several thousand acres of tidal restoration, though they give minimal guidance about how it should be configured on the landscape to meet conservation goals. The three regions in **Figure 7** constitute approximately 5-12 thousand acres each. As a group they each have different advantages and disadvantages and are more or less suitable for various native fish and terrestrial species and life stages. These regions represent nominally ideal configurations based on the criteria for reasons described below. We assume that such a contiguous acquisition of multiple properties will be challenging and will require many years to achieve; consequently, a long-term effort focused on ecological goals, ecosystem science advancement, and land management will be essential.

For each subregion, we have identified a subregion-specific conceptual model with associated hypotheses regarding the potential outcomes restoration may achieve. We acknowledge that these hypotheses are preliminary and warrant continuous improvement over time and recommend that an interdisciplinary team be established for this purpose. Following the discussion of the three priority restoration regions, we present a discussion about the remaining areas of Suisun that we did not recommend as priority restoration areas. Those conclusions, too, warrant further discussion by this proposed interdisciplinary team.

Table 1. Acreages in Each Priority Restoration Subregion

Restoration Subregions	Tidal Channels (ac)	Tidal Marsh (ac)	Diked (ac)	Total (ac)
Southeast	100	1,050	11,850	13,000
Northeast	450	1,100	5,900	7,450
Central	1,250	3,250	8,000	12,500
Total	1,800	5,400	25,750	32,950



CN = Central; NE = Northeast; SE = Southeast

Figure 7. Restoration Subregions at Species- and Ecosystem Process-Relevant Scales

Southeast Suisun Subregion

The Southeast Suisun Subregion consists of about 13,000 acres. It includes Chipps, Van Sickle, Wheeler, and Simmons islands and the southern part of Grizzly Island. About a thousand acres of this subregion are tidal marsh or muted tidal marsh including the Chipps Island fully (western) and partially (eastern) restored parcels. It encompasses about 100 acres of tidal channels (including Spoonbill Creek between Chipps and Van Sickle islands). It includes all of Roaring River, formerly a major tidal slough and used today as a water distribution canal to several diked managed wetlands on these islands. Its northern extent is to the crest of the small "ridge" on Grizzly Island just north of Grizzly Island Road (**Figure 4**). Its elevations are comparatively subsided (**Figure 4**) so tidal marsh restoration would occur comparatively slowly unless subsidence reversal is pursued.

The southeast Suisun subregion (**Figure 8**) is situated geographically adjacent to the "low salinity zone" where peaks in abundance often occur across trophic levels (Jassby 1995). Tidal restoration of these properties would provide over 15 miles of Bay front shallow water and tidal marsh habitat in a region known for its importance for Delta Smelt and migrating salmon refuge, rearing, and migration corridor habitat (Nobriga and Herbold 2009, Williams 2009). In addition, simple reconnection of the extensive remnant tidal creek systems (shown in blue on **Figure 8**) would significantly increase land-water edge extent and provide conduits for exchange of materials and energy between restoration areas and adjacent open water. Expanded connectivity and tidal currents would also interact with the extensive near shore sea grass beds providing food and refuge options in close proximity. The region also provides multiple opportunities for scientific experimental treatments that would promote rapid learning about ecological and geomorphic consequences of hydraulic connectivity through levee manipulation options. Experimental modifications would examine that effect of levee opening extent, width, depth, shape, and location. Numerous hypotheses would flow from a formal landscape scale conceptual model for this region.

Southeast Suisun

- Adjacent to X2
- Salinity gradient corridor
- Potential Delta smelt habitat
- Adjacent to major migratory corridors
- Sediment source rich
- Large remnant tidal creek systems
- Extensive shallow bay connectivity
- Subsidence: mostly shallow subtidal
- Natural topographic divide on Grizzly Island
- Total size: 13,000ac, 1,150ac already tidal

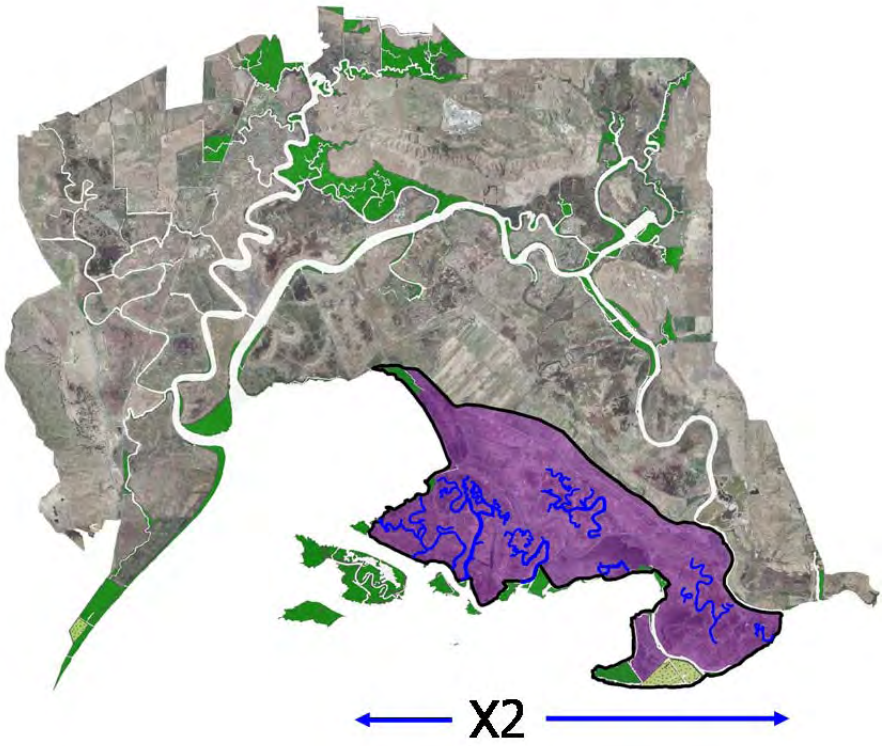


Figure 8. Southeast Suisun Subregion

Hypotheses for geomorphic change and native species use in the southeast Suisun subregion

Some of the overarching hypotheses that might arise from further landscape-scale conceptual modeling include:

- **H1:** The region is adjacent to the highest turbidity zone in the northern reach of the estuary. As such, hydrodynamic connectivity can be designed to encourage net sediment fluxes on to the properties and "rapid" mineral sediment accretion.
- **H2:** Along with mineral sediment accretion, the region will quickly fill with emergent vegetation where land elevation allows soil oxygenation. We can expect recovery of elevation on pace or faster than sea level rise.
- **H3:** The region will contain expansive emergent vegetation edge, an important ecotone where ecological community dynamics can flourish.
- **H4:** Tidal restoration, in absence of substantial subsidence reversal efforts, will initially create expansive shallow water with high wind-wave energy and turbid waters, possibly

providing brackish delta smelt habitat. Other natives including splittail, longfin smelt, and tule perch will also find preferred habitat characteristics.

- **H5:** Extensive sunlight penetrating shallow water areas will make restorations mostly autotrophic (sunlight driven) producer habitat. Some Delta smelt life stages, which may not otherwise use the habitat directly, will benefit from this production and its high frequency export of primary, secondary and tertiary food resources to the nearby pelagic region.
- **H6:** Extensive tall emergent vegetation including bulrush (*Bolboschoenus*), tules (*Schoenoplectus*), and cattails (*Typha*) could support relatively protected nesting habitat for passerines and rails. Areas isolated from uplands or with limited upland connection may have more limited predator corridors, further enhancing nesting conditions.
- **H7:** Low-salinity zone (X2) productivity is partly explained by proximity to shallow water habitat with strong gradients of current energy, residence time, and edge/bathymetric complexity, and trophic dynamics.
- **H8:** The initial subtidal elevation of much of the area (Figure 4) will be good habitat for sea-grass species including *Potamogeton* and *Ruppia* that support diverse primary and secondary production; these species are found extensively in nearby waters. *Egeria* should not be a concern in Suisun due to salinity.

Northeast Suisun Subregion

The Northeast Suisun Subregion consists 7,450 acres along Nurse Slough. It includes all lands along Nurse, Denverton, Arnold, Cross, and Hastings sloughs and it includes Bradmoor Island and Meins Landing. About 1,100 acres of this subregion are tidal marsh including the restored Blacklock property and comparatively wide fringing marsh long these sloughs. It encompasses about 450 acres of open water including tidal sloughs and Little Honker Bay, the only shallow interior embayment in Suisun. Its elevations are relatively high (**Figure 4**) so tidal marsh restoration would occur comparatively quickly except at the more subsided high Meins Landing. Meins Landing connects to a small creek with an intact riparian corridor downstream of the hamlet of Birds Landing

Similar to southeast Suisun, the “Nurse Slough complex” or northeast subregion encompasses a freshwater to brackish salinity gradient corridor and significant sediment sources (Figure 10). Unlike southeast Suisun, the region generally exhibits less land subsidence, which suggests that historical elevations and processes could be restored more quickly. It is also perhaps one of the best regions in the estuary for accommodating sea level rise as it is surrounded by upland transitions both shallow and steep (section 5). The upland transition at the northern edge,

notwithstanding the Highway 12 crossing, is gently sloping and ultimately connects with the Lindsey Slough complex and the Jepson Prairie vernal pool preserve. The upland edge east toward Shiloh has no major infrastructure constraints. Sea level rise could claim large expanses of this landscape over time. Very rare to all of Suisun Marsh is the intact riparian corridor from Meins Landing up to Birds Landing, a rare opportunity to restore this ecosystem complex so easily (Meins Landing restoration is complicated, however, by underground pipeline crossings). Other unique attributes of this region for conservation of native species include extensive remnant tidal channel systems that would be easily re-connected. Further, the region has over 1000 acres of so-called “fringing tidal marsh” where levees were set back from the channel edge by significant distances. These marshes are ostensibly seed habitats that would readily expand if levees are removed from their landward edge. It is speculated that these fringing marsh habitats in combination with the shallow Little Honker Bay may explain the relatively high abundances of native fish in the region (Peter Moyle pers. comm.). Lastly, it is linked to the Jepson Prairie watershed to the northeast that over a short distance connects to the Cache Slough Complex of the northwest Delta, another primary restoration focus area in the greater estuary.

Northeast Suisun

- Sea level rise accommodation
- Minimal subsidence
- Terrestrial corridor across Jepson Prairie to Cache Slough complex in the Delta
- Extensive upland transition ecotone
- Extensive remnant tidal creek systems
- Fringing tule marsh
- Little Honker Bay: shallow bay, local sediment source, risk of excess scour?
- Blacklock restoration constructed 2006
- Riparian corridor at Meins Landing
- Extensive native fish use
- Total size: 7,450 ac, 1,500 ac already tidal

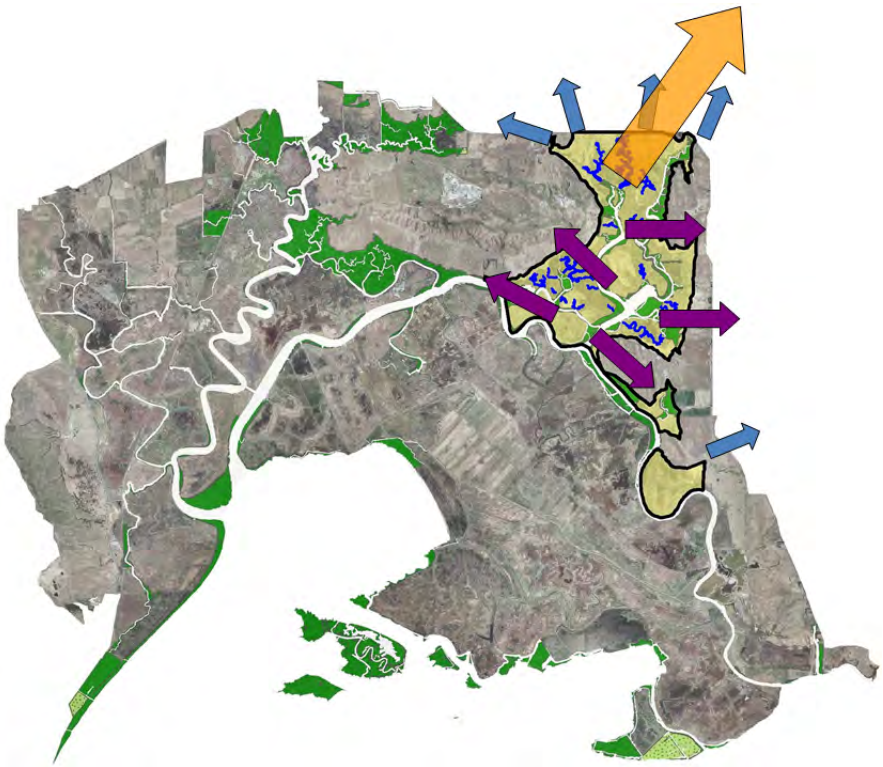


Figure 9. Northeast Suisun Subregion

Hypotheses for geomorphic change and native species use in the Northeast Suisun Subregion

Some of the overarching hypotheses that might arise from further landscape-scale conceptual modeling include:

- **H1:** Existing fringe marshes and associated tidal creeks systems will expand readily if landward levees are graded down.
- **H2:** Simple reconnection of tidal soughs to tidal channels will expand structurally complex habitat space that will be used dominantly by native species.

- **H3:** Relatively high abundances of native fish in this region are explained by proximity of extensive fringing marsh habitats and the shallow Little Honker Bay and their associated connectivity and resources especially food and cover.
- **H4:** Minimally subsided systems with fringing marshes and remnant tidal creek system will recover native elevation, morphology, and ecological functioning more quickly than more subsided regions.
- **H5:** This large, dead-end slough system exhibits a residence time gradient from one end to the other and will therefore exhibit differential temperature, salinity, hetero- and autotrophic production, and regional ecosystem subsidy characteristics.
- **H6:** Reconnecting the small creek and riparian corridor between Meins Landing and Birds Landing will reestablish an ecosystem complex well suited to support native species and its rarity may bring unexpected beneficial outcomes.

Central Suisun Subregion

The Central Suisun Subregion consists 12,500 acres along Suisun and Montezuma sloughs and western Suisun Bay. It includes all lands between these sloughs west of Beldon's Landing, Hill Slough, portions along Peytonia and Boynton sloughs, and from Goodyear Slough down to Suisun Bay by the Mothball Fleet. About 3,200 acres of this subregion are tidal marsh including Rush Ranch, the tip of Joice Island, and along Hill, Peytonia and Cutoff sloughs. It encompasses about 1,200 acres of open water including all of Suisun, Hill, and Cutoff sloughs and much of Peytonia and Boynton sloughs. Its elevations are varied (**Figure 4**) so tidal marsh restoration would occur comparatively quickly in some areas and more slowly in others. The northern extent of this subregion adjoins the urban areas of Fairfield and Suisun City including portions of Travis Air Force base and the watershed further to the north some of which is in agricultural use. All of the storm flows enter Suisun Marsh untreated.

Suisun Slough is the largest dead-end tidal slough in Suisun Marsh. Historically it was likely a 5th to 6th order tidal channel with many tidal watersheds arrayed along its length. At its mouth, tidal exchange is +/- 15,000 cfs while its connection to Montezuma slough through Hunter Cut averages +/- 30,000 cfs. At its eastern end, Montezuma Slough tidal flow is near +/- 50,000 cfs. These are the primary conduits of tidal volume and material exchange into and out of Suisun Marsh. Approximately 30-60% of Suisun Marsh's tidal prism is exchanged with Grizzly Bay each tide. This corridor is located squarely between these two sloughs making restorative tidal connections potentially valuable for native species (**Figure 10**). Its primary attribute at this scale is that it spans a significant physical/chemical gradient from freshwater connection of the watershed in the north to the strongly tidally forced mesohaline habitats of western Suisun Bay.

If restored, the region therefore constitutes a significant corridor for cross-habitat movement of both terrestrial and aquatic species. Habitat choices for native fish would be richly variable, allowing finely tuned options for food, refuge, and physiological adaptation space. In addition, this region is primarily public land (Solano Land Trust, CDFG, and Suisun Resource Conservation District). This affords a special opportunity for connecting landscapes at ecologically relevant scale more easily than the rest of Suisun.

Central Suisun

- Estuarine corridor
- Mostly public land
- Topographic diversity
- Remnant tidal sloughs
- Existing tidal marsh including one of the estuary's largest remnant Holocene-era marshes (Rush Ranch)
- Sea level rise accommodation at Rush Ranch and portions of Hill Slough
- Watershed connectivity though mostly passes through Fairfield and Suisun City
- Total size: 12,450 ac, 4,450 ac already tidal

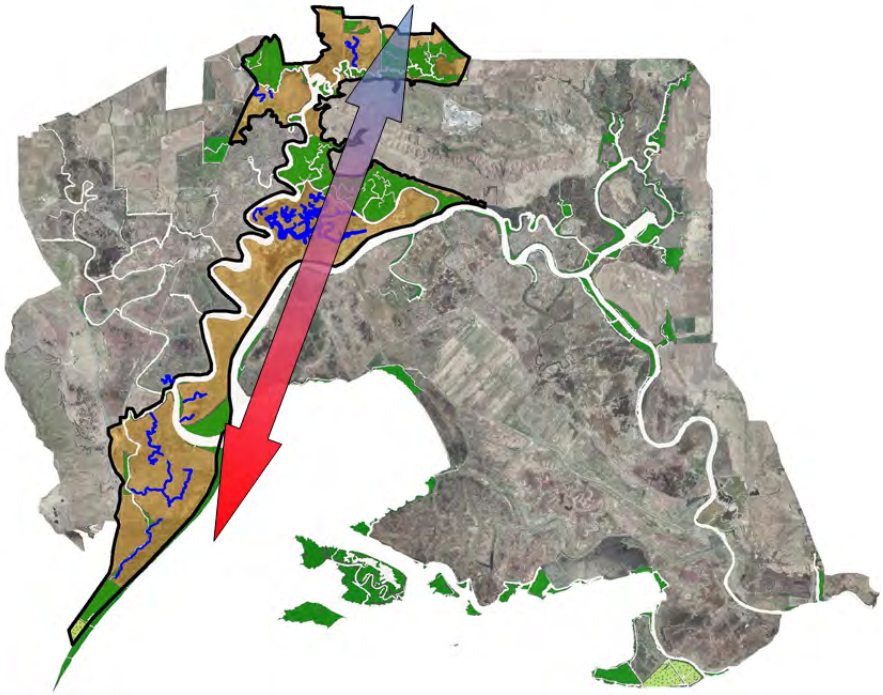


Figure 10. Central Suisun Subregion

Hypotheses for geomorphic change and native species use in the Central Suisun Subregion

Some of the overarching hypotheses that might arise from further landscape-scale conceptual modeling include:

- **H1:** There is a continuous overlap of physical system components from marsh plain/tidal creek systems to moderately sized dead-end tidal sloughs to energetic tidal channels to open bays (**Figure 10**). With extensive tidal restoration, we would expect to amplify the cascade of hydrodynamic interactions between aquatic habitat types. This dynamic

would improve ecosystem outcomes, including native species abundances, more than any of the sub-systems could alone achieve. Apropos of that:

- **H2:** Experimental testing of the value of estuarine corridors lends itself to BACI designs (before-after-control-impact) that would characterize existing terrestrial and aquatic species life history use of the region to that which emerges after connectivity and habitat functions are restored. One hypothesis would be that a functioning corridor would increase species biodiversity, population abundances and opportunities for expanding genetic diversity within species.
- **H3:** Simple reconnection of tidal soughs to tidal channels will expand structurally complex habitat space that will be used dominantly by native species.
- **H4:** Proximity to energetic hydrodynamics and long tidal excursions make export of excess production from restored shallow autotrophic habitats potentially powerful regional ecosystem subsidy engines.
- **H5:** By a variety of mechanisms, joining restoration projects to relatively intact tidal marshes (Rush Ranch and Hill Slough in particular) will aid restoration of chemical and biological processes in adjacent restored areas.
- **H6:** This large, dead-end slough system exhibits a residence time gradient from one end to the other and will therefore exhibit differential temperature, salinity, hetero and autotrophic production, and regional ecosystem subsidy characteristics.

Other Areas of Suisun Marsh not Identified as Restoration Priority

The three priority restoration regions described above by necessity omit more than half the 53,000 acres of diked lands in Suisun Marsh. We must first add the caveat that there does exist some lands outside these three areas that could yield effective ecological outcomes under certain circumstances and that if those circumstances arise then those properties could be considered for restoration. Here we describe all the areas not included in the three priority restoration subregions: Grizzly Island, Between Suisun Slough and Railroad, and West of Railroad.

One key factor in considering what areas not to focus on for restoration is that the diked managed wetlands of Suisun Marsh provide important wintering waterfowl habitat for the Pacific Flyway and, as such many of these lands are used for hunting purposes, there exists a tremendous impetus to maintain substantial portions of Suisun Marsh in its current land use.

Grizzly Island

A bulk of Grizzly Island is not included for a relatively simple reason: it would require extensive tidal flood control levee improvements to protect lands retained as diked managed wetlands. In addition, most of the salt marsh harvest mouse conservation areas are located on Grizzly Island and restoring these areas to tidal marsh could require more complicated mitigation efforts (USFWS 2010). Grizzly Island also supports dozens of privately owned duck clubs and from a practical standpoint one would have to acquire so many of these properties to achieve a relatively reduced extent of tidal flood control levee improvements to make restoration cost effective; acquiring so many separate ownerships would be a very daunting task. Grizzly Island also floods and drains from Montezuma Slough and Grizzly Bay and thus wetland discharges are not likely to contribute to low dissolved oxygen problems found at times along the smaller sloughs around the Marsh perimeter.

Between Suisun Slough and Railroad

These properties in fact might have good restoration potential. They are located along the salinity gradient of Suisun Slough. At the north end they are directly across from the large ancient tidal marshlands at Rush Ranch thereby providing close proximity to populations of many marsh-dependent species. Elevations vary from relatively higher lands to more subsided lands.

The primary uncertainty is the railroad itself. Currently it is above the tide level with its embankments grading down into the diked managed marshes. Whether Union Pacific Railroad, the rail line owner, would require improvements to protect the railroad from erosion were tides restored in these properties is not clear. If such improvements were required, they would likely have high cost and feasibility concerns such as wetlands loss, making the overall feasibility of restoring these properties comparatively low. If UPRR did not require such improvements, then these properties could be quite feasible.

Were it known with certainty that improvements to protect the railroad would not be needed and if multiple properties could be restored to obtain large-scale restoration, then these lands may be well suited for tidal restoration.

West of Railroad

The case of lands west of the railroad is complicated. On the positive side, these lands offer two primary opportunities: extensive upland edge and higher salinities that would yield different ecological outcomes from the more brackish marshes that would result throughout much of the rest of Suisun Marsh. Also, some properties are situated such that comparatively little tidal

flood protection improvements would be needed to protect retained diked managed wetlands. Those are the upside considerations.

On the down side are several factors that we deemed amply significant not to include these lands as priority restoration areas. First, tides must pass under the railroad. There are a total of six tidal slough crossings. The size of each crossing limits the volume of water that can pass through without causing scour of the railroad bridge footings; we have not attempted any quantification of that capacity here. Though we anticipate that there exists some capacity for increased tidal exchange without threatening these crossings, that capacity is unlikely to be sufficient to support extensive tidal restoration. Were any efforts undertaken to pursue restoration west of the railroad, undertaking numerical hydrodynamic modeling would be essential before proceeding too far down the planning road.

Second, tidal restoration has a high potential to dampen the tides upstream of a restoration project, thereby greatly complicating water operations of the diked managed wetlands along the affected sloughs. The larger the restored tidal prism (larger properties, more subsidence), the greater the magnitude of tidal dampening. The primary means to overcome this problem is to restore all the lands along an affected slough to tidal action. But that approach loops back to the conveyance capacity limitations of the railroad crossings. And it would require bringing all the properties into restoration which could be a daunting task.

Third, it is possible but not documented that water quality in the tidal sloughs west of the railroad may be poor at certain times of year, thereby limiting the ecosystem functions that might otherwise be achieved. In particular, dissolved oxygen (DO) levels have the potential to be low in the fall and at certain times in the winter due to the fall flood up of the diked managed wetlands and the later winter drawdown events (Siegel et al. 2011). These concerns stem from the comparatively small size of these tidal sloughs combined with the many managed wetlands that flood and drain from them. This area does have connectivity to its watershed and the associated storm flows from Suisun and Green Valley creeks which presumably would function to flush poor quality waters downstream and ameliorate the problem. Low DO concentrations in the water column can act to limit access to aquatic habitat by functioning as a migration barrier to organisms intolerant of the reduced DO levels such as salmonids; thus, restored tidal marshes upstream of low DO waters would be inaccessible to those species. As DO levels drop lower they can lead to mortality of fish and other aquatic organisms. There are no documented low DO problems in these sloughs; however, very little systematic monitoring has taken place as the long-term UC Davis fish monitoring program, which has documented many of the low DO problems in Suisun, does not have stations upstream of the railroad due to their boats not being able to navigate under the crossings.

Lastly, most of the properties west of the railroad are fairly subsided (see **Figure 4**). Their evolution to higher elevation marshes would be expected to be slow for two reasons. First, these lands are fairly remote from the large sediment sources of the large bays and thus sediment accretion may be fairly slow. Second, the higher salinities drive the plant community to more salt-tolerant species that produce less annual biomass to support organic matter accumulation for subsidence reversal and these species cannot grow in the lower elevations (see **Figure 5**) so would not colonize until elevations are high enough.

4 Individual Properties and Restoration Clusters Used in Feasibility Analyses

This feasibility analysis considers most of the 53,000 acres of diked lands in Suisun Marsh (**Figure 11**). Excluded from the analyses are uplands, tidal marsh, and the Montezuma Wetlands Project which is under construction. Two muted tidal marshes are included in the analyses (property 910 on Chipps Island and property 539 on the east shore of Grizzly Bay) as both likely could provide improved ecological functions through active enhancement efforts.

The restoration feasibility analyses presented in the next chapter are all evaluated at the individual property level. In practice, however, restoration is likely to be far more cost effective and ecologically beneficial when several properties are grouped into 'restoration clusters' that yield far larger projects with a significant reduction or complete elimination of the need for tidal flood protection levees.

We have identified 12 such clusters (**Figure 12**) within the three priority restoration subregions. The feasibility assessments for tidal flood protection and natural upland edge address both the individual properties and the restoration clusters. By achieving this outcome, we minimize restoration costs, maximize restoration acreage, and maximize potential for meeting our strategic conservation vision of landscape-scale and native species relevant tidal restoration. Several of these 'restoration clusters' correspond to entire reclamation districts (see **Figure 25**) which can simplify procedural efforts in restoration planning. Most if not all clusters encompass multiple property owners and all encompass at least two individual properties (Table 2). One property falls into two clusters as it divided into two parts by a tidal slough. Note that the names of these clusters we have established purely for the sake of convenience.

Central Priority Restoration Subregion clusters are:

- **Morrow Island** consists of six privately owned properties situated between Goodyear Slough, Suisun Slough, and Suisun Bay (properties 702 [RD 2138], 703, 705, 707, 715 and 721). Restored together, this cluster would not require any ongoing levee maintenance.
- **Joice Island** consists of three properties along Suisun, Montezuma and Cutoff sloughs' two properties are privately owned (219 and 220 which constitute all of RD 2141) and the third is the DFG Joice Island Unit; this cluster is one of only two clusters with publicly owned property. Restored together, this cluster would not require any ongoing levee maintenance.
- **Peytonia-Boynton Slough** consists of two privately owned properties (123 and 211) bounded by the two name-sake sloughs plus Suisun Slough and the railroad. Restored

together, this cluster would not require any ongoing levee maintenance; it may require a berm alongside the railroad.

Northeast Priority Restoration Subregion clusters are:

- **Bradmoor Island** consists of three private properties (322, 329, 330) surrounded by Denverton and Nurse sloughs and including an upland island.
- **Cross Slough** consists of two private properties (southern half of 526 and all of 601 which are part of RD 2139) between Montezuma and Cross sloughs; currently, Cross Slough has a levee serving as vehicle access to this island and preventing tidal flows from traversing all of Cross Slough the removal of which is presumed to be very advantageous ecologically. Restored together, this cluster would not require any ongoing levee maintenance.
- **Denverton Slough** consists of two private properties (303 and 304) with upland edge along Highway 12. Restored together, this cluster would limited levee maintenance to protect diked marsh on its western boundary.
- **Hasting Slough** consists of three private properties (northern half of 526 and all of 320 and 321) which round out properties in RD 2139; this cluster has extensive upland edge along the southeast side of Potrero Hills. Restored together, this cluster would not require any ongoing levee maintenance.

Southeast Priority Restoration Subregion clusters are:

- **Chipps Island** consists of two private properties (910 and 915); the southwest third of Chipps Island is already tidal marsh and the southeast (property 910) is muted tidal marsh. Restored together, this cluster would not require any ongoing levee maintenance.
- **Grizzly Island** consists of the DFG Grizzly Island Unit south from the higher-elevation 'ridge' (see **Figure 4**) to Roaring River and including two private properties near Grizzly Bay (513 and 539). This cluster could be restored realistically only through Roaring River which would itself have to be tidally restored. Were lands south of Roaring River also restored, no levees would have to be maintained. If some or all of those lands are not restored then some segments of the southern Roaring River levee would have to be maintained. Modifications in water management for properties that receive Roaring River water would have to be evaluated.
- **Honker Bay** consists of six private properties on the north shore of Honker Bay (902-906 and 933, five of which constitute RD 2130 with the eastern property part of RD 1607); these properties have experienced repeated levee failures in recent years and some are currently open to the tides. A short levee segment on the east adjoining Van Sickle

Island would have to be maintained if Van Sickle Island itself is not restored. Protection of the Roaring River levee may be needed depending on whether or not surrounding clusters are restored.

- **Simmons Island** consists of five private properties (802, 803, 804, 805, 807) which constitute all of RD 2127. Only the Roaring River levee would have to be maintained and if other lands along Roaring River are also restored then that levee requirement could go away.
- **Van Sickle Island** consists of 17 private properties in RD 1607. A small segment of levee in its northwest corner and the short segment of Roaring River levee would have to be maintained unless adjacent properties are also brought into restoration.

Table 2. List of Restoration Clusters

Cluster Name	Total Size (ac)	No. of Properties	Properties in Cluster
Central Subregion			
Joice Island	2,500	3	219, 220, DFG Joice Island Unit
Morrow Island	2,300	6	702, 703, 705, 707, 715, 721
Peytonia-Boynton	610	2	123, 211
Northeast Subregion			
Bradmoor Island	480	3	322, 329, 330
Cross Slough	470	2	526 (southern part), 601
Denverton Slough	1,150	2	303, 304
Hastings Slough	1,000	3	526 (northern part), 320, 321
Southeast Subregion			
Chipps Island	610	2	910, 915
Grizzly Island	5,400	3	513, 539, southern half of DFG Grizzly Island Unit
Honker Bay	900	6	902, 903, 904, 905, 906, 933
Simmons Island	3,400	5	802, 803, 804, 805, 807
Van Sickle Island	2,400	17	907, 908, 912, 913, 916, 917, 918, 923, 926, 927, 928, 929, 930, 931, 932, 934, 940

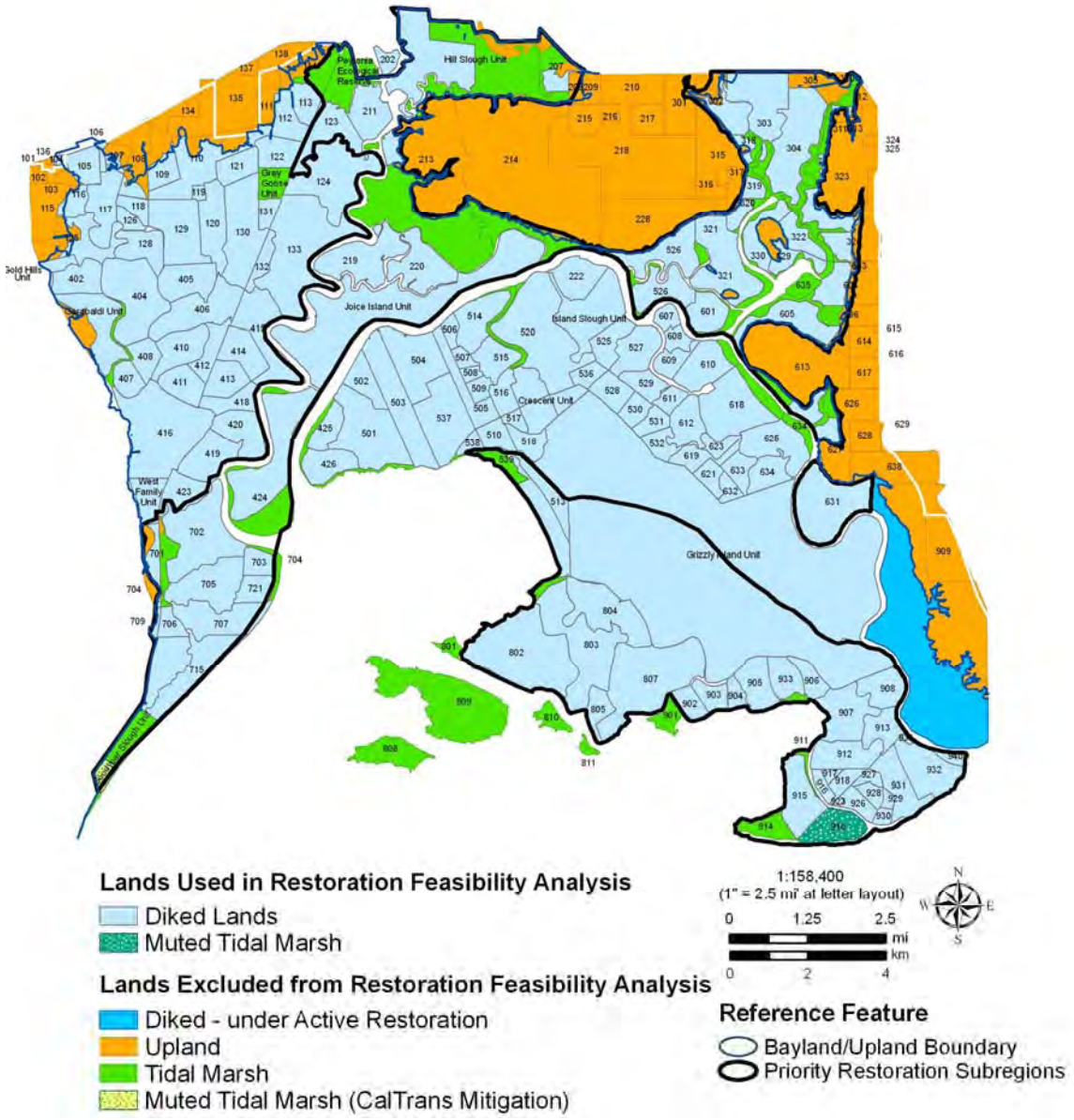


Figure 11. Lands Used in Quantitative Feasibility Analyses of Restorable Intertidal Elevation Properties

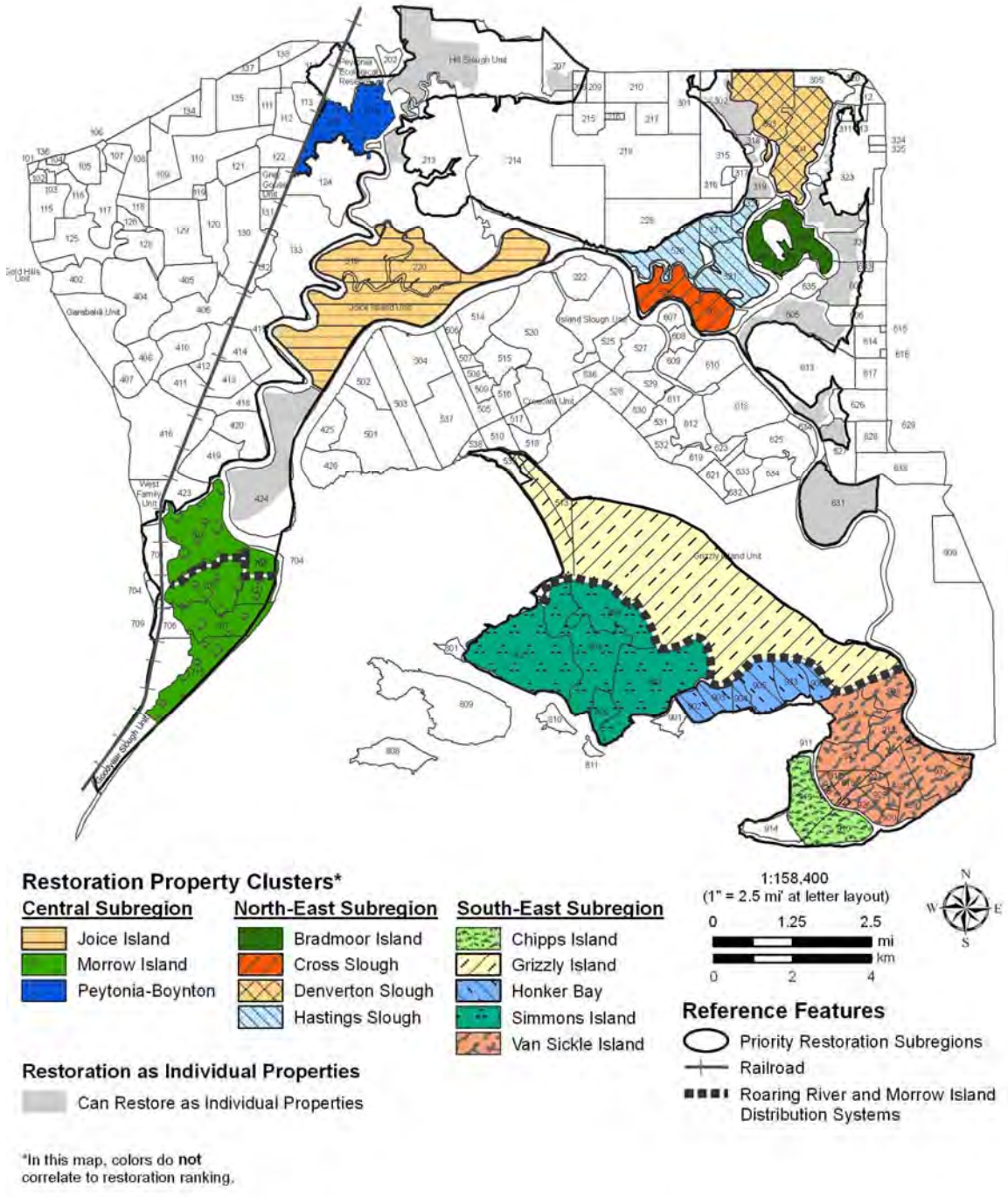


Figure 12. Recommended Restoration Clusters within Priority Subregions

5 Feasibility Assessment by Restoration Criterion

This chapter provides the restoration feasibility assessment by property for each of the 15 restoration criteria and by restoration cluster for two of those criteria (tidal flood protection and natural upland edge). In the case of restoration clusters, the assessment indicates the feasibility of each property within that cluster, rather than the cluster as a whole, thereby allowing determination of how incorporation into a restoration cluster improves the restoration feasibility of any given property within that cluster.

For feasibility criteria readily calculated, this assessment covers all diked lands in Suisun. For criteria more complex to calculate, this assessment focuses largely on lands within the three priority restoration subregions (**Figure 7**). These feasibility criteria cover both opportunities and constraints to restoration. Table 1 summarizes the criteria, their relevance, units of measure, and ranking values. These 15 criteria fall into three groupings of relative importance (high, medium, low) which are then used qualitatively in Chapter 6 in developing the integrated restoration feasibility results. These analyses involved considerable GIS analysis; **Appendix A** presents the methods used.

Table 2. Restoration Feasibility Ranking Criteria Weighting, Rationale, and Ranking Values
Suisun Marsh Strategic Plan

Description of Criteria			Description of Ranking Values		
Weighting	**Rationale**	**Units**	**Value**	**Feasibility**	**Reasoning/ Description**
(H-1) DEPENDENCY ON ADJACENT PROPERTY FOR TIDAL CONNECTION					
High	Need hydrologic connection to the tides to restore tidal action	Yes/No	No/not dependent	HIGH	Direct tidal connection can be established
			Yes/dependent	LOW	Must restore adjacent properties to establish tidal connection
(H-2) EXTENT OF TIDAL FLOOD PROTECTION NEEDS					
High	Tidal flood protection requires levees which are very costly to build, upgrade, and maintain and which interfere with providing ecological functions	Percent of diked property edge needing tidal flood protection	0%	HIGH	No adjacent lands require protection (all tidal or upland edge)
			< 20%	MED-HIGH	Some adjacent lands require protection
			20 - 60%	MEDIUM	Considerable adjacent lands require protection
			60 - 99%	LOW-MED	Extensive adjacent lands require protection
			100%	LOW	All adjacent lands require protection
(H-3) SUBSIDENCE					
High	Higher initial elevations translate to earlier recovery of emergent vegetation and associated range of ecological functions; if elevations below vegetation colonization heights, will be open water. Thus must wait for subsidence reversal (post restoration sedimentation or pre-restoration intervention) to raise to colonization elevation	Elevation (ft NAVD88)	5 - 7ft	HIGH	centered around MHHW: roughly 'high marsh'
			3 - 5ft	MED-HIGH	centered around MTL: roughly 'low marsh'
			1 - 3ft	MEDIUM	MLLW to 2ft above MLLW: roughly below vegetation colonization elevation)
			-2 - 1ft	LOW-MED	shallow subtidal: 0 - 3ft below MLLW
			< -2ft	LOW	deeper subtidal: more than 3ft below MLLW
(H-4) HYDROLOGIC AND WATER QUALITY					
High	Limited tidal flow capacity in source sloughs (railroad crossings) and limited tidal mixing/tidal range impacts/risk of low DO waters (long, small peripheral channels with many diked wetlands) can impose significant limits on restoration effectiveness	Geographic position relative to rail and long, small channels	Not connected to peripheral sloughs	HIGH	Not subject to hydrologic or water quality constraints (adjoin major sloughs, bays, MIDS, or RRDS
			Other medium sloughs	MED-HIGH	Limited tidal mixing, high potential for low DO
			Other smaller sloughs	MEDIUM	Least tidal mixing, high potential for low DO
			West of railroad, medium sloughs	LOW-MED	Limited tidal mixing, high potential for low DO, tidal flow constrained
			West of railroad, smaller sloughs	LOW	Least tidal mixing, high potential for low DO, tidal flow constrained

Table 2. Restoration Feasibility Ranking Criteria Weighting, Rationale, and Ranking Values
Suisun Marsh Strategic Plan

Description of Criteria			Description of Ranking Values		
Weighting	**Rationale**	**Units**	**Value**	**Feasibility**	**Reasoning/ Description**
(M-1) GAS WELL PRESENCE					
Moderate	Active gas wells require either provision of access and tidal flood protection or decommissioning. Gas wells not in active use need to be reviewed for closure status and extant drilling rights; in theory, directional drilling from adjacent lands would not interfere with restoration	Presence and status	no gas wells	HIIGH	No interference
			plugged wells only	MEDIUM	Ensure wells closed properly and no extant drilling rights
			active and other gas wells present	LOW	Either provide access and tidal flood protection or close well and extinguish drilling rights
(M-2) PIPELINES					
Moderate	Active underground pipelines cross Suisun in the east, alongside the railroad line in the west, and along the northwestern boundary. Pipelines are not incompatible with restoration but measures must be taken to protect them from damage and access may be required at a future date for maintenance, repairs, or upgrades	Presence	None present	HIGH	None present so no concern
			At property edge	MED-HIGH	May need to include access and protection into design
			Crosses property interior	MEDIUM	Must determine details of pipeline location, depth, condition, and product carried and options to protect and allow for possible future access must be incorporated into restoration
(M-3) SALT MARSH HARVEST MOUSE CONSERVATION AREAS					
Moderate	If present, DFG will require review of effects and possible establishment of replacement conservation area if restoration outcomes not likely to support SMHM	Presence	No	HIGH	None present so no concern
			Yes	MED-HIGH	Restoration likely to yield SMHM habitat
			Yes	LOW-MED	Restoration unlikely to yield SMHM habitat so may have to establish replacement conservation area elsewhere in Suisun
(M-4) OWNERSHIP TYPE					
Moderate	Restoration can take place only on lands of willing landowners	Owner Type	Public	HIGH	No acquisition required; may require affirmative action of public entity landowner to use for restoration
			Private	MEDIUM	Requires acquisiton or other mechanism to bring property into use for restoration

Table 2. Restoration Feasibility Ranking Criteria Weighting, Rationale, and Ranking Values
Suisun Marsh Strategic Plan

Description of Criteria			Description of Ranking Values		
Weighting	**Rationale**	**Units**	**Value**	**Feasibility**	**Reasoning/ Description**
(M-5) RECLAMATION DISTRICT					
Moderate	Reclamation Districts provide tidal flood protection to one or more diked properties and assess landowners to fund protection. Removing lands from an RD can be an issue if not all lands restored, as future assessment allocation must be addressed	Within an RD	No	HIGH	None present so no concern
			Yes	MEDIUM	Must coordinate wth RD and address future assessment allocations
(M-6) EXTENT OF INVASIVE PLANT SPECIES					
Moderate	Presence of the invasive plant species Phragmites or Lepidium can interfere with the establishment of target native emergent wetland plant species. Pre-restoration control, design elements to discourage colonization, and post-restoration management may be needed in some locations. Presence on or nearby a restoration site can be an issue	Percent of property area covered by invasive plants	0	HIGH	Both species absent
			< 2%, but present	MED-HIGH	
			2 - 10%	MEDIUM	
			> 10%	LOW-MED	Relatively high cover of one or both species
(M-7) EXTENT OF NATURAL UPLAND EDGE					
Moderate	Upland edge allows for long term sea level rise and marsh expansion as well as provides rate and ecological important marsh-upland ecotone	Miles of upland edge	2.1 - 5.7 mi	HIGH	maximum upland edge
			1.1 - 1.8 mi	MED-HIGH	
			0.6 - 1 mi	MEDIUM	
			0.2 - 0.5 mi	LOW-MED	
			0	LOW	No upland edge
(M-8) EXTENT OF DIKED RELIC SLOUGHS					
Moderate	Relic sloughs facilitate more rapid restoration of natural tidal marsh hydrologic functions and serve as aquatic habitat within tidal marshes. Importance increases for higher elevation properties as tidal channels do not easily scour substrate	Percent of diked area	> 5 - 9%	HIGH	Extenstive relic sloughs
			>2 - 5%	MED-HIGH	
			>1 - 2%	MEDIUM	
			>0 - 1%	LOW-MED	
			None	LOW	No relic sloughs
(M-9) NUMBER OF PROPERTIES WITHIN RESTORATION CLUSTER *(APPLICABLE TO RESTORATION CLUSTER ANALYSIS ONLY*)					
Moderate	Restoration clusters (multiple properties grouped into single restoration 'projects') improve overall feasibility. Landowner participation is required for any restoration	Number of properties in restoration cluster	1-3	HIGH	Fewer landowners = less complexity
			4-6	MEDIUM	
			>6	LOW	Many landowners = complex land negotiations

Table 2. Restoration Feasibility Ranking Criteria Weighting, Rationale, and Ranking Values
Suisun Marsh Strategic Plan

Description of Criteria			Description of Ranking Values		
Weighting	**Rationale**	**Units**	**Value**	**Feasibility**	**Reasoning/ Description**
(L-1) WILLIAMSON ACT CONTRACTS					
Low	Williamson Act established to protect open space and agricultural lands via State subsidy of property taxes so land owners not taxed at prospective development potential rates	Presence	No	HIGH	None present so no concern
			Yes	MEDIUM	Restoration consistent with open space purpose of Williamson Act; need to validate contract explicitly references open space purpose
(L-2) LAST PROPERTY TRANSFER DATE					
Low	Land speculation, particularly for mitigation banks, can drive up restoration costs; transfers could reflect modification of existing ownership vs. sale	Date of recorded transfer at County	Before 2001	HIGH	Longer term ownership
			2001 - 2007	MEDIUM	Ownership change less likely speculation
			2008 - 2011	LOW	May signal speculation; need to examine whether sale or ownership reconfiguration

5.1 High-Priority Restoration Criteria

We have identified four of the 15 restoration criteria as being the most importance relative to restoration feasibility; when developing the integrated restoration feasibility assessment in Chapter 6, these four criteria are given the greatest weight. These four criteria are:

H-1) Dependency upon Adjacent Properties to Reconnect to the Tides
H-2) Extent of Tidal Flood Protection Required
H-3) Average Diked Lands Elevation
H-4) Hydrologic and/or Hydraulic Limitations

Dependency upon Adjacent Properties to Reconnect to the Tides (H-1)

A basic requirement of tidal restoration is the ability of the tides to reach a restoration site. Suisun Marsh consists of several leveed islands with numerous properties within each island. Many of these islands have Reclamation Districts that maintain the perimeter levees (see **Figure 25**). Properties that do not have any tidal frontage are entirely dependent on restoration of adjacent lands in order to be restored themselves. Thus, these properties must be restored as part of restoration clusters. Most of these properties are located on Grizzly Island, a few are located on Van Sickle Island, and another few are located in the northwestern corner of Suisun (**Figure 13**). The remainder of properties within Suisun Marsh have at least some ability for a direct connection to tidal sloughs or bays though in some cases those sloughs may be quite small.

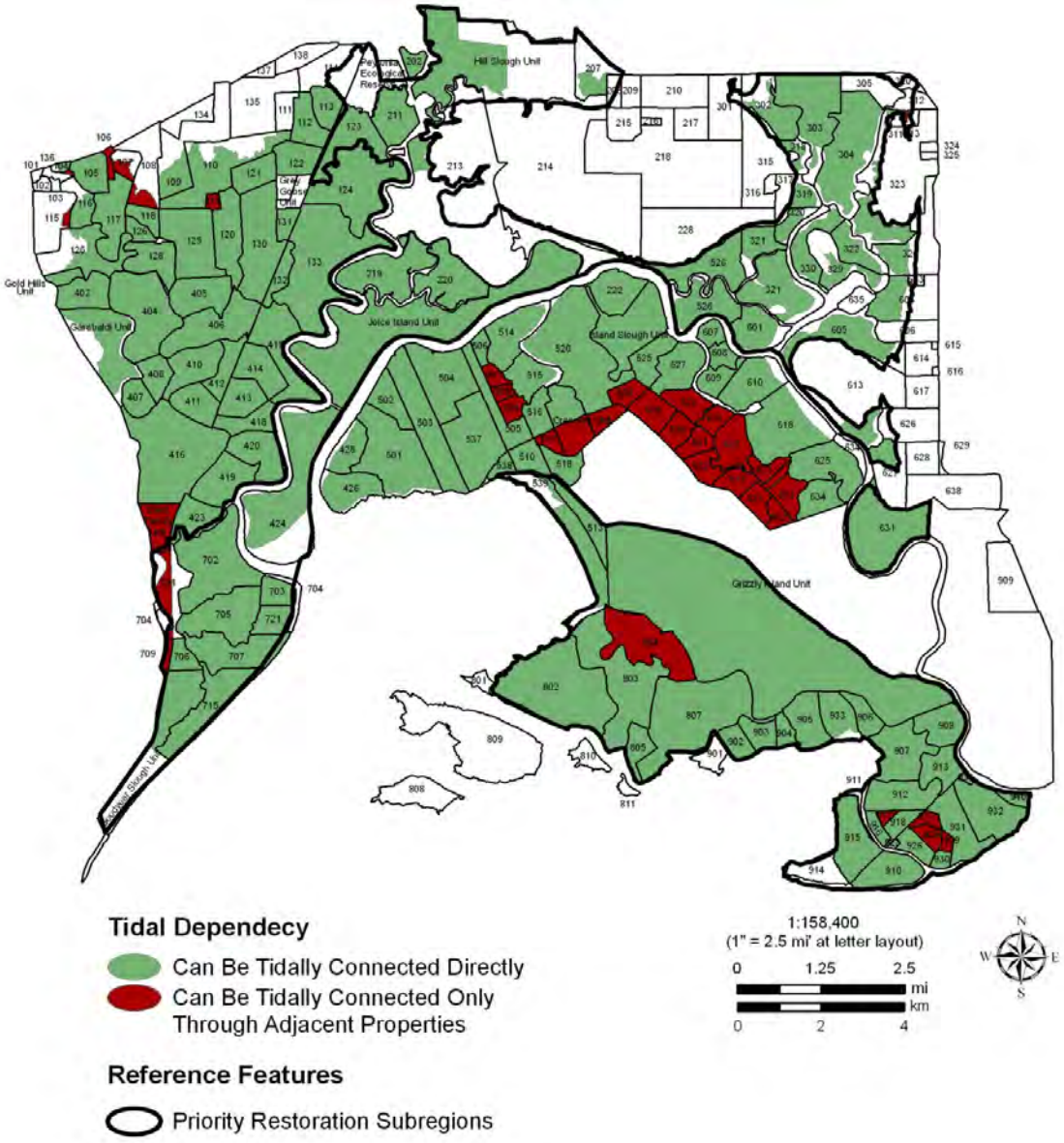


Figure 13. Feasibility: Tidal Dependency of Linking to Adjacent Clubs, by Property

Extent of Tidal Flood Protection Required (H-2)

Building on the concept that levees are anathema to ecosystem restoration from an ecological as well as economic perspective (see discussion above in Chapter 4 of Volume II), we now want to examine the extent of tidal flood protection of adjacent lands that would be needed for each property to be restored. The metric for this criterion is the percent of the restoration property boundary that is adjacent to diked lands that would continue needing flood protection from tidal waters.

The most feasible property requires no tidal flood protection at all, which means its border are either all tidal waters or a combination of tidal waters and upland edge. Next most feasible would be 'peninsula' properties (e.g., Blacklock) that have a relatively small amount of levee needing to maintain tidal flood protection. The low feasible properties are those with extensive boundaries to other diked managed wetlands. The least feasible properties are those with zero tidal waters or natural uplands boundaries (i.e., fully interior to an island).

Figure 14 maps this criterion for each diked property in Suisun Marsh when considering restoration at the individual property. **Figure 15** maps this same criterion when restoration clusters (**Figure 12**) are considered. The ranking still applies to each diked property but its assigned value reflects its improved feasibility by being restored as part of a cluster.

The side-by-side comparison of restoring properties as individual properties (**Figure 14**) vs. restoration clusters (**Figure 15**) is immediately apparent: the clusters make a demonstrable improvement in restoration feasibility on the single most costly and ecologically intrusive aspect of the restorable lands in Suisun: tidal flood protection levees. These findings provide very strong support to pursuing restoration at the cluster level.

What **Figure 15** does not illustrate is a higher-level grouping of restoration clusters in the southeast restoration priority subregion. Specifically, maintaining tidal flood protection of the Roaring River Distribution System could be eliminated if all restoration clusters were restored and it could be greatly reduced with the combination of restoring the Grizzly Island, Simmons Island, and Honker Bay clusters collectively.

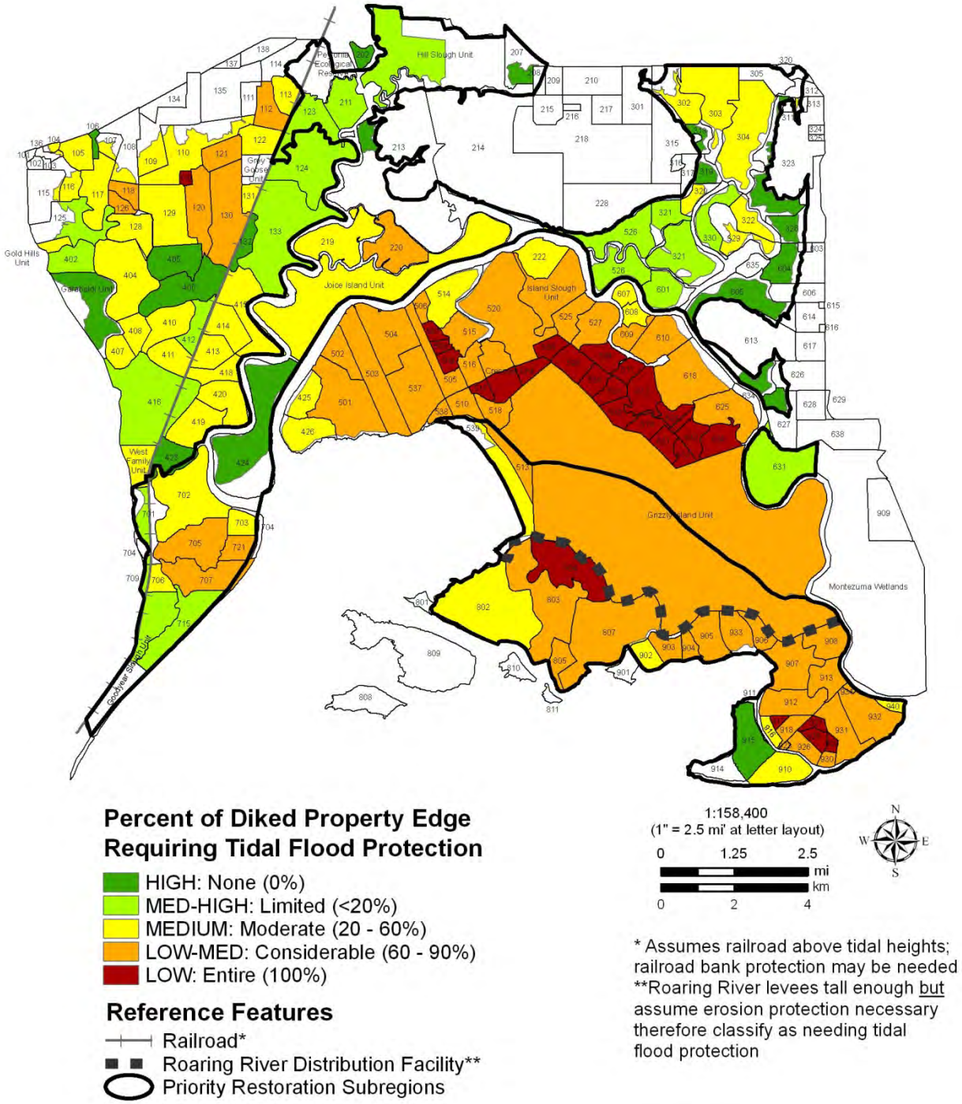


Figure 14. Feasibility: Tidal Flood Protection Requirements, by Property

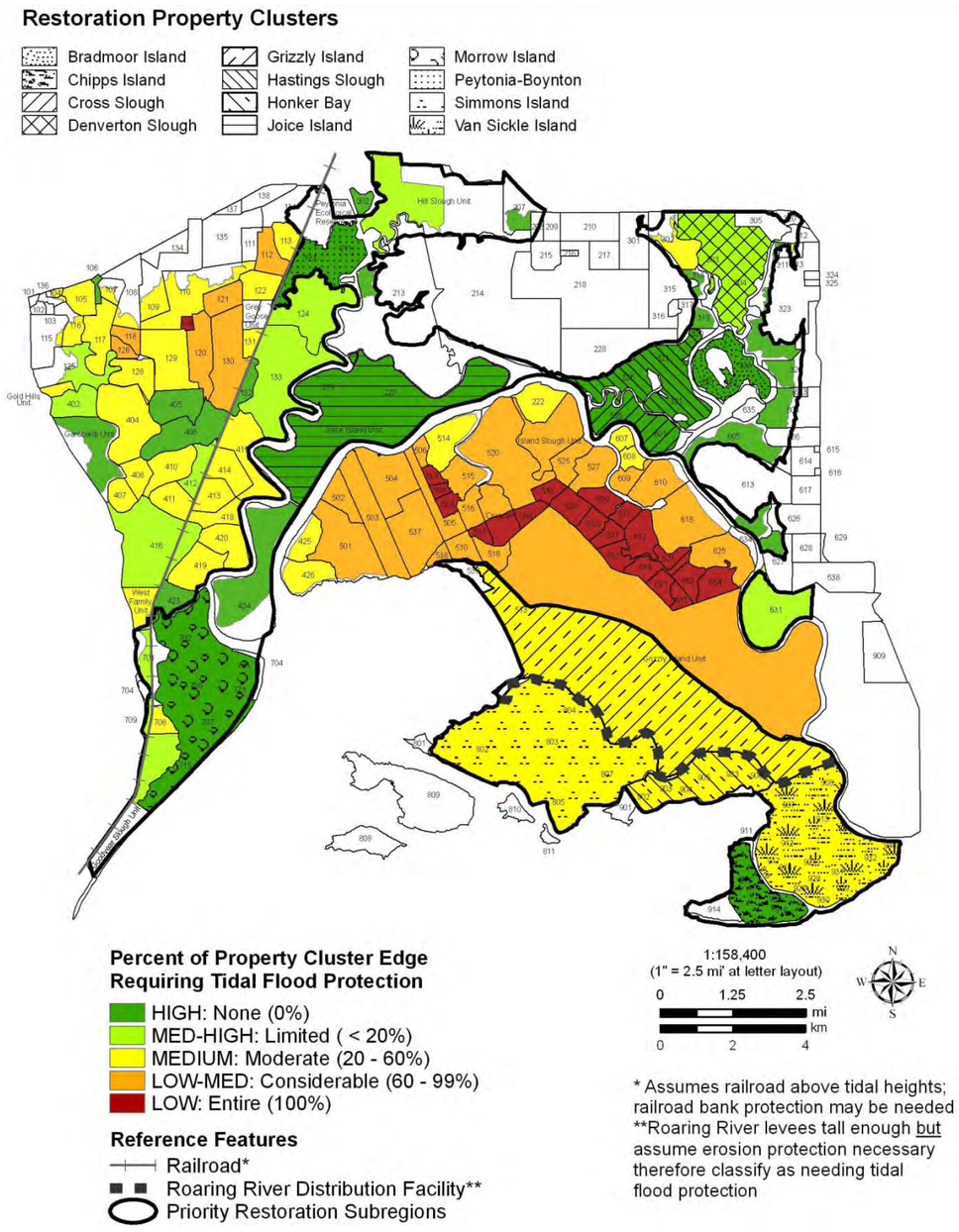


Figure 15. Feasibility: Tidal Flood Protection Requirements, with Restoration Clusters

Average Diked Lands Elevation (H-3)

Figure 16 shows the average elevation for each diked property, based on the 2005 LiDAR data that DWR adjusted as an approximation to account for vegetation interference with the LiDAR measurements. Consequently, these data must be considered approximate and restoration planning requires some degree of data validation. Figure 4 shows the topographic detail; here we average that data for quick reference. Higher elevation properties will restore to emergent tidal marsh more rapidly. The most subsided properties could remain shallow open water for extended periods of time if they are in areas of low sediment supply and high wave energy.

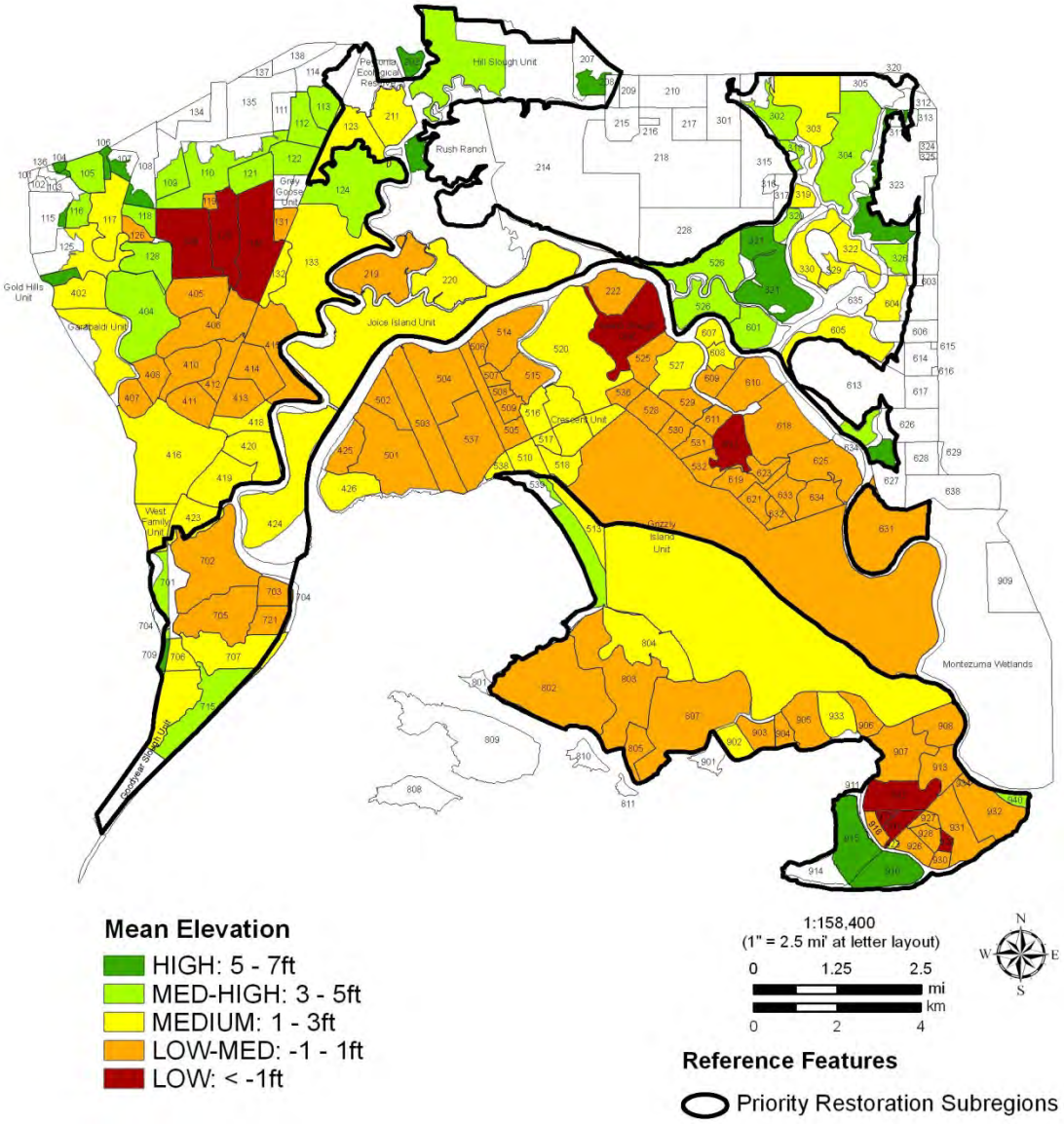


Figure 16. Feasibility: Average Land Surface Elevation of Each Diked Property

Source: LiDAR adjusted downward 1.5 ft to account for vegetation interference (DWR 2005)

Hydrologic and Water Quality Limitations (H-4)

Three considerations related to hydrology impose constraints for restoration in certain regions of Suisun Marsh: water quality, limits on tidal exchange, and effects on tide stage. Areas of Suisun with relatively long, small tidal sloughs that connect to a large number of diked managed wetlands are of particular concern. These sloughs include all those tributary to Suisun Slough along the western Marsh (longest and smallest), Nurse and Denverton Sloughs in the northeast to some extent (not quite as long and not quite as small), and to a limited extent Hill Slough in the north (also not quite as long and with far fewer diked managed wetlands).

Water Quality. First is that the tidal excursion distance of these long, small peripheral sloughs is less than the length of the sloughs themselves (C. Enright in WWR 2011). In these circumstances residence time increases which can promote aquatic productivity (phytoplankton and zooplankton) but also can limit tidal mixing of the wetland and aquatic productivity downstream to the larger sloughs and bays more abundant in fishes. In other words one of the intended benefits of restoration – aquatic food web support – is limited in effectiveness. The second is that low dissolved oxygen sags have a moderate likelihood of occurring in these sloughs in the fall and winter under certain circumstances of managed wetlands flood and drain operations combined with external factors like warm weather in the fall and low rainfall limiting creek runoff (Siegel et al. 2011). Low DO can limit access to upstream aquatic habitats by those fishes intolerant of these low DO levels and, in extreme circumstances, can result in fish mortality. It is also possible but not evaluated that aquatic and benthic invertebrates may be reduced in abundance in areas affected by low DO conditions. Low DO conditions have been documented for some sloughs (e.g., Peytonia, Boynton, Goodyear) but evaluations have not taken place for any sloughs upstream of the railroad line in the western Marsh. Some sloughs have winter creek inflows that, when large enough during winter storms, can help to ameliorate some of these water quality and tidal mixing considerations.

Effects on Local Tide Stage. Restoring tides to a diked managed marsh can have two mechanisms that dampen tidal range upstream and/or downstream of a restoration site. Upstream effects can result from a restoration diverting tidal energy in a slough into the restoration site at the expense of tidal energy upstream of the restoration (e.g., Noble Consultants 2006 modeling of Novato Creek effects of the Bel Marin Keys restoration; **Figure 17**). The diverted tidal energy results in a dampening of the tides upstream of the connections into the restoration site. Downstream effects can result from a restoration functioning as a large reservoir of water (i.e., large tidal prism) that drains throughout the ebb tide cycle and, by its continuing to supply a slough with upstream inflows during ebb tide, results in higher water levels at low tide. The magnitude of these two effects is a function of the tidal prism of the

restored property (size and extent of subsidence), the size of the water body onto which the levee breaches are connected, and the length of slough before reaching open water areas. Large, subsided sites along small, long tidal sloughs would result in a large tidal dampening effect whereas a small, higher elevation site along a major slough or bay would be result in minimal if any effects. Tidal dampening is of considerable concern for water management operations in all the diked managed wetlands subject to the dampened tides, as nearly all managed wetlands in Suisun depend upon gravity flooding and draining with the tides.

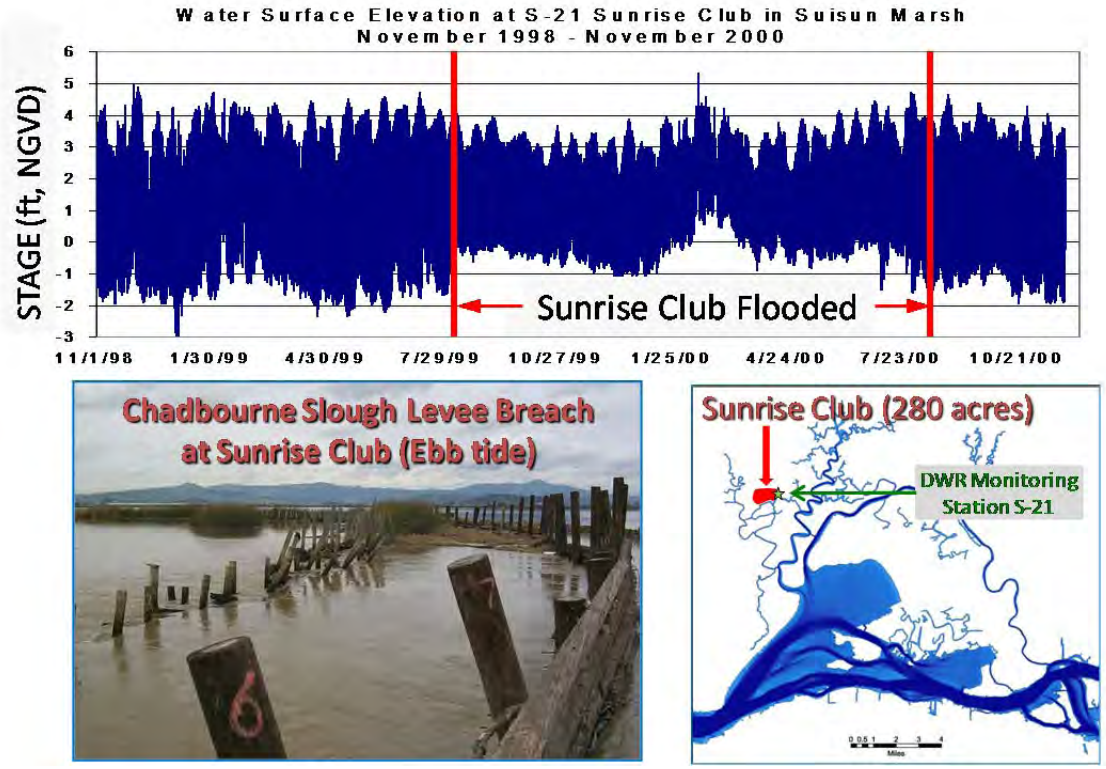
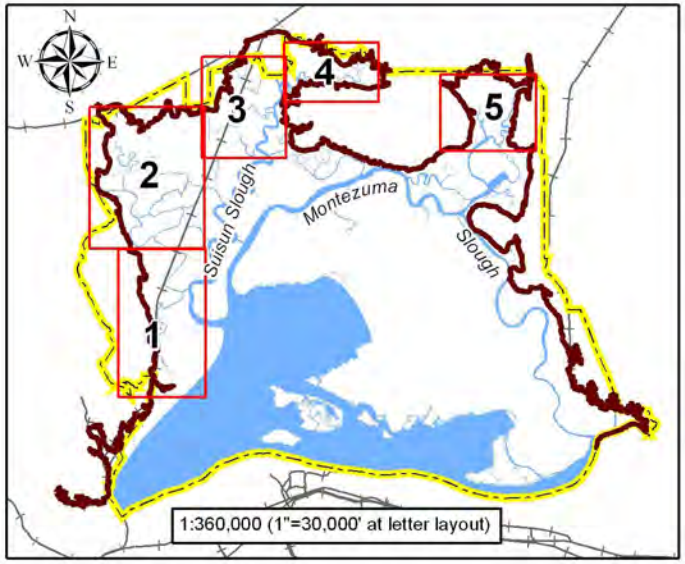


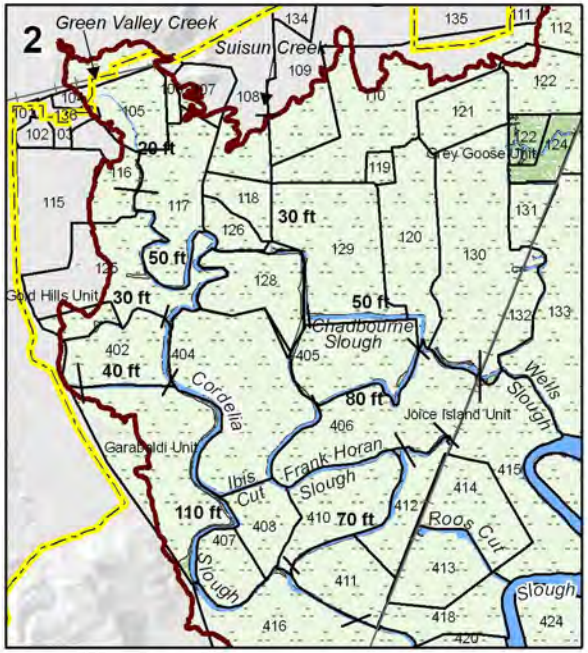
Figure 17. Tidal Dampening with Tidal Restoration Projects

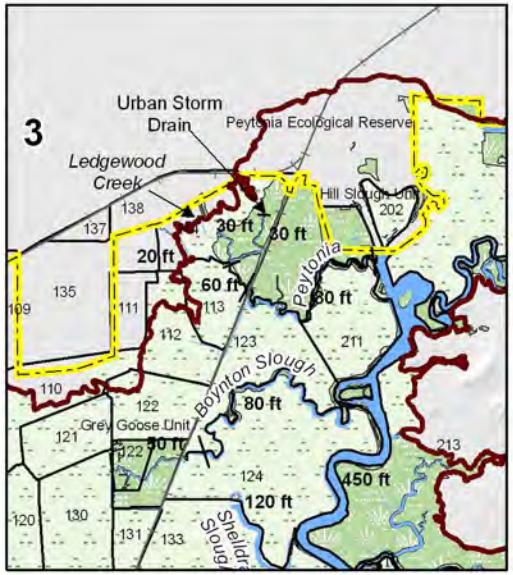
Source: Chris Enright (DWR/DSC). These data show the effects on tidal range due to a levee breach on a property alongside a smaller peripheral slough in Suisun Marsh. Levee breach occurred in July 1999 on a 280 duck club in northwest Suisun Marsh. The upper chart shows tidal stage between November 1998 and September 2000. The breach was open between July 1999 and July 2000. The DWR stage gage is within one-quarter mile of the breach and recorded a significant reduction of the tidal range while the breach was open. The distributary channels leading to the site experienced higher tidal flows to accommodate the expanded tidal prism.

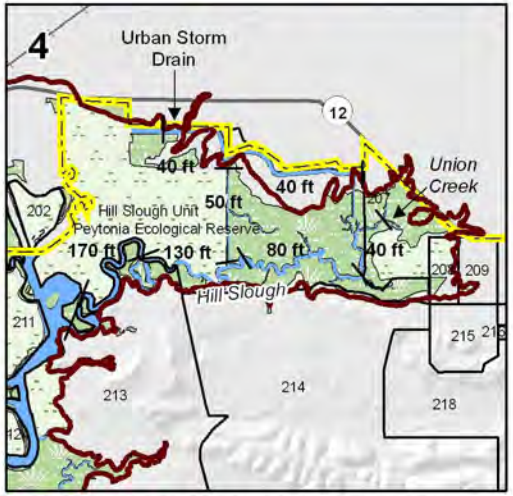
Limits on Tidal Exchange West of Railroad. There are a total of six tidal slough crossings beneath the railroad line in western Suisun Marsh. These crossings vary in size and in nature of their construction but all are designed to support rail traffic and thus are hardened against scour of their footings. The resulting fixed cross sectional dimensions of these crossings impose a limit on the volume of tidal exchange possible without risking damage to the crossings. Consequently, the amount of tidal restoration upstream (west) of the railroad is limited to that

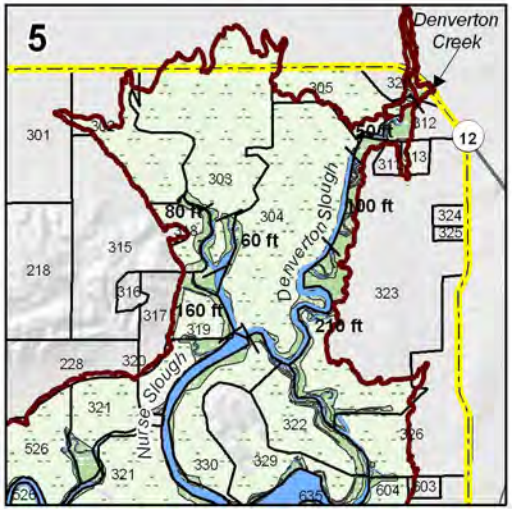
which these crossings can accommodate in their present conditions, unless restoration includes the very costly and logistically complicated process of replacing these crossings. The quantitative limits of these crossings on tidal exchange has not been analyzed but could be estimated through numerical hydrodynamic modeling.











***slough widths measured on 2009 NAIP air photo**

Suisun Marsh Protection Plan Boundary
Historic Bayland Margin
Railroad
Existing Tidal Marsh
Diked Marsh
Club IDs

1:90,000 (1" = 7,500' at letter layout)
*applies to all frames except where noted

0 3 6 mi
0 5 10 km

Data sources: tidal sloughs (CDFG, USGS various years); railroad (USGS); Historic Margin (SFEI 1998)
Produced by WWR, May 2011
map file: perimeter-slough-widths-suisun_AL_1149_2011-0928mdl.mxd

WETLANDS AND WATER RESOURCES

WIDTH OF PERIMETER SLOUGHS IN SUISUN MARSH

Suisun Marsh
Solano County, California

May 2011 | Project No. 1149 | **Figure 18**

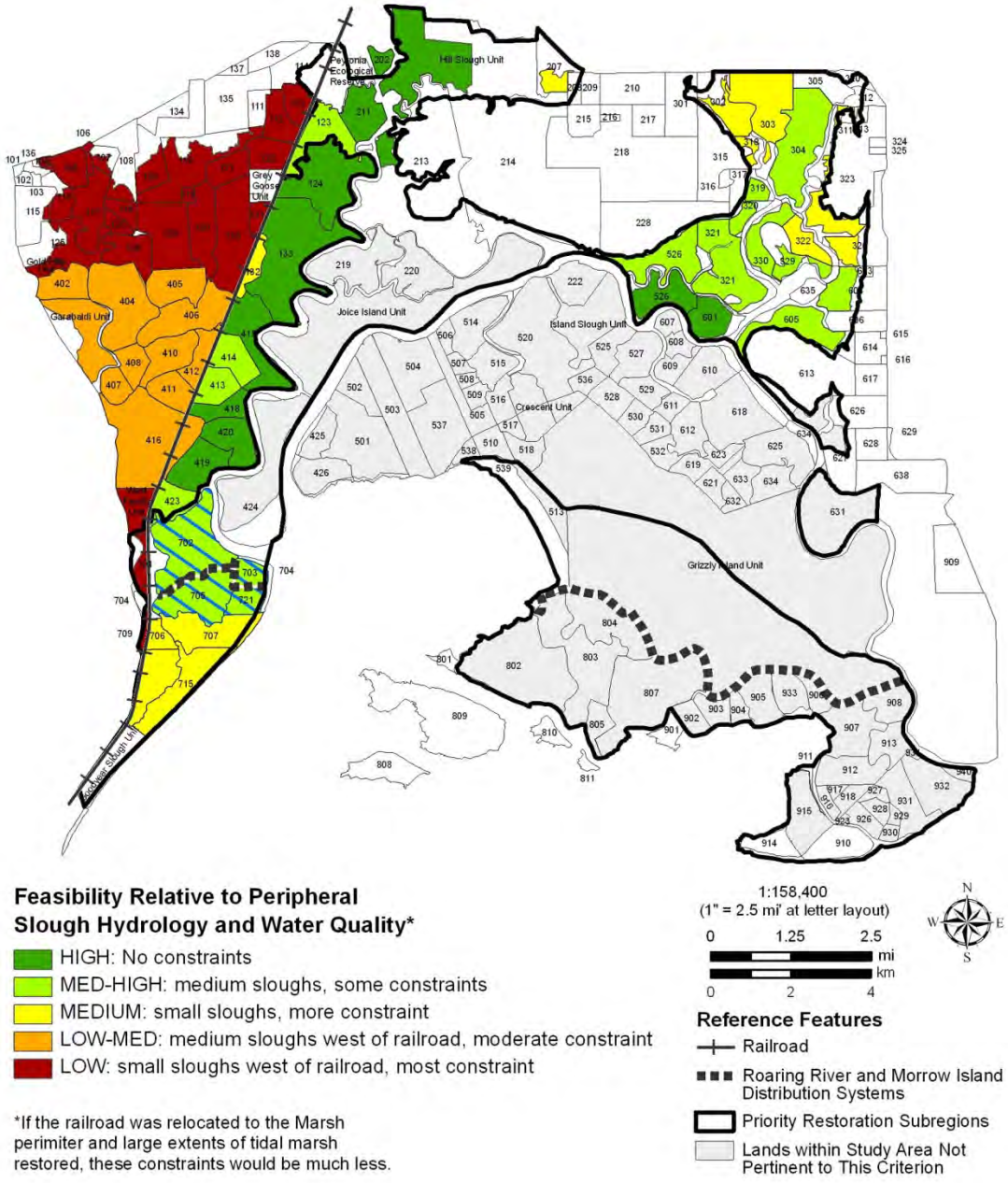


Figure 19. Feasibility: Hydrologic and Water Quality Constraints in Peripheral Sloughs

5.2 Medium-Priority Restoration Criteria

We have identified nine of the 15 restoration criteria as being of moderate importance to restoration feasibility, relative to the other criteria; when developing the integrated restoration feasibility assessment in Chapter 6, these seven criteria are given a moderate weighting. These eight criteria are:

M-1) Gas wells
M-2) Pipelines
M-3) Salt marsh harvest mouse conservation areas
M-4) Land ownership type
M-5) Reclamation Districts
M-6) Extent of invasive plants (*Phragmites* and *Lepidium*)
M-7) Extent of natural upland edge
M-8) Extent of Remnant Tidal Sloughs
M-9) Number of properties within restoration cluster (applicable to restoration cluster analysis only)

Gas Wells and Mineral Rights (M-1)

Natural gas production has a long history in Suisun Marsh and is incorporated into the Suisun Marsh Protection Plan. In Suisun Marsh, there are five types of gas wells present: plugged, cancelled, idle, new, and active (**Figure 20**). Where active, new, and idle gas wells are present, we assume their ongoing operations will require accommodation (e.g., access) or termination of their production as part of restoration activities, making restoration feasibility comparatively low. The California Department of Oil, Gas, and Geothermal Resources (DOGGR) may require 're-abandonment' of plugged wells when construction of any structure over or in the proximity to a well could result in a hazard (PRC Section 3208.1); consequently, we assume presence of any plugged (or cancelled) wells could require added site requirements and thus results in a medium feasibility ranking. Where no gas wells are present we assume no effect on restoration feasibility. **Figure 21** shows the resulting feasibility ranking for gas wells.

Mineral rights have not been researched for this Strategic Plan. Given that Suisun Marsh is a known region of natural gas reserves (BCDC 1976), it is safe to assume that ownership of mineral rights is an important aspect of restoration feasibility. Consequently, it is an element of due diligence that must be examined as part of any restoration project. If mineral rights remain intact for a restoration site, then a restoration effort has the choice of seeking their acquisition and extinction which lays the concern to rest or incorporating future accommodation of access and drilling pad construction and possible pipeline construction into the restoration design.

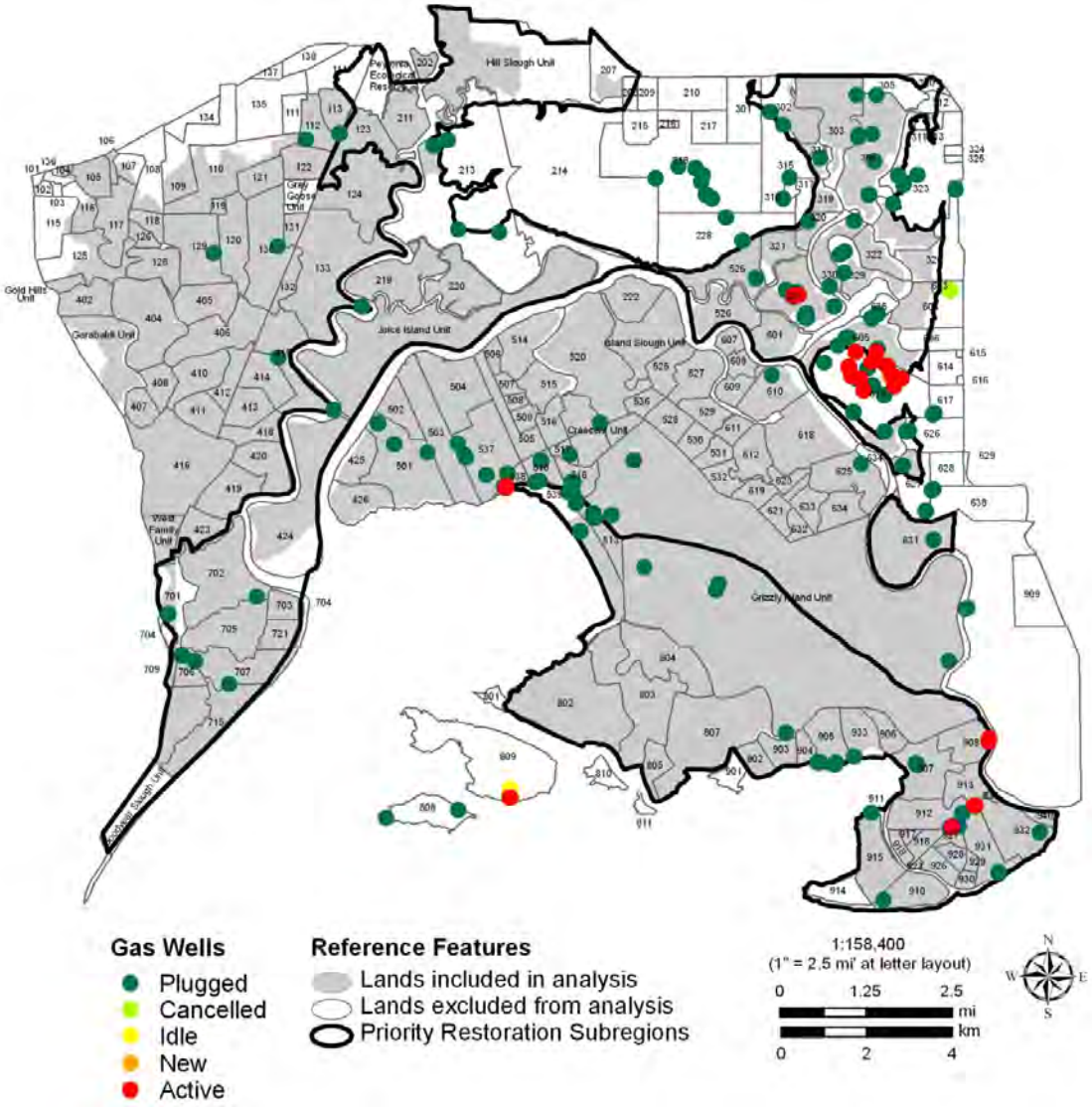


Figure 20. Gas Well Locations and Operational Status

Source: Data from Department of Oil, Gas and Geothermal Resources, March 2011

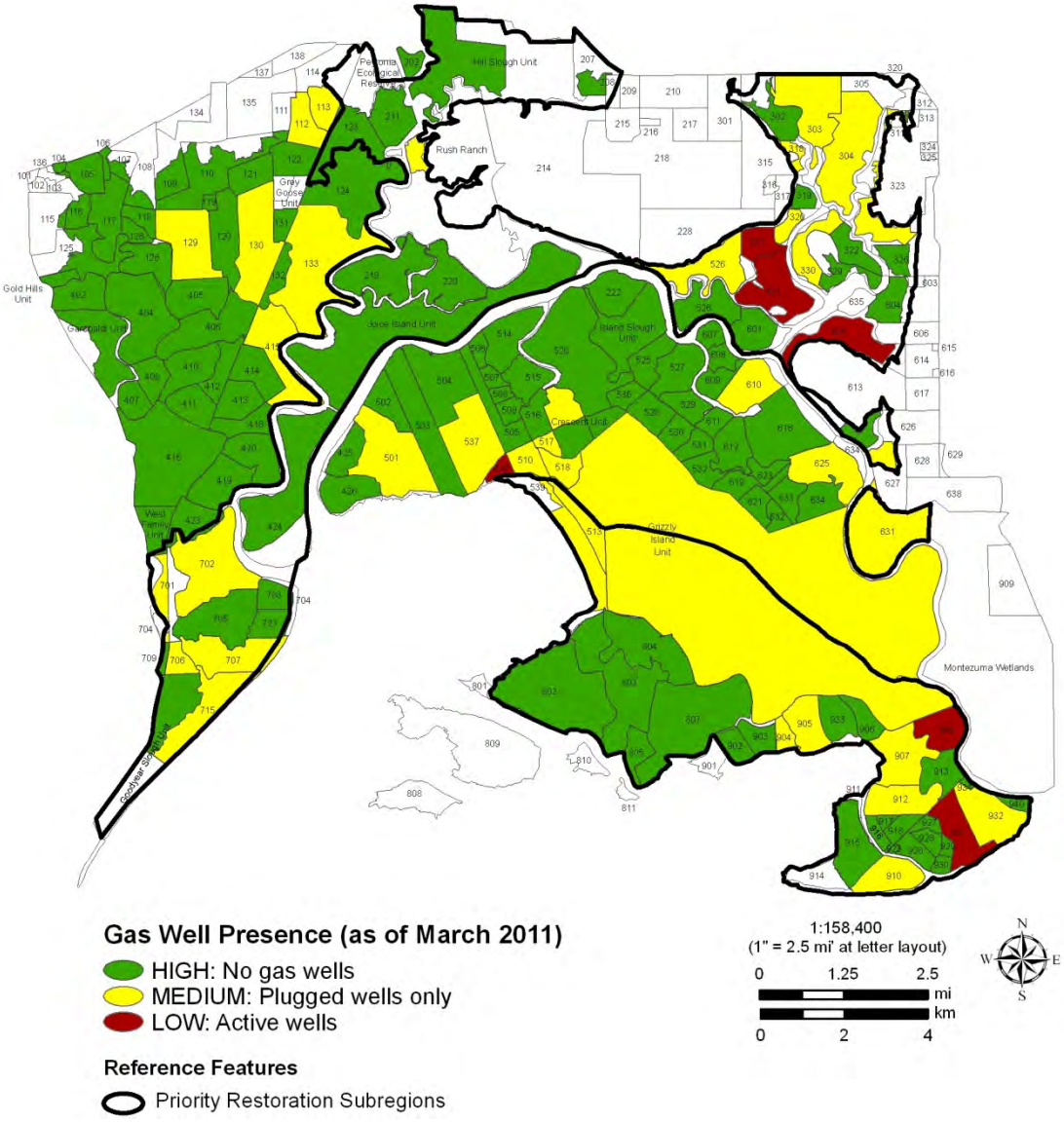


Figure 21. Feasibility: Gas Well Effects on Restoration Feasibility, by Property
Source: Data from Department of Oil, Gas and Geothermal Resources, March 2011

Pipelines (M-2)

Several active underground pipelines cross Suisun Marsh, carrying natural gas, crude oil, and refined petroleum products. From a restoration perspective, the presence of pipelines presents two questions. First, how can access be accommodated in case future maintenance or repairs are needed. Second, would pipelines be at risk of damage from tidal scour. As **Figure 22** shows, most of these pipelines are located around the perimeter of Suisun Marsh. Addressing these pipelines relative to these two questions is assumed not to pose a significant restoration constraint as the pipelines are either upland of restorable lands or on their margins. As for all pipelines, site-level knowledge would have to be obtained prior to pursuing an acquisition. One

pipeline parallels the rail line in the western marsh; we assume it is located within or very close to the railroad right-of-way; we have not investigated whether it is located east or west of the rail. Were restorations along this corridor to be considered, it is assumed that providing an upland cover, such as in the form of a low-slope berm abutting the rail line, would address the two questions.

The remaining three pipelines cross through the eastern Marsh and require the most significant consideration for restoration. These pipelines cross Suisun Bay from Contra Costa County, traverse two properties south of Roaring River (905 and 933), the DFG Grizzly Island property north of Roaring River, across Montezuma Slough and through Meins Landing (property 631), then into uplands on the east side of Suisun Marsh. DWR, which purchased Meins Landing for tidal restoration, has at this time suspended restoration planning of this property because of potentially high costs to address the pipelines. Options considered at Meins Landing included locating breaches away from the pipelines along with adding ballast, constructing berms through the property to cover the pipes (which would divide the restoration into cells), and relocating the pipelines around the perimeter. Properties 905 and 933, the owners of which have expressed interest in their restoration, poses the same questions as does Meins Landing. In all these cases, the existing depth of the pipelines, their design, and whether they have ballast installed all affect how they may be addressed in restoration. Another question raised for these pipelines is that product release into the tidal environment were a pipeline leak to occur. What would need to be examined in this context is whether the pipelines would need to be upgraded to match existing construction where they already cross tidal areas or if they are already at the same design level.

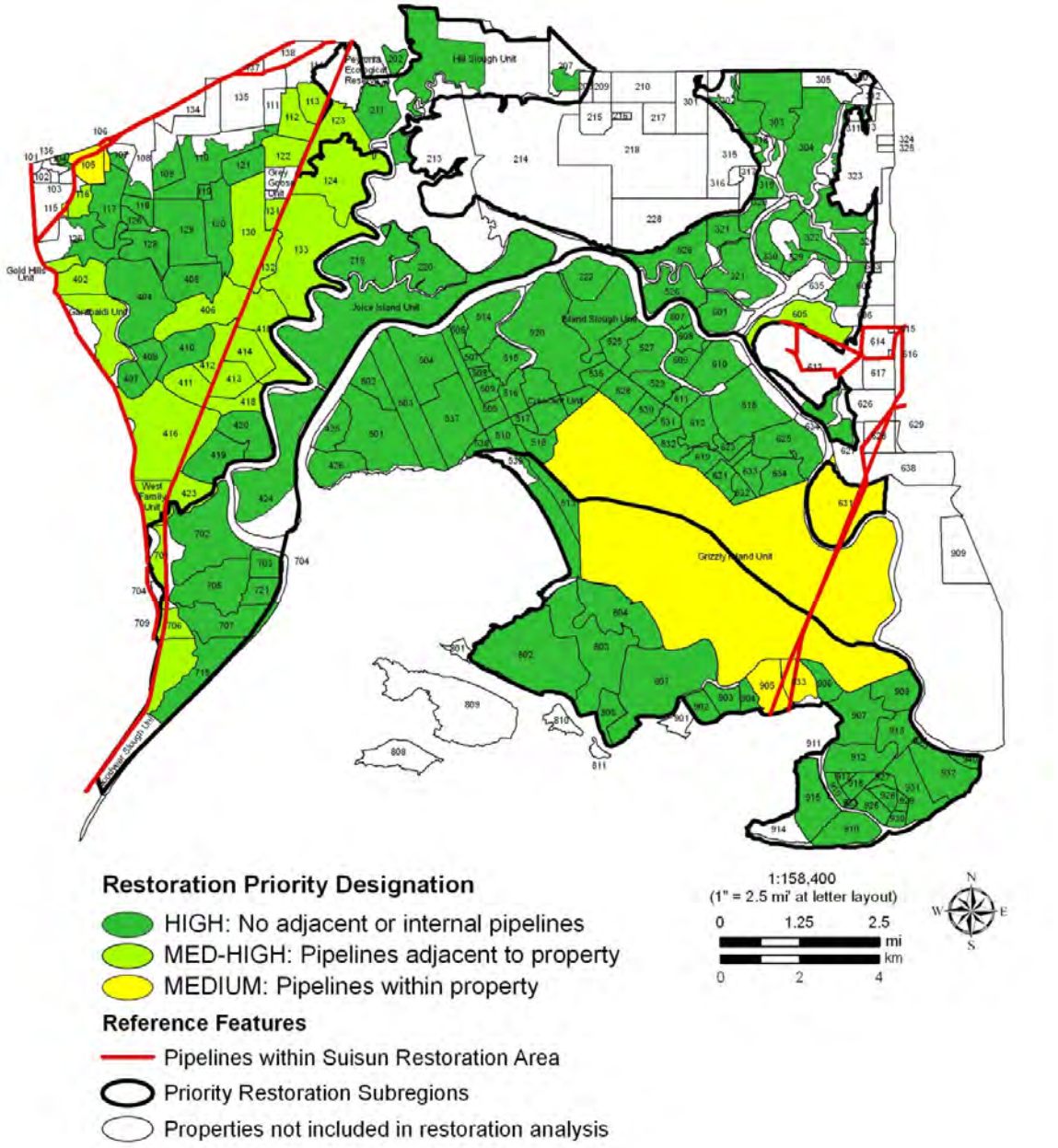


Figure 22. Feasibility: Pipelines, by Property
Source: digitized from USBR et al. 2010

Salt Marsh Harvest Mouse Conservation Areas (M-3)

Several Conservation Areas have been set aside in Suisun Marsh for the purpose of supporting recovery of the state and federally endangered salt marsh harvest mouse. These conservation areas exist on diked and tidal marshlands (**Figure 23**). The effect of these Conservation Areas will matter only if tidally restored conditions would not be conducive to supporting salt marsh harvest mice (USBR et al. 2010) which could be the case in the fresher regions of Suisun toward the southeast. In those cases, restoration efforts may have to provide replacement

Conservation Areas. As **Figure 23** shows**,** the diked lands with these Conservation Areas are located on Grizzly Island and in Hill Slough; DFG owns all these properties (**Figure 24**). The Grizzly Island Conservation Areas might raise concerns; the Hill Slough property would probably support suitable vegetation for salt marsh harvest mice given its higher elevations.

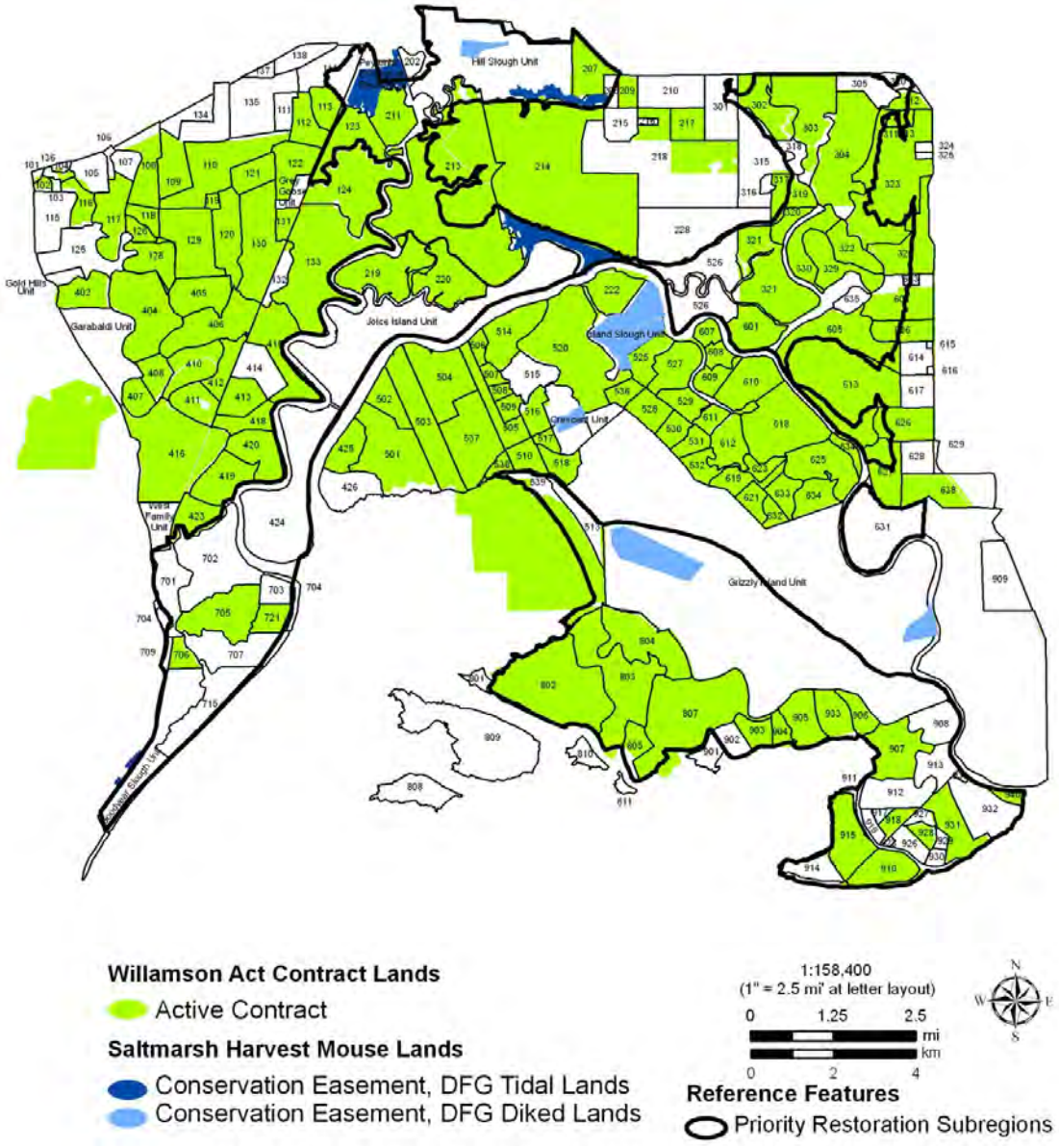


Figure 23. Salt Marsh Harvest Mouse Conservation Easements and Williamson Act Contracts, by Property

Source: SMHM Conservation Easements from DFG 2008; Williamson Act contracts from Solano County Assessor's Parcel database accessed March 2011

Land Ownership Type and Inclusion in Priority Restoration Subregions (M-4)

Figure 24 shows the landowner type for each property in Suisun: private, Department of Fish and Game, and other public lands (Suisun Resource Conservation District, Department of Water Resources, Rush Ranch, Fairfield-Suisun Sewer District, and the U.S. Navy). These landowner types represent the groups with whom negotiations must occur to bring land into restoration. Public lands may involve less complex efforts to bring them into restoration; in fact, some of these properties were acquired specifically for restoration (Blacklock, restored 2006; Meins Landing, may or may not be restored) and others (Hill Slough) are currently being planned for restoration. Private landowners require participation in restoration either through acquisitions or other forms of entitlement.

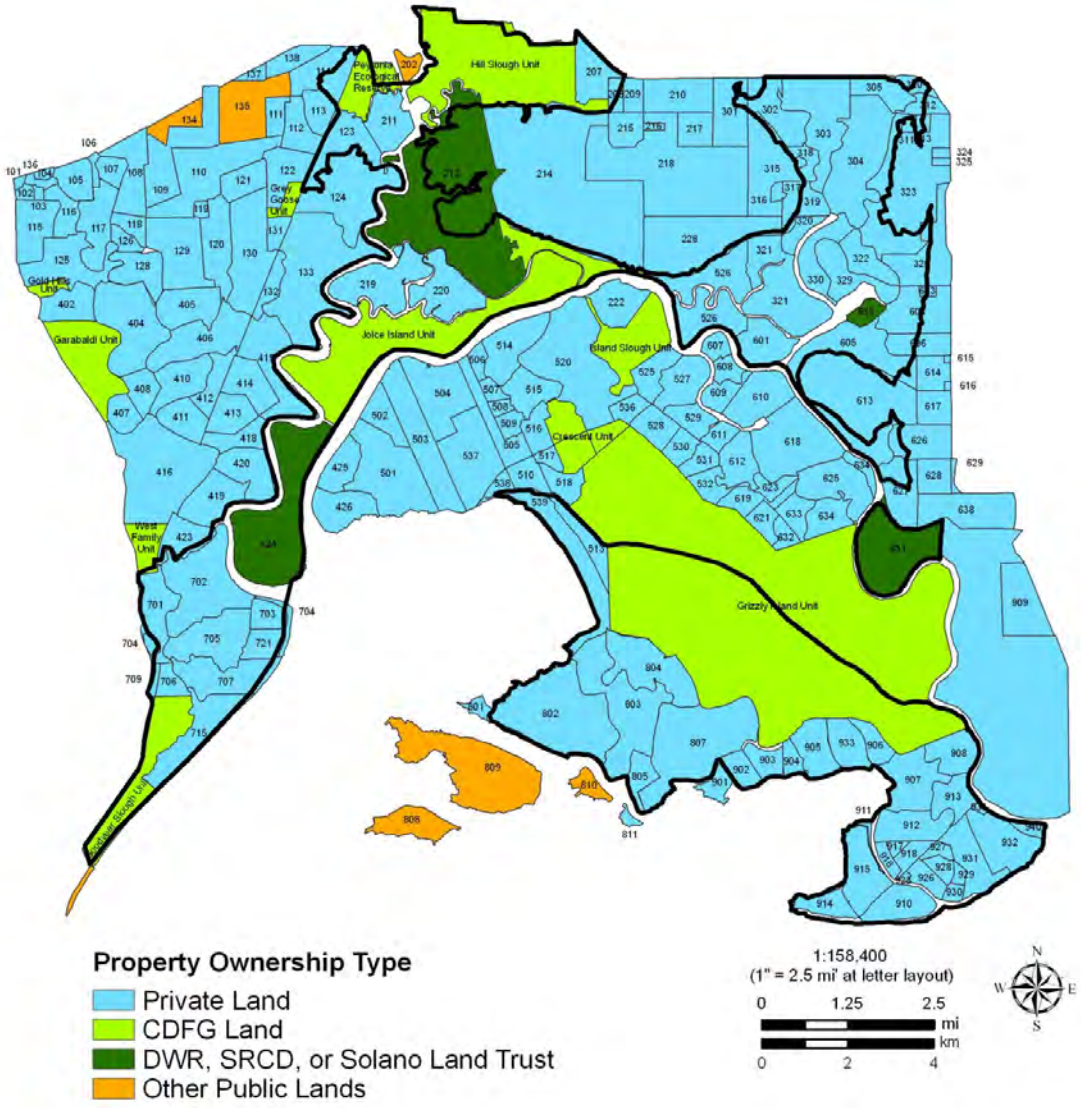


Figure 24. Ownership Type, by Property
Source: Suisun Resource Conservation District, Wetlands and Water Resources

Reclamation Districts (M-5)

Figure 25 shows the location of the many levee reclamation districts in Suisun. Reclamation Districts serve the purpose of maintaining perimeter levees to protect against tidal flooding and are comprised of landowners within their borders that are assessed levee maintenance fees. Restoration efforts that comprise portions of a Reclamation District will have to include levee upgrades that allow for continued tidal flood protection of remaining lands within the District. Restoring contiguous properties and ideally all properties within a District reduces or eliminates this issue.

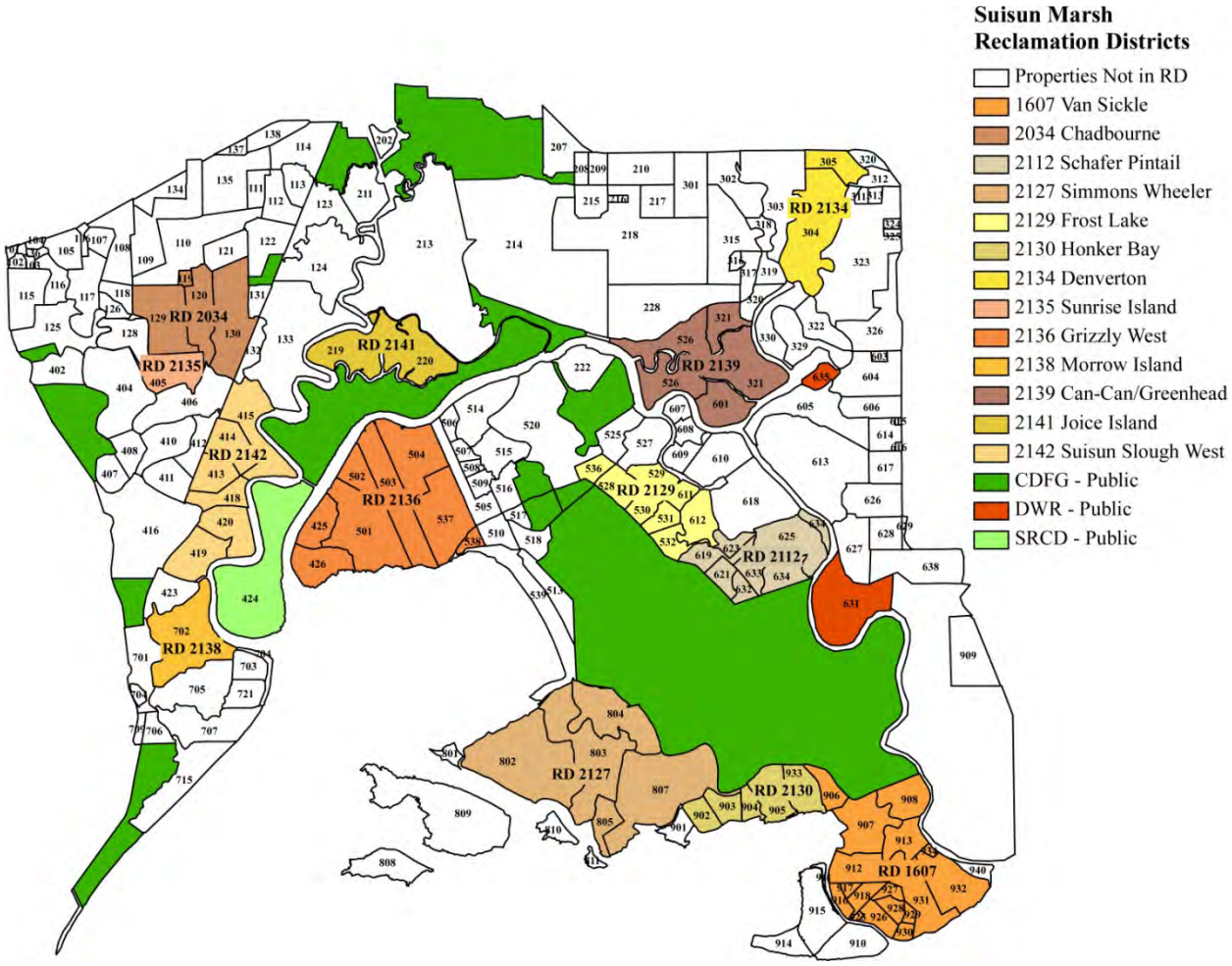


Figure 25. Reclamation Districts in Suisun
Source: Suisun Resource Conservation District

Extent of Invasive Plants (*Phragmites* and *Lepidium*) (M-6)

The presence of the two invasive plant species of concern in Suisun – *Phragmites australis* and *Lepidium latifolium* – have the potential to complicate tidal restoration efforts. Where either of these species is present within or nearby to a restoration site, restoration efforts may require control measures prior to constructing the restoration project along with post-restoration

monitoring and early control efforts to try and avoid its colonization and establishment. Both species are challenging to control and require either herbicide application and/or physical removal though the latter must be done with great caution so as not to create propagules that can disperse widely.

There are several other invasive plant species found in the diked and tidal marshes in Suisun but to date have not exhibited the same level of dominance and tidal restoration may eradicate populations on a restoration site either through submergence or pre-restoration removal. These other species include: yellow star thistle (*Centaurea solstitialis*), black rush (*Juncus gerardii*), hybrid smooth cordgrass (*Spartina alterniflora* X *foliosa*), wild celery (*Apium graveolens*), brass-buttons (*Cotula coronopifolia*), and narrow-leaf cattail (*Typha angustifolia*). This last species may present invasive concerns similar to Phragmites (WWR 2010).

Phragmites (*Phragmites australis*). Phragmites is a tall emergent wetland plant tolerant of a greater degree inundation and thus it is capable of growing at lower elevations in restored marshes. It is a widespread invasive plant throughout freshwater and brackish tidal marshes around the United States. It can displace other vegetation resulting in reduced biodiversity and reduction in insect, avian, and other animal assemblages. Other ecosystem services such as sediment retention and flood attenuation have not been documented to be diminished (Chambers et al. 1999).

Broad-leaved pepperweed (*Lepidium latifolium*). This clonal forb is the most invasive plant in emergent marsh of brackish to oligohaline reaches of the estuary. It ascended from a common to widespread dominant weed in this region between the 1980s and 1990s, and abruptly increased in abundance and distribution following the 1998 El Nino event. It readily forms monotypic stands or similar monotypic canopies above shaded persistent antecedent marsh vegetation it invades. Broadleaf pepperweed is a dominant species of the southern marsh plains (slough system) of Rush Ranch (**Figure 26**), but has remained a frequent but marginal element of high fringing marsh vegetation along Suisun Slough and Hill Slough. It is not known whether its limited abundance in local fringing marshes is due to greater resistance to invasion, or circumstantial factors (timing, disturbance opportunities). Pepperweed control in brackish marshes is problematic because of many factors, including important native species diversity or special-status plants around or beneath pepperweed canopies, limited efficacy of most herbicide and surfactant combinations currently available for use in estuarine marshes, problematic indirect or non-target impacts of effective herbicides, and high clonal persistence of colonies. Pepperweed is apparently suppressed in seasonal wetlands of alluvial fans by intensive cattle grazing above Grizzly Island Road, and summer desiccation of saline/alkaline

soils below the road, but little is known about factors controlling its spread in local terrestrial wetlands.

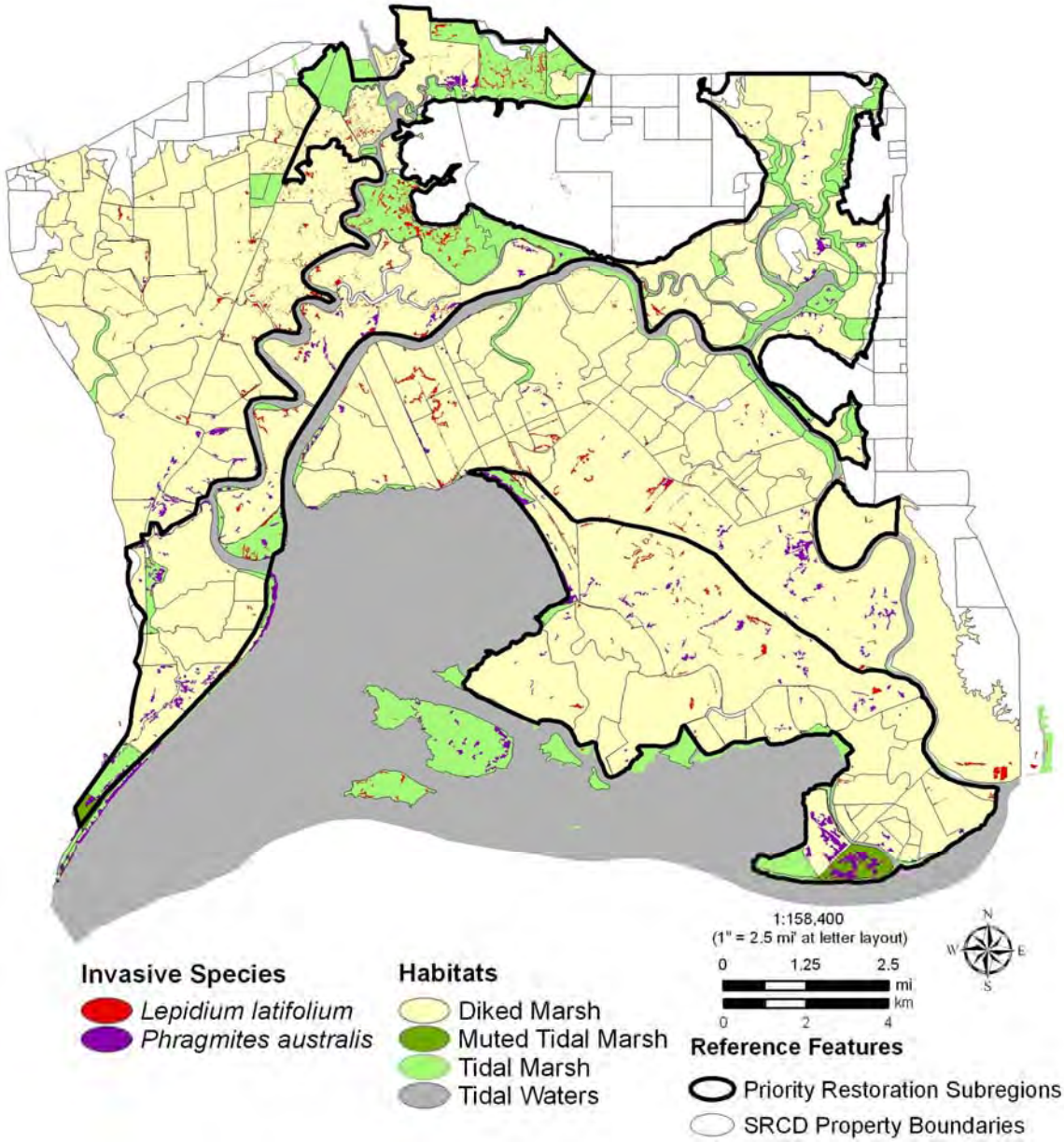


Figure 26. *Phragmites* and *Lepidium* Distribution, Circa 2006

Source: Department of Fish and Game Vegetation Survey, 2006; Rush Ranch surveys

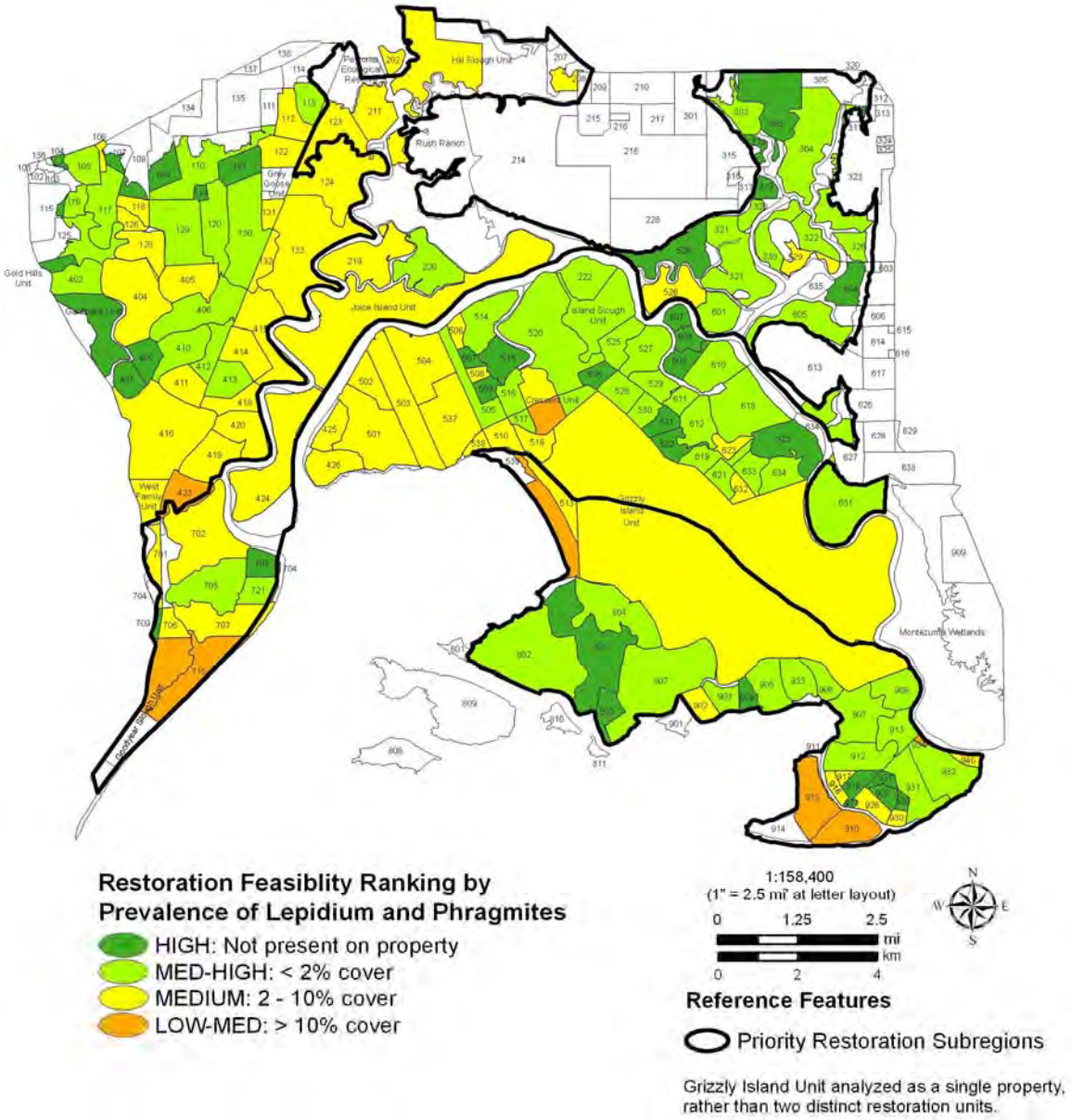


Figure 27. Feasibility: Invasive Plant Species Effects

Extent of Natural Upland Edge (M-7)

Natural upland edge is a highly desirable attribute of a restoration property for two reasons: (1) it provides for a marsh-upland ecotone including all the associated rare species habitats and ecosystem corridors, and (2) it provides for sea level rise accommodation over the long term. These upland edges in Suisun range from fairly steep to quite gentle (see **Figure 4**), with gentle slopes offering greater opportunity for expansive sea level rise accommodation (see Chapter 1). This natural upland edge is quite rare throughout the San Francisco Estuary and its restoration can have a far greater positive impact at the landscape level for natural community restoration.

Figure 28 ranks properties by the absolute extent (in miles) of natural upland edge for each diked property in Suisun. The most feasible properties are those that have a large natural upland edge, such as that found along the north and east boundaries of the Nurse Slough complex, along the eastern side of Montezuma Slough at the Montezuma Wetlands, Meins Landing, and the Kirby Hills properties, the north side of Hill Slough, between Potrero Hills and Highway 12, and quite a bit in the northwest region of Suisun along Highways 680 and 12.

When looking at this same criterion for restoration clusters, the rankings change only for properties in the northeast priority restoration subregion. **Figure 29** displays the side-by-side comparison of upland edge rankings for individual properties (**Figure 29-A**) and for those same properties when considered as part of restoration clusters (**Figure 29-B**). The 'cluster ranking' still applies to each diked property but its assigned value reflects its improved feasibility by being restored as part of a cluster. All but the Cross Slough cluster show a significant improvement in feasibility of restoring the wetland-upland ecotone when utilizing these restoration clusters. Cross Slough is an island so is without an upland edge regardless of whether restored as a cluster.

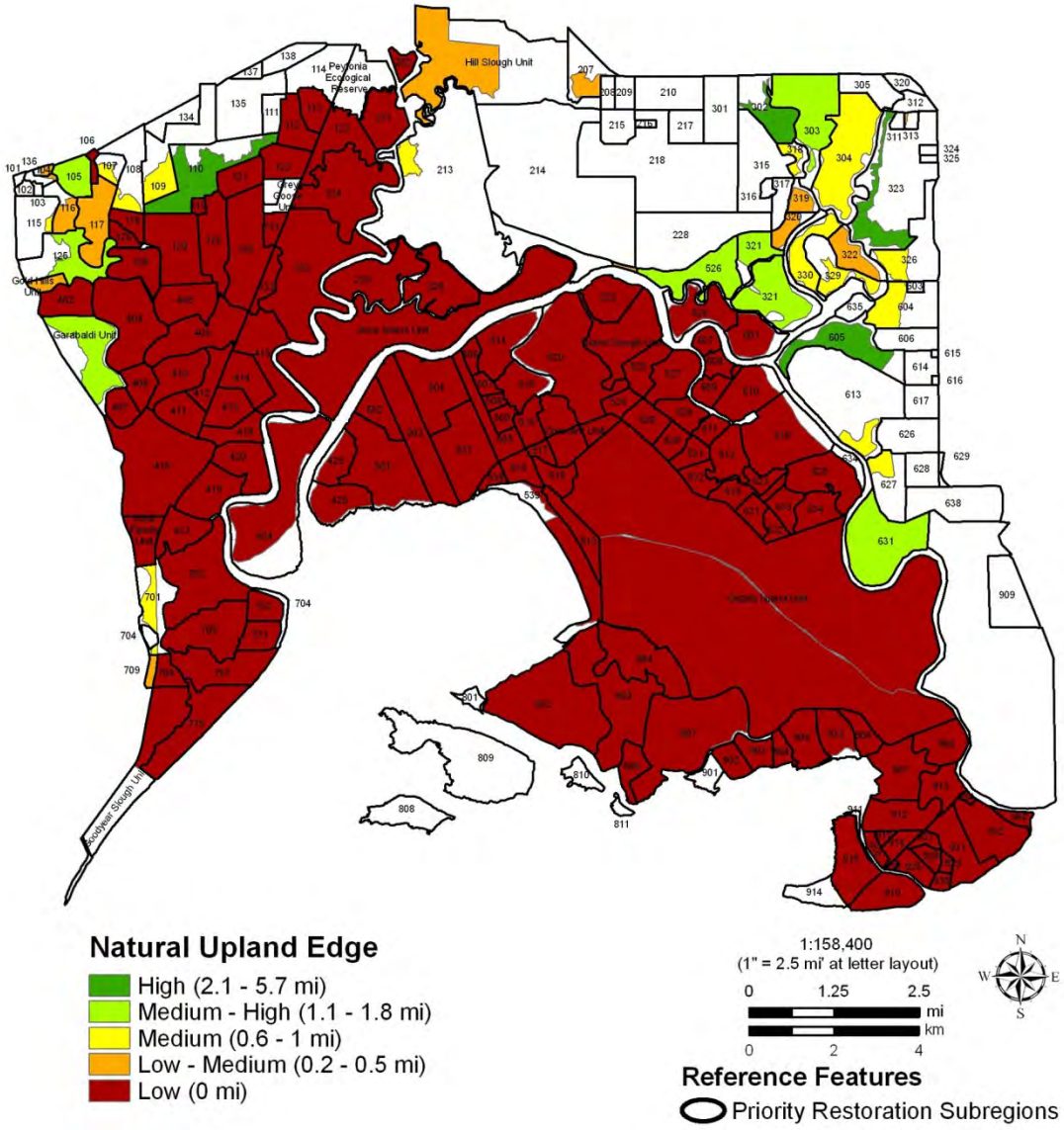


Figure 28. Feasibility: Natural Upland Edge Extent, by Property

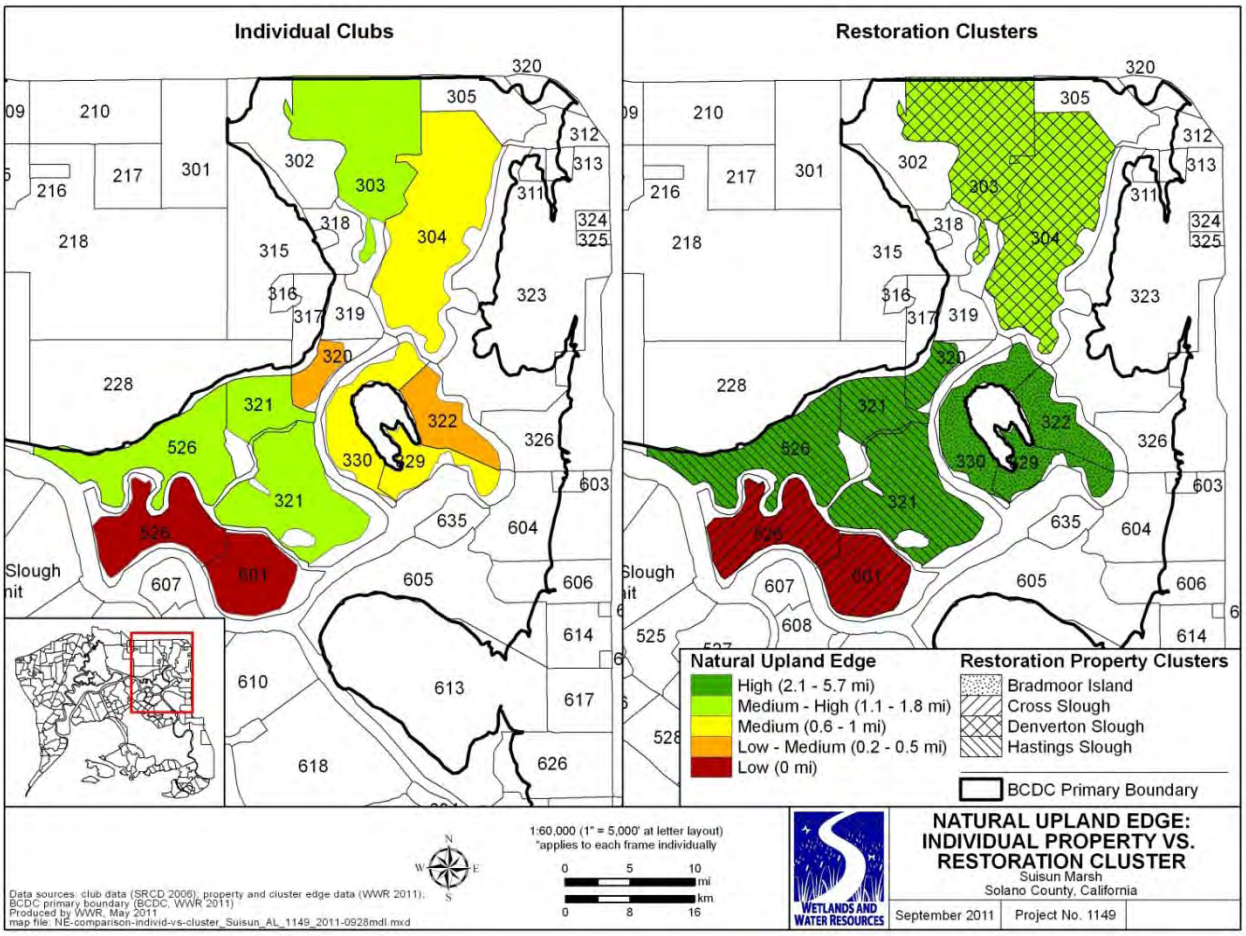


Figure 29. Feasibility: Change in Natural Upland Edge Feasibility with Restoration Clusters: the Nurse-Denverton Slough Area

Extent of Remnant Tidal Sloughs (M-8)

Sloughs within tidal marshes serve several important ecological functions, centered largely around exchange of materials between the marsh and the surrounding landscape. Thus, restoring sloughs including their natural geomorphology (sinuosity, bifurcation (branching or dendritic), cross sectional area, length, surface area) are key elements of effective tidal marsh restoration. Sloughs in the brackish marshes of Suisun tend to be larger in size (width and depth) and less in total length than for tidal salt marshes found in the lower estuary (Siegel 1993). The means to arrive at a restored natural slough network depends on baseline elevation of restoration sites and the extent to which an existing slough network exists. Higher properties need either a remnant network or one has to be excavated. Lower properties are somewhat more flexible as the sloughs will form naturally as the marsh builds vertically upward; depending on degree of subsidence, remnant channels or construction small pilot channels can serve that purpose.

Properties shown in green in **Figure 30** have a reasonable extent remaining of the historic tidal sloughs and thus a greater likelihood of forming effective slough channels. The caveats are (1) that the mineral soils of tidal slough banks subside less than the peat soils of the marsh plain, resulting in modern diked baylands with 'inverted' landscapes where the remnant sloughs are now the higher ground, and (2) the full natural form of these sloughs in many cases is dissected by levees or situated around the perimeter of a property not necessarily consistent with feasible levee breach locations. Properties shown in red in **Figure 30** have no remnant tidal sloughs so would require excavation of channel network invert elevations to what would be anticipated once a restored marsh has developed. The intermediate colors represent intermediate extents of remnant slough networks and thus variable degrees of intervention would be needed.

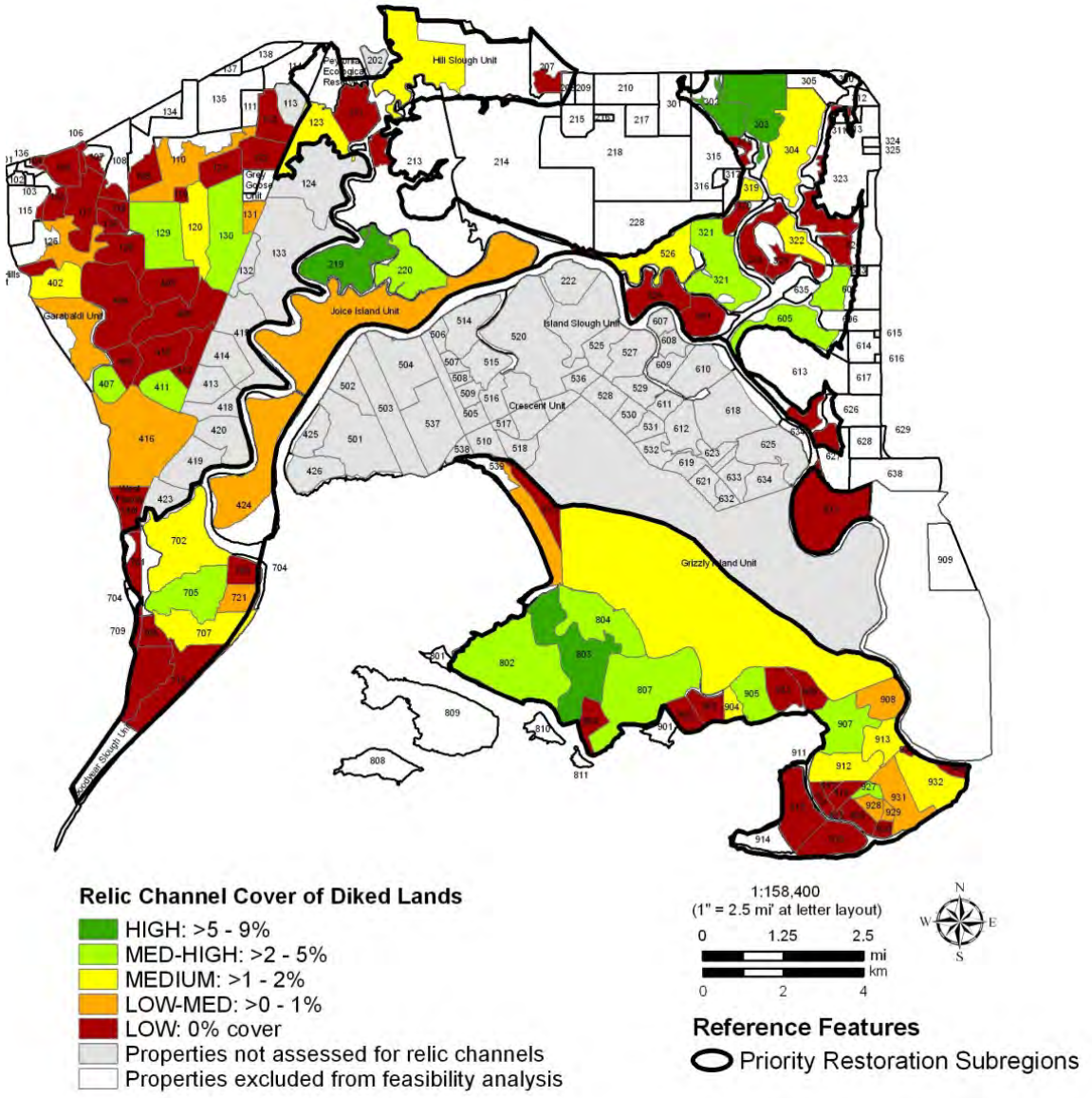


Figure 30. Feasibility: Remnant Natural Sloughs Extent, by Property

Number of Properties in Restoration Cluster (M-9)

Restoring lands in Suisun Marsh as groupings, or clusters, of multiple properties (restoration clusters) requires that all the lands within the cluster participate. As mentioned in Chapter 1, the purpose of restoration clusters is threefold: (1) reduce or eliminate the need for tidal flood protection levees because of their very high costs, (2) levees interfere with promoting desired ecological functions restoration seeks to achieve, and (3) restoration at larger scales is more likely to yield significant beneficial ecological outcomes. Omission of any one property in a cluster either eliminates the cluster advantage altogether or diminishes its advantages. Taking the premise that working with landowners to bring any single property into restoration availability is a complex process, the greater number of properties needed for a restoration cluster equates to a vast increase in overall complexity of bringing a cluster to restoration implementation. Thus, the fewer the properties in the cluster the more feasible would be its implementation and, conversely, more properties equates to less feasibility.

5.3 Lower-Priority Restoration Criteria

We have identified two of the 13 restoration criteria as being of lower importance to restoration feasibility, relative to the other criteria; when developing the integrated restoration feasibility assessment in Chapter 6, these two criteria are given the least weighting. These two criteria are:

L-1) Williamson Act Contracts
L-2) Date of Property Transfer

Williamson Act Contracts (L-1)

The Williamson Act (California Land Conservation Act of 1965) provides relief of property tax to owners of farmland and open-space land in exchange for a ten-year agreement (a Williamson Act Contract) that the land will not be developed or otherwise converted to another use. The motivation for the Williamson Act is to promote voluntary land conservation, particularly farmland conservation. Since 1965, the state's general fund has paid counties and cities about $40 million a year to make up for the property tax revenues lost because of lowered assessments. In addition, the general fund automatically backfills school districts for lost property taxes. Recent California budget problems have lead to these funds being earmarked for elimination and most recently Governor Brown has proposed abolishing the Act altogether. Many landowners entered into Williamson Act Contracts in the late 1960s and early 1970s. For Suisun, these contracts, or their abolishment were Governor Brown to eliminate the Williamson Act, are not likely to be a major factor for restoration. Where present (**Figure 23**), at most the

contracts may have to be amended with Solano County. From a property tax perspective, the 1977 Suisun Marsh Protection Act eliminated land uses other than wildlife (and natural gas extraction) and thus elimination of the Williamson Act may not be that significant. In many cases, mineral rights are retained by their owners when surface land rights are transferred.

Date of Property Transfer (L-2)

Figure 31 shows the timing of property transfers, which can be acquisitions but also can represent reconfigurations of existing multi-party ownership groups. This Strategic Plan has not advanced this analysis to make the distinction between these two transfer types. Properties transferred in recent years may reflect speculation activity in anticipation of restoration obligations though not all transactions are likely to be so characterized. Land speculation complicates restoration efforts as it introduces high monetary expectations into the restoration equation. These expectations may also apply to lands not recently sold; longer-term landowners may be watching the outcomes of these earlier actions.

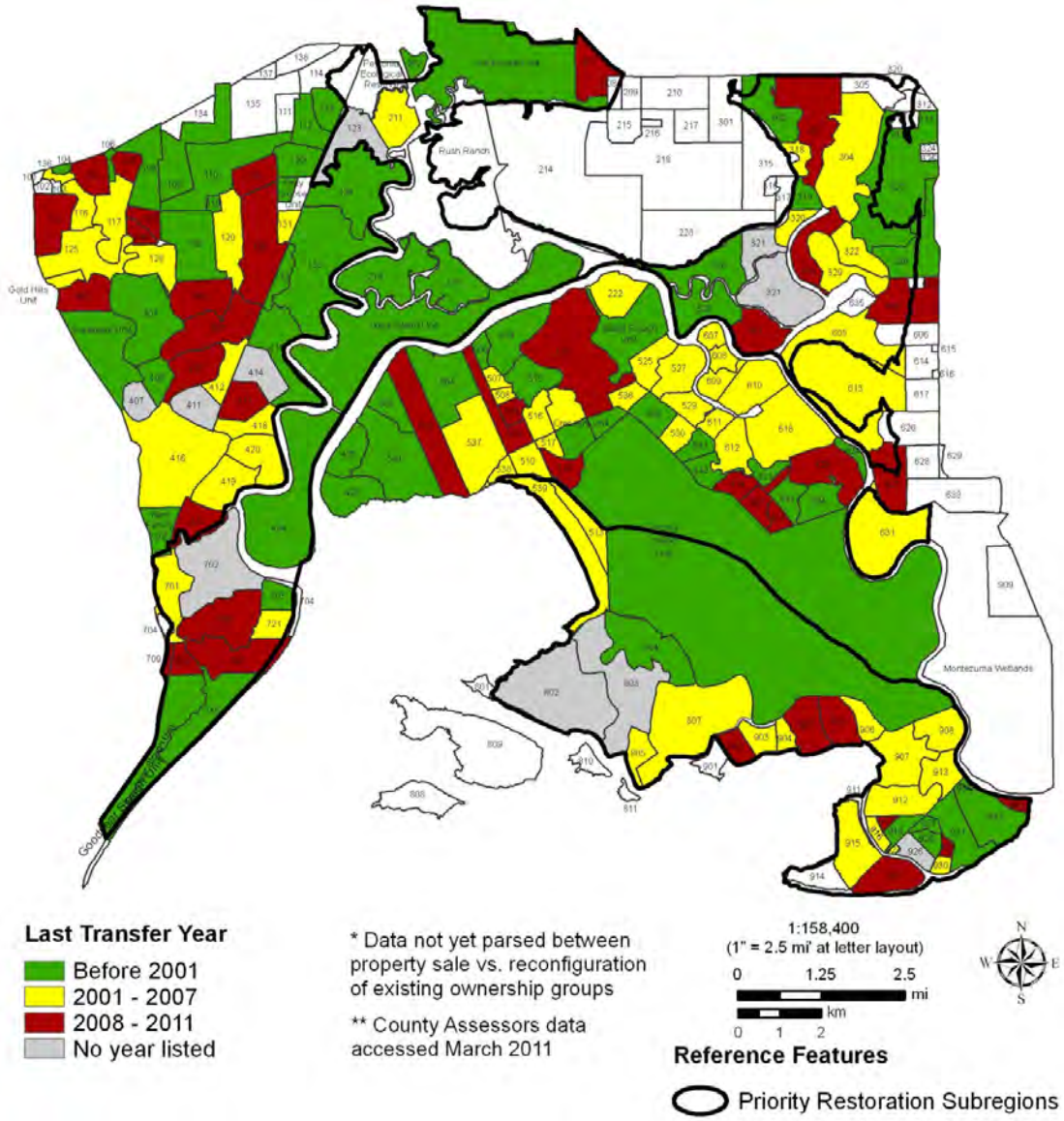


Figure 31. Feasibility: Land Transfer Timing, by Property
Source: Solano County Assessor's Office, accessed March 2011

6 Integrated Restoration Feasibility and Restoration Priorities

With our solid foundation in the restoration opportunities and constraints at the property level throughout Suisun Marsh (Chapter 3), we now integrate our findings. In this chapter we integrate across the 15 individual feasibility criteria findings presented in Chapter 4 to develop an overall assessment of restoration feasibility of each property in Suisun Marsh (**Figure 32**) and we examine how utilizing restoration clusters improves those overall feasibilities (**Figure 33**). Comparing these two figures side-by-side quickly illustrates that value of seeking to restore lands in restoration clusters. **Appendix B** presents the database we used for assigning these feasibility rankings.

We then combine the Volume II Strategic Plan elements (summarized in Chapter 2 of this Volume III) of our strategic vision for conservation with our restoration hypotheses, our key principles, our understanding of factors driving restoration outcomes, and our subregional priorities into where we would recommend restoration at large scales. We will find that the places we would like to pursue restoration the most may have their challenges and that places easy to restore may not be our highest priorities. Working within such a framework is part of what will follow from this Strategic Plan.

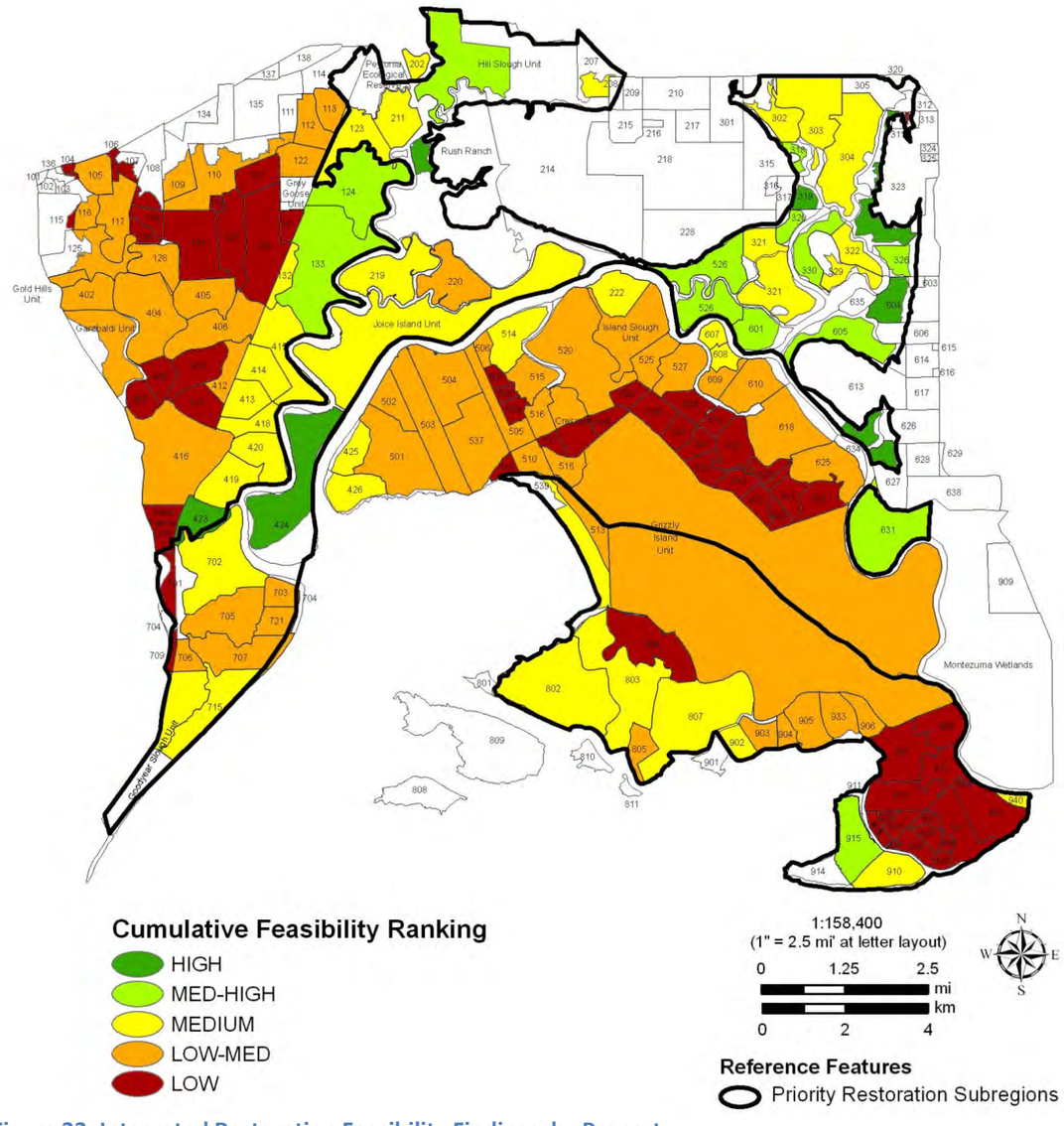


Figure 32. Integrated Restoration Feasibility Findings, by Property

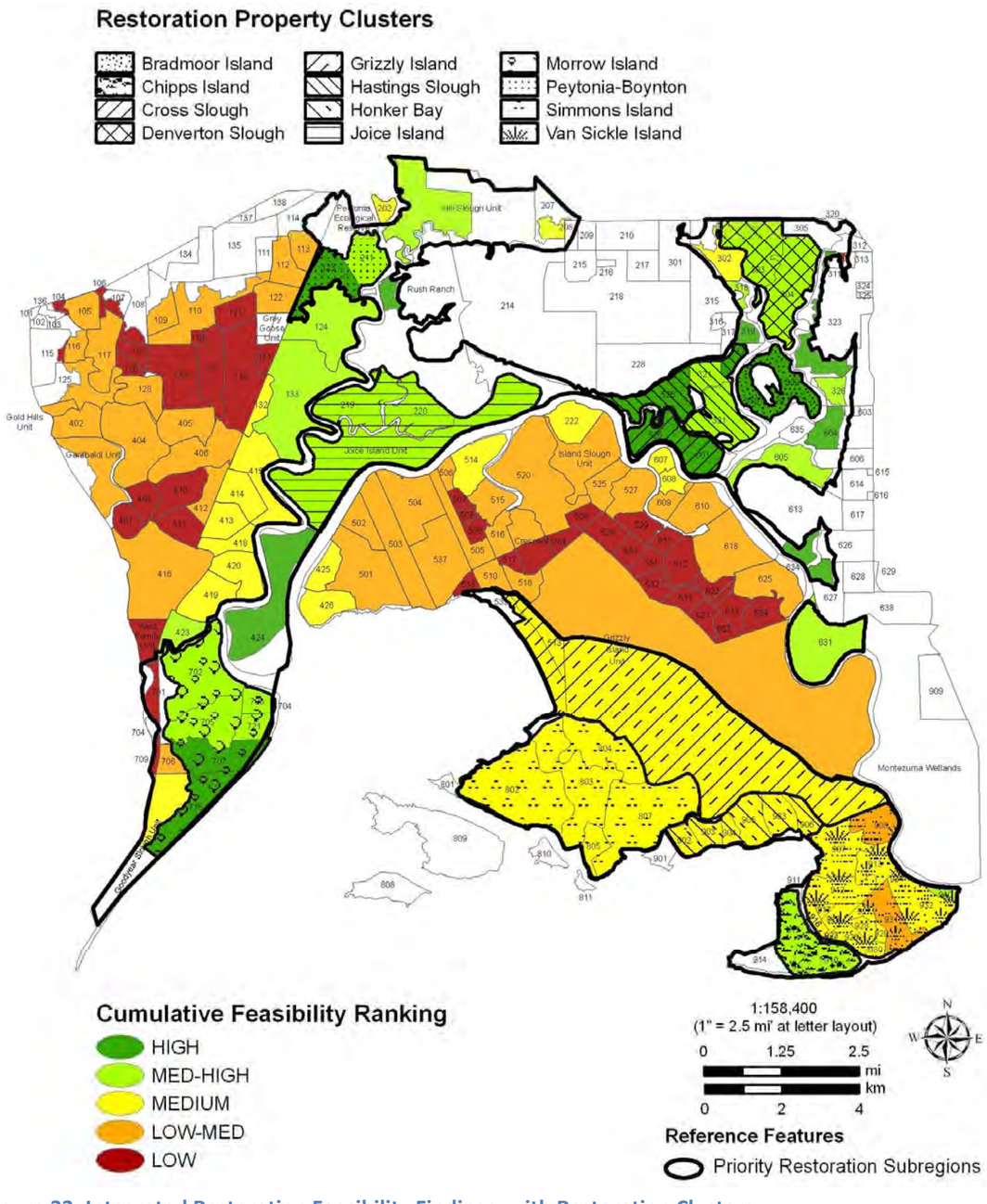


Figure 33. Integrated Restoration Feasibility Findings, with Restoration Clusters

6.1 Central Priority Restoration Subregion

There are six discrete restoration projects that could be pursued in the Central Subregion. Three are individual properties and three are restoration clusters.

Individual Property Restorations

Rush ranch – higher priority

This **80-acre** property is owned by the Solano Land Trust and is in restoration planning. It should move forward. It has an extensive upland edge, connects to a small creek, and requires no tidal flood protection. It is adjacent to the largest natural ancient tidal marsh in Suisun, the Rush Ranch Marsh. The project lacks final planning and implementation funds.

Lower Joice Island – higher priority

This **760-acre** property is owned by the Suisun Resource Conservation District. It is an island and thus has no tidal flood protection requirements. As an island, it has upland ecotone. It is located at the confluence of Suisun and Montezuma sloughs with Grizzly Bay and as such would have very immediate aquatic benefits. It has moderate subsidence and is probably at elevations within range for colonization by emergent tidal marsh vegetation. This property was donated to SRCD for specific purposes and restoration would likely be consistent with those purposes (Steve Chappell, pers. comm.). The SRCD Board would have to approve use of this property for restoration. As the Suisun Marsh Plan (USBR et al. 2010) requires tidal restoration acreage targets to be met at 10-year increments to meet Regional General Permit mitigation requirements for ongoing diked managed wetlands operations, it is quite possible to use this property to meet those obligations.

Hill Slough – moderate priority

This **860-acre** property is owned by DFG and is in restoration planning. It should move forward. Property provides an important upland ecotone. It does have complications with Grizzly Island Road, the only vehicle access into much of Suisun Marsh, requiring tidal flood protection. High-voltage PG&E transmission lines cross the property and likely have to be raised. The new Grizzly Island Road bridge across Hill Slough, constructed in 2010 by Solano County, apparently constricts tidal flows upstream and it was built with a low road deck elevation meaning it will have to be replaced in the not too distant future because of sea level rise.

Restoration Clusters

Upper Joice Island – higher priority

This **2,500-acre** restoration cluster consists of three properties (219, 220, DFG Joice Island Unit) – two privately owned and the DFG Joice Island Unit. As a cluster it would be an island having

no tidal flood protection requirements and no upland edge. Aside from its large size and small number of properties, the cluster has one of the largest intact remnant sloughs, translating into a very effective tidal marsh restoration. Its northern boundary adjoins more than 1,000 acres of natural ancient tidal marsh at Rush Ranch and the Cutoff Slough tidal marsh segment of the DFG Joice Island Unit, meaning its restoration would create a very large contiguous patch of tidal marsh.

One variant for this restoration cluster could be to exclude the northeastern peninsula of Upper Joice Island at the boundary with Property 220. This variant would require maintenance of about 1,700 feet of levee. The purpose would be allow retention of some managed wetlands closest to the Joice Island Bridge accessible off of Grizzly Island Road and the associated recreational uses those lands currently provide. The value of pursuing this variant requires further evaluation. The retained area is higher elevation than the rest of the DFG property (**Figure 4**) which does make it better suited for tidal restoration.

Peytonia-Boynton – higher priority

This **610-acre** restoration cluster consists of two privately owned properties (123, 211). It is bounded on three sides by tidal sloughs (Suisun, Peytonia, and Boynton) and on the fourth side by the railroad line. Whether the railroad would seek construction of a berm alongside the rail line to provide erosion protection would have to be investigated; both properties would need some channel excavation to restore tidal sloughs and that soil would be well suited for such a berm. Peytonia and Boynton sloughs have been amongst the worst documented locations for periodic low dissolved oxygen events in Suisun Marsh (Siegel et al. 2011); restoring these two properties would provide a major improvement for this water quality problem. The 275-acre Wings Landing property (211) has been for sale repeatedly over the past several years; it is fairly high elevation, may have had some dredged material placement, and has a fairly updated and large club house and associated grounds. The 335-acre Walnut Creek property (123) is owned by a group many of whom live nearby; their motivation to sell is not likely very high (Steve Chappell, pers. comm.). However, these owners may be open to a trade for another locally accessible property that is of comparable suitability for managing as a hunting club.

Morrow Island – moderate priority

This **2,300-acre** restoration cluster consists of six privately owned properties (702, 703, 705, 707, 715, 721), four of which are connected to the DWR Morrow Island Distribution System (MIDS) which allows improved water management. As a cluster it would be an island having no tidal flood protection requirements and no upland edge. Some of these properties are moderately subsided and since the cluster is in the more saline western side of Suisun those elevations may be too low to support vegetation colonization at the outset. Sedimentation

rates here could be moderate given the proximity to a reasonable sediment supply, though tides would more effectively be restored from the 'back' via Goodyear Slough than directly onto Grizzly Bay due to longshore sediment transport being more likely to silt in levee breaches and connecting tidal channels. Improved tidal exchange on Goodyear Slough would be likely to help with low dissolved oxygen problems that have occurred in the past, though depending on where breaches were constructed the restoration could dampen tides along Goodyear Slough. Hydrodynamic modeling would be important to employ for planning restoration of this cluster. Restoring this cluster may obviate the need for DWR to continue operating (and monitoring) MIDS, a significant potential cost savings. This cluster is the only area that falls within the Suisun Marsh Plan western region and its restoration would meet the entire SMP targets for that region. Bringing the restoration cluster together could be complicated and take a long time given it consists of six separate private properties.

6.2 Northeast Priority Restoration Subregion

There are 14 discrete restoration projects that could be pursued in the Northeast Subregion. Ten are individual properties and four are restoration clusters. ***The large number of properties that could be restored individually and their generally high feasibility are major positives for focusing considerable restoration energy into this priority subregion.***

Individual Property Restorations

The ten individually restorable properties in the Northeast Subregion (302, 318, 319, 323, 326, 604, 605, 613, 627, and 631), representing a total of **1,950 acres**, all share several traits in common:

1) All but one property require no tidal flood protection for adjacent properties
2) All have natural upland edges
3) All have fairly little subsidence

Given that all ten properties exhibit desirable restoration traits, the primary basis for assigning relative restoration priority amongst them is then the nature of their upland edge (gentler slope is better because it offers greater long-term sea level rise accommodation), extent of upland edge, size, and whether they have restoration impediments.

Higher Priority Individual Properties (1,165 acres)

631 (Mein's Landing, 650 acres) – Owned by DWR for tidal restoration. Its main concern is three underground petroleum product pipelines cross the property. Though these pipelines do present a challenge, engineering solutions exist; some of these same pipelines cross properties in the Southeast Subregion and have been addressed there in the context of restoration. Mein's Landing also offers a unique opportunity: it links to an upland stream with an extensive

forested riparian corridor, a very rare natural community in Suisun Marsh. During early restoration planning efforts, DWR contacted that landowner for a possible acquisition and received a positive response but did not follow through when restoration planning was suspended because of the pipeline concerns. Tidal restoration of Mein's Landing should be an imperative for these reasons and because it is one of the very few properties in Suisun Marsh in public ownership.

604 (Blacklock, 175 acres) – Has extensive, gentle-sloped upland edge with natural and restored tidal marsh surrounding it. Remnant tidal sloughs present. DWR already purchased portion of property and restored it in 2006. Property underwent sale in recent years.

326 (Tonneson Ranch, 110 acres) – Same landscape setting as Blacklock property: large, gentle-sloped upland edge.

323 (Duck & R, 230 acres) – Has very extensive upland edge though a bit steeper than that of the other properties.

Moderate Priority Individual Properties (275 acres)

627 (Honneger Ranch, 75 acres) – Large upland edge though diked acreage relatively small.

613 (Kirby Hills, 85 acres) – Large upland edge though diked acreage relatively small.

318 (Brass Button, 50 acres) – Large upland edge though diked acreage relatively small.

319 (Stole Farms, 65 acres) – Large upland edge though diked acreage relatively small.

Lower Priority Individual Properties (510 acres)

605 (The Duck Club, 325 acres) – Very large upland edge though steep; has active gas well and pipelines though on upland edge so comparatively easy to accommodate.

302 (Pickleweed Ponds, 185 acres) – Requires some tidal flood protection levees, most distant up Nurse Slough.

Restoration Clusters

Bradmoor Island – higher priority

This **480-acre** restoration cluster consists of three privately owned properties (322, 329, 330). It is one of two locations in Suisun Marsh with an upland island surrounded by wetlands (the other, much smaller in size, being within the Hastings Slough restoration cluster), translating into a very large upland edge though in this case a relatively steep one. Through combining

these three properties, remnant tidal sloughs could likely be utilized for the restored marsh channel network. This cluster is an island requiring no ongoing levees and it has an upland edge. It is located in a region with known high aquatic productivity, high native fish abundances, and extensive fringing marsh along the outboard levees.

Cross Slough – higher priority

This **470-acre** restoration cluster consists of two privately owned properties (526 southern segment, 601). This cluster is an island requiring no ongoing levees, though it has no upland edge. It is located along Montezuma Slough and Nurse Slough, both important aquatic migratory corridors and regions of aquatic productivity. With its restoration, Cross Slough could become continuous once again, as the levee blocking it to provide access to the island would no longer be needed. Its elevations appear to be reasonably high so emergent marsh would be anticipated relatively rapidly. It has some remnant tidal sloughs though they appear to be relatively filled in with vegetation. There appears to be no infrastructure impediments.

Hastings Slough – moderate priority

This **1,000-acre** restoration cluster consists of three privately owned properties (320, 321, 526 northern segment). It has an extensive upland edge along the southeast side of the Potrero Hills. Property 321 has extensive remnant tidal sloughs. Two factors impede its overall restoration suitability though both can be addressed through design with associated costs: (1) an active gas well is present on Property 321 access to which would have to be retained or the mineral rights purchased and the well abandoned, and (2) the property has a somewhat greater extent of invasive plant species that would require some eradication efforts prior to restoration. The gas well issue stands out as a greater impediment. An alternative approach to this cluster if access to the gas well must be maintained is to restore Property 526 only which would require maintaining roughly 2,000 feet of levee.

Denverton Slough – lower priority

This **1,150-acre** restoration cluster consists of two privately owned properties (303, 304). We have assigned it a relatively lower priority due to the need for some ongoing tidal flood protection levees and because the lands have been intensively altered in recent years by their current landowners in ways that diminish their restoration suitability (creation of very large borrow pits, considerable levee construction). Though these properties do have some upland edge, they mostly abut Highway 12 and as such have limited long-term sea level rise accommodation.

6.3 Southeast Priority Restoration Subregion

The southeast subregion consists of 33 properties in total. We have clustered all 33 properties into five restoration clusters. Restoration of all except one or two of these 33 properties stand-alone will require significant tidal flood protection levees.

Roaring River Distribution System. Many of these properties are supplied today by the Roaring River Distribution System, part of the DWR Suisun Marsh facilities. If all these properties were restored then Roaring River itself could be reverted back to its original state as a large tidal slough. Roaring River has a major fish screen on Montezuma Slough so if some lands remain as diked managed marsh that draw from Roaring River, then either a series of smaller fish screens would be needed at each smaller diversion or Roaring River would have to be retained as a non-tidal water supply canal. If Roaring River is retained as a diked water supply canal, DWR will continue to be responsible for maintenance of its southern and northern levees. It is reasonable to assume, however, that DWR would require any restoration abutting these levees to incorporate levee erosion protection features – preferably through gentle-sloped toe berms that provide ecological functions including a natural wetland-upland ecotone and far less preferably through rock riprap.

Chipps Island cluster – higher priority

This **610-acre** restoration cluster consists of two privately owned properties (910, 915). The northern portion of Chipps Island, Property 915, is diked with moderate subsidence. The southeastern portion, Property 910, is muted tidal, its levees having failed naturally in the 1990s. This cluster is high priority for several reasons. First, it is positioned alongside the main east-west channel of Suisun Bay just west of the confluence of the Sacramento and San Joaquin rivers – it is directly along a major migratory route for numerous fish species. Second, the surrounding shallow waters have extensive beds of native submerged aquatic vegetation which are likely (but not established) important elements for supporting native fishes. Third, elevations are moderate which means it would be emergent tidal marsh upon restoration. Fourth, it is an island and would require no levee maintenance. Fifth, the western portion of the island is already tidal so the complete restoration would create a large tidal marsh. Sixth, sediment supply is comparatively high in this area indicating sediment accretion will help restore marsh elevations relatively rapidly. Lastly, the cluster consists of only two properties which makes negotiations comparatively less complex.

These properties do have some challenges. First, both properties have extensive stands of the invasive plant *Phragmites australis*. Controlling it on the diked northern property is possible though potentially challenging and controlling it on the southeastern muted tidal property may

be more challenging as herbicide application may be restricted and the other possible strategy is removal of the upper soil layer. Second, neither property has much in the way of effective tidal sloughs so excavation may be needed to recreate the slough network. Disposition of excavated soils would have to be addressed and may increase restoration costs. Finally, Property 910 sold recently; given it is already open to the tides its uses are very limited which suggests the new owner may be envisioning its use for a mitigation bank.

Honker Bay cluster – higher priority

This **900-acre** restoration cluster consists of six privately owned properties (902, 903, 904, 905, 906, 933). Wildlands, a mitigation bank company, recently purchased Property 902 at the west end of this cluster. Jeff Cavanaugh has been organizing a mitigation bank from four of these properties. Only the eastern-most property, #906, has not been the subject of recent mitigation bank proposals. These properties are all located alongside a major sediment source and we know from observing the natural restoration of San Souci (Property 901) where the levees failed in 1998 that sediment accretion can be effective. Honker Bay supports extensive stands of native submerged aquatic vegetation and is near the major fish migratory route of the estuary. The bayfront levees of these properties have been subject to several failures in recent years and are difficult to maintain. Two pipelines cross two of these properties though both were recently upgraded to provide protection from tidal flooding during a period when the bayfront levees had failed and allowed tidal action into some of the properties. The northern boundary is Roaring River (see above).

Simmons Island cluster – higher priority

This **3,400-acre** restoration cluster consists of five privately owned properties (802, 803, 804, 805, 807). These properties have some of the best preserved remnant tidal sloughs in Suisun Marsh, making them of great restoration interest. All are moderately subsided; some degree of pre-restoration vegetation management would be beneficial, either to reverse subsidence with plant biomass and/or to provide higher sediment capture once tides are restored. Unless Roaring River is reverted to a tidal slough, this cluster would continue to require consider tidal flood protection levees though a vast majority of that levee would be along Roaring River (see above). These properties comprise a single Reclamation District and appear to have no infrastructure impediments. Unlike the Honker Bay cluster, landowners of these five properties have not expressed great interest in restoring these properties. Restoring these properties individually would be a costly endeavor due to the extent of tidal flood protection levees that would be needed within the cluster and it would fail to take advantage of much of the remnant tidal sloughs.

Grizzly Island cluster – moderate priority

This **5,400-acre** restoration cluster consists predominantly of the southern half of the DFG Grizzly Island Unit along with two privately owned properties facing Grizzly Bay (513, 539). Its northern extent aligns with a topographic high on Grizzly Island; that high ground would need to be raised some to provide tidal flood protection but because it would be so small in height above existing grade it would be a comparatively low cost tidal flood protection feature. In addition, emergent vegetated tidal marsh would contribute to tidal flood protection. The primary challenge for this cluster is that its tidal source would most likely need to be Roaring River so its restoration is feasible only if all or most of the clusters on the south side of Roaring River are also restored so that Roaring River itself can be reverted to a tidal slough. It is possible to restore the very western end of this cluster – Property 539 – by itself though it would require a long reach of tidal flood protection levee maintenance.

Van Sickle Island cluster – lower priority

This **2,400-acre** restoration cluster consists of 17 privately owned properties (907, 908, 912, 913, 916, 917, 918, 923, 926, 927, 928, 929, 930, 931, 932, 934, 940). Because of its shape, degree of subsidence, and small size of most of the properties, Van Sickle Island is feasible to restore only if all properties are included otherwise very costly tidal flood protection levees would be needed. Van Sickle Island would provide significant aquatic food web support at an important geographic location of the confluence of the Delta and Suisun Marsh, hence its importance. Its considerable subsidence means it would be open water and the local wind regime combined with its large size means sediment accretion could be comparatively slow. Pre-restoration subsidence reversal could be employed here and if wetlands carbon sequestration protocols are in place the island has the potential for significant wetland plant biomass sequestration which could help fund its restoration. One of the 17 properties also has an active gas well though fortunately it is located on the property edge at Montezuma Slough in the northeast corner of the cluster and thus may be comparatively easy to accommodate. Perhaps the most challenging aspect of this restoration cluster is its composition of 17 properties – gaining participation of so many landowners could be daunting.

7 Advancing Restoration Efforts: the Conservation Strategy

Now that we have an understanding of where the restoration priorities reside in Suisun, how each property fairs in terms of its restoration feasibility, and relative priorities, we are ready to address the topic of how to proceed with bringing restoration efforts into the planning and implementation realm: the Conservation Strategy.

In this final chapter we tackle the following topics:

1) **Key issues to take into account** – now that know where we would like to place restoration, what are key issues in front of us.
2) **Deciding whether to focus broadly or in targeted areas** – should we move forward in a highly selective manner or should multiple fronts be pursued concurrently?
3) **Bringing privately owned lands into restoration** – overview of the private landowner community, types of land agreements that may be effective, and strategies for working with them.
4) **Bringing publicly owned lands into restoration** – some suitable lands already are in ownership, so here we discuss specific strategies for putting them into restoration efforts.
5) **Next steps** – a set of actions to pursue from this point forward.

7.1 Key Issues to Take into Account

We have identified a number of key issues to consider in moving forward with the details of bringing restoration projects into the planning and implementation phase. The order presented here roughly reflects their relative priority.

Suisun Needs Restoration Coordination and Oversight

In order to achieve the ecological benefits described throughout the three volumes of this Conservation Assessment, it will be critical to coordinate and oversee restoration efforts. There are several reasons that coordination and oversight needs exist. First, there will be multiple entities pursuing restoration activities concurrently as multiple targets and obligations exist. Ensuring that these efforts are complementary (e.g., when involving restoration clusters) and avoid conflicting actions will conserve human and financial resources and yield more effective ecological outcomes. Second, restoration will involve a wide range of complex technical, regulatory, land acquisition and management, resource management, and cultural issues. Ensuring that this full range of issues are addressed effectively as restoration planning and implementation proceeds, especially the application of lessons learned, will be essential to overall success and in particular the effectiveness of bringing private and public lands into restoration alongside improving management of diked lands. Third, applying adaptive

management with restoration of tidal marshlands alongside ongoing operations of managed wetlands will be essential to ensure that the full range of plant, fish and wildlife resources are benefited to the greatest extent practical. Adaptive management at the large Suisun Marsh scale can only happen with coordinated oversight. Lastly, the national ecosystem restoration practitioners brought together in November 2009 by the CALFED Science Program (CALFED 2009) emphasized a critical feature essential to successful ecosystem restoration: "*Success demands a hero – a single visionary project leader with authority and sufficient resources for success. Committees are a good way to prevent progress. The leader should have advisory groups with expertise in the science, sociology, politics, economics and history of the area. But these must be advisory only, without veto power*."

Seek Landscape-Scale Restorations

We restate this issue here because of its importance to accomplishing the ecological outcomes intended by restoration. Working at the patchwork property level is going to yield costly and far less ecologically effective restorations yet it is the natural default approach for many because it is the easiest path. So we reiterate here the importance of following the more challenging path in order to keep restoration costs as low as possible and restoration outcomes as ecologically effective as possible.

Avoid Purchasing Commercial Mitigation Bank Credits

Commercial mitigation banks operate by purchasing land or entering into contracts with landowners, executing a Banking Agreement with the state and/or federal resource agencies, constructing the restoration, and marketing the credits established. Mitigation banks often try to sell their credits at prices ranging up to $200,000 per acre though many banks sell credits in the $50,000-$100,000 range. These for-profit ventures have great utility to aggregate many small development projects that require compensatory mitigation into larger, more ecologically effective restoration efforts. In the case of restoring 5,000-7,000 acres under the Suisun Marsh Plan, 8,000 acres under the FWS and NMFS BOs, or 65,000 acres under BDCP, mitigation banks are a major impediment. First, the very high costs to purchase mitigation bank credits translate into a fiscal inability to meet the SMP, BO or BDCP targets, as the billions of dollars that would be necessary are very unlikely ever to exist. Consequently, far less restoration could be implemented. Second, the role of market signals is vital. Clear policies not to purchase mitigation bank credits is likely to have the effect of stopping the rampant land speculation currently underway by mitigation bank entrepreneurs, resulting in reasonable land values and ongoing ability to achieve restoration targets within reasonable fiscal limits. In contrast, the purchase of mitigation bank credits will signal the market to move forward, fueling rampant land speculation and the probable fiscal inability to meet the regional restoration targets. Third, mitigation banks tend to operate at the property scale and perpetuate the associated scale

issues that this Strategic Plan recommends to avoid through restoration clusters and carefully selected individual properties. Finally, mitigation banks as a means to meet the large regional restoration targets lack the underlying mitigation bank rationale of aggregating many small development impacts into more ecologically effective, larger mitigation projects. In other words, mitigation banks in the SMP/BO/BDCP context have no supporting rationale, would drain fiscal resources resulting in a significantly reduced likelihood of meeting regional restoration targets, and are likely to produce restoration projects with sub-optimal ecological performance.

Investigate Mineral Rights Ownership Status

Suisun Marsh has known natural gas reserves and the Suisun Marsh Protection Plan (BCDC 1976) provides for the development of exploratory and production natural gas wells and associated infrastructure. Many landowners have sold their mineral rights over the years, largely as a means to raise funds to cover operating expenses. Researching the status of mineral rights ownership requires examining the deeds for each property in Suisun Marsh, a time-consuming process not yet undertaken for this Strategic Plan. Where mineral rights have been sold to another party and thus could not be purchased from the surface rights landowner, two issues follow. First, mineral rights holders must be allowed certain levels of access for establishing gas wells. Here we have not explored the range of feasible options to accommodate that access but such determinations would have to be made as part of property acquisition. A future iteration of this Conservation Strategy could delve into this optic more systematically. Second, an alternate strategy is to extinguish those third-party mineral rights through acquisition or other contractual agreement, obviating the need to make any future access accommodations. Where mineral rights reside with the surface land owner, they should either be included within the acquisition (or otherwise extinguished through contractual agreements) or the means by which those rights could be exercised at a later date incorporated into the restoration design. Mineral rights values have not been researched for this Conservation Strategy.

Prepare for Interim Land Management

The time between land acquisition and restoration construction can range from a couple of years for projects move rapidly through the planning process to several years if planning is slower (typical) or if lands are held awaiting acquisition of additional parcels to make effective restoration clusters. Interim land management is necessary during this period. At a minimum, that management typically consists of levee and water control structure maintenance, ongoing water operations, vector control, and the like; i.e., actions typical to the diked managed marshes of Suisun. More beneficial to restoration outcomes, however, would be active land management to prepare the site for restoration, including promoting wetland plant growth for

the purpose of subsidence reversal or promoting sedimentation when the property is opened to the tides. Funds and mechanisms for carrying out interim land management need to be established at the outset. A future possibility is growing carbon sequestration credits (wetlands plants) and selling those credits on carbon exchange markets. Such an option may come to exist in the next few years.

Existing landowners may make ideal interim land managers. They already know the property well and in some cases it may be desirable for them to continue waterfowl hunting until restoration is ready to move forward. "Hiring" them as land managers also provides them added revenue stream which can be a mechanism to bridge the gap between appraised land values and what a landowner would like to be paid for their property. Where existing landowners are not capable of or interested in serving in the interim land management role, another entity with suitable expertise is necessary, including other Suisun landowners. An active role for SRCD is also very conceivable and should be examined thoroughly.

Diked Managed Wetlands Must Implement Restoration to Comply with the SRCD Regional General Permit

One of the key purposes of the Suisun Marsh Plan (USBR et al. 2010) is that it provides a 30-year program for allowing the diked managed wetlands to dredge tidal sloughs to obtain levee maintenance materials. Dredging would supplant scraping down wetland interiors as a soil borrow source, a vast improvement in terms of supporting restoration feasibility. The U.S. Army Corps of Engineers is expected to issue a 30-year Regional General Permit (RGP) for those activities. The mitigation requirements of the Suisun Marsh Plan DEIS/EIR (USBR et al. 2010) include about 1,400 acres needing to be restored each 10 years following Plan adoption. If these restoration acreage targets are not met, then actions allowed under the RGP are either curtailed or suspended. Consequently, SRCD and the private landowners in Suisun have an incentive to see those minimum acreage targets met. Efforts to advance restoration therefore can be coordinated effectively with SRCD as a means to provide additional capacity for advancing restoration.

Recognize and Utilize External Factors that May Affect Land Values

The Suisun Marsh of the past is not going to be the Suisun Marsh of the future, with or without active restoration efforts or implementation of the Suisun Marsh Plan. The diked managed wetlands of Suisun require exactly what their name says – management. Regularly. The cost of wetland management varies widely from property to property based on its specific setting. Future drivers of change will make management efforts more constrained and more costly just to maintain today's conditions. Eventually it may not be possible to maintain today's conditions. Sea level rise, whether or not slough dredging can be used for levee maintenance

materials, diversion restrictions for endangered species protections, mosquito control, water quality considerations, severe storms and high water events, land subsidence, and other unpredictable changes (e.g., earthquakes) all contribute to more costly and constrained land management with a high degree of uncertainty and risk. As operational costs and complexities increase, land values could well decline accordingly. Selling now may yield landowners higher prices than waiting to sell later.

Carry Out Due Diligence on Prospective Acquisitions

Nearly all lands in Suisun have gone through a variety of land uses and owners in the past hundred or so years since they have been diked. The potential for costly and complicating issues at any given property always exists. Contaminants from heavy equipment and materials storage can always arise. Old structures that may contain lead paint or asbestos may be present. Conducting Phase I environmental assessments will always be essential.

Consider that Restorations Become Navigable Waters

Once lands are restored to tidal action, they become Navigable Waters of the U.S. under the Clean Water Act and Rivers and Harbors Act. Public entry through the water side of restoration sites is thus allowed. Though there is no inherent problem with this public access, it can lead to problems such as vandalism of the restoration efforts as well as hunting or fishing which may or may not be legal. Some adjacent landowners may express concern on this issue. For now, this topic is a heads-up for further discussion rather than in need of a specific action at this early stage. The California Department of Parks and Recreation just released its Draft Recreation Plan for the Delta and Suisun Marsh (CDPR 2011) which may provide a suitable venue to begin examining this issue.

Consider Whether or Not Tidal Restorations Are Hunting Refugia

One oft-cited concern of Suisun landowners is that waterfowl utilize tidal restoration sites as hunting refugia, resulting in lowered bag limits. Some data exists to support this perception (Ackerman 2011). The recreational status of these lands will need to be considered carefully. DFG for example allows hunting and fishing in the restored wetlands of the Napa-Sonoma Marsh Complex[1].

7.2 Bringing Privately Owned Lands into Restoration

Many suitable and priority restoration lands are privately owned. Here we discuss the landowner community, the types of land agreements that could be put to use, and strategies for engaging the private landowner community.

[1] http://www.dfg.ca.gov/lands/wa/region3/nsmwa/index.html

Private Landowner Community Overview

Private property ownership in Suisun is most commonly in the form of multiple owners of each property, reflecting the hunting club membership of that property. Numbers of owners can range from a few to perhaps a dozen or so. Some clubs sell memberships which may not confer ownership status but which may confer decision-making participation. Solano County tax assessor's records generally do not provide any information on these ownership details. Private property owners include individuals, corporations, and trusts. Some lands are 'owner occupied' and other lands are under short- or long-term leases. Fiscal resources of landowners to maintain and improve properties varies widely in Suisun. Many landowners are aging. Circumstances vary widely in regards to the younger generation's interest levels in carrying on the hunting club activities; owners may be far more interested in selling now or in the not too distant future where that interest lacks. Many landowners hold a strong attachment to their land stemming from their years of ownership and use of the property. Several long-term landowners were the drivers of Suisun Marsh conservation in the 1960s and 1970s, leaving us with the valuable legacy of the Suisun Marsh Protection Act that conserved the Marsh.

Mitigation Bank Speculation

Most recently, mitigation bank companies have been acquiring lands or entering into contracts with landowners to develop cooperative mitigation banks and landowners themselves have been seeking to establish their own mitigation banks. Wildlands recently purchased Property 902 (Atlantis Gun Club) on Honker Bay. Jeff Cavanaugh has banded together his family's property and adjacent properties in an effort to enable a mitigation bank on Properties 903-904-905-933 (Blue Bird, Wingnuts, Mallard Farms, and Mallard Farms II) along Honker Bay. Property 404 (Cordelia Gun Club) has been trying to pursue a bank. Property 211 (Wings Landing) apparently now has an LLC promoting a mitigation bank. Properties 120-129-130 (Suisun Marsh Hunting Preserve, a pheasant hunting club) has also apparently entered into a banking contract. There likely are others about which we are not currently aware. The primary intended market for these banks are fish species requiring restoration under the FWS and NMFS Biological Opinions, though some may also seek additional markets. The purchasers of credits for compliance with the BOs would be DWR and/or SFCWA. In June 2011, the SFCWA Board of Directors adopted a policy of not purchasing mitigation bank credits to satisfy its BO or BDCP obligations. DWR may follow suit. As some of the Suisun properties currently with control of mitigation banking entities are desirable for restoration, finding ways to work with them short of purchasing bank credits needs to be pursued.

Types of Land Agreements with Private Landowners

Given the interesting and complex dynamics of Suisun Marsh land ownership and the priority restoration areas and feasibilities, the first consideration is the types of agreements that could

be pursued to bring private lands into restoration. The list here could well be expanded through additional discussions (see Next Steps below). It is important to remember that public agencies are obligated to pay fair market value as established through an appraisal. Consequently, mechanisms that fulfill this requirement and that can establish mechanisms to provide landowners additional earned income from their property may be particularly effective.

Acquire restoration properties from willing sellers

This approach is the most straightforward. Acquire fee title and initiate interim management and restoration planning.

Acquire conservation easements with future purchase agreements

The purpose of this approach is to lock up suitable restoration properties while allowing existing landowners some additional time to use the property and at the same time providing them an initial financial benefit. It could be suited well to landowners that do not have a younger generation to take over but would like to continue hunting for a while longer. It would consist in essence of a binding purchase agreement that brings the land into restoration at a set time down the road (say 5 or 10 years) combined with a conservation easement or similar instrument at present. The landowners would receive some money up-front with the initial easement or purchase agreement and the remaining funds at completion of the property transfer, thereby allowing them to extract some near-term fiscal benefits. We have queried some landowners about their interest in such an approach and received a very positive response in terms of fiscal feasibility and suitability to those landowners who fall into the group that would benefit from this arrangement. This approach could allow restoration planning to proceed in parallel so that when the final transfer takes place restoration could be implemented shortly thereafter. The seller in essence functions as an interim land manager and as such the total land transaction valuation may be able to accommodate that added value.

Acquire trade parcels from willing sellers then trade properties for other high priority restoration properties

The purpose of this approach is to gain access to desired restoration parcels whose owners would like to continue having a duck club and would be interested in selling only if they had another property. In this arrangement, lands not well suited to restoration or not within priority restoration areas would be acquired and title “exchanged” with owners of the restoration parcel. The details presumably would require considerable formulation. One can presume that the trade property being continued as a hunting club would need to be of approximately similar size with approximately similar facilities and either approximately similar or acceptable land management capabilities; in other words, a reasonably even trade. Geographic location and access would also be important. Where properties are dissimilar then there may be need for

some amount of net funds transfer to facilitate bringing the retained hunting club property up to functional condition.

Acquire conservation easements with retained private landowners and hold until complete acquisition of full restoration clusters

The purpose of this approach is to obtain complete restoration clusters incrementally, in recognition that it may take time to get all properties and losing opportunities would be detrimental. The mechanism of this approach would likely follow #2 above with the main variation that the time frame of the final purchase may be more flexible or tied to other criteria than simply establishing a set time period to continue hunting the property.

Purchase conservation easements along with landowner acting as project manager of restoration

The purpose of this approach is to engage landowners more actively in the restoration process and through that engagement provide a mechanism to net them increased compensation for restoring their land. The mechanism is essentially that the planning, design, and/or construction work for the restoration is carried out contractually through the landowner with the public agency that is "purchasing" the restoration providing the funding. The key to its success is that the full extent of restoration planning is carried out identically to that done by one of the public agencies in terms of guidance and oversight by those agencies.

Strategies for Engaging the Private Landowner Community

Now that we have a sense of the kinds of people that make up the landowner community, a reasonable range of mechanisms to bring land into restoration projects, and knowledge of what properties we would like for restoration, we finish with suggestions for how to engage that private landowner community.

Work with the Suisun Resource Conservation District

SRCD has intimate knowledge of the specific situations of many of the private landowners in Suisun Marsh, largely because most are members of the District. Steve Chappell, the SRCD Executive Director, is a valuable resource in this regard both in terms of personal knowledge of and relationships with landowners as well as the responsibility under the Corps RGP to see that the 10-year increment restoration targets are met. SRCD also has considerable knowledge of property conditions, a valuable resource. Therefore, ongoing collaboration with SRCD is of vital importance and benefit to bringing private lands into restoration.

Outreach to Target Landowners

Once decisions are made of where to place initial focus, outreach to all the landowners of those properties should begin. In advance of direct contact, as much information should be gathered

from Solano County Tax Assessor's office, SRCD, and on-line searches if necessary. SRCD may be able to facilitate this outreach. It will be important to match the interpersonal communications approaches between outreach individuals and landowners.

Contact the Current Mitigation Bank Entities Controlling Desirable Properties

Existing discussions, if any, should be continued and new discussions initiated with the mitigation bank entities with the desirable properties to pursue solutions that fit within the framework described in this Conservation Strategy.

Be Prepared to Respond to Incoming Inquiries

From time to time, landowners interested in selling will contact SRCD, DWR or DFG to inquire about acquisition interest. With this Conservation Strategy in place, responding to those inquiries can be rapid as the information necessary to know whether the property is of interest or not is contained in this document.

7.3 Bringing Publicly Owned Lands into Restoration

The publicly owned lands in Suisun Marsh that we identify below are of restoration priority and total about 4,000 acres. For each property, we discuss the status and the steps needed to bring them into restoration implementation.

Mein's Landing (DWR, 660 acres)

DWR purchased this property for restoration. The three underground pipelines that cross the property have led DWR to reconsider its restoration of Mein's Landing. The property is well suited for restoration otherwise and engineering solutions, albeit perhaps somewhat costly, exist. The next step would be to work with DWR to address concerns and gain management support to continue with restoration planning efforts. These planning efforts should include seeking to acquire the adjacent parcel that includes the small creek from Birds Landing that supports a rare riparian corridor; the landowner had previously expressed interest in selling to DWR for restoration purposes.

Hill Slough (DFG, 840 acres)

DFG has been planning this restoration for many years. Outstanding issues are tidal flood protection for Grizzly Island Road, sag clearance for high voltage PG&E transmission lines, tidal exchange constraints from the new Grizzly Island Road bridge across Hill Slough, implementation funds, and completing regulatory compliance.

Rush Ranch (SLT, 80 acres)

SLT has been planning this restoration for many years. Outstanding issues are securing implementation funds, updating the project design, and completing regulatory compliance.

Lower Joice Island (SRCD, 760 acres)

SRCD has not to date considered restoration of this property. To move forward will require its Board to support the effort then securing funds for restoration planning, regulatory compliance, and implementation. Its mineral rights status would need to be examined. The specific terms of its original transfer to SRCD will need to be examined relative to allowed land uses.

Upper Joice Island (DFG, 1,650 acres)

DFG has not to date considered restoration of this land. We did not research whether it has any encumbrances on land use that came with its original acquisition. The next step would be to work with DFG to determine land use requirements if any then to establish how its restoration would fit in with DFG's overall land management mission in Suisun Marsh. Funds for restoration planning, regulatory compliance, and implementation would have to be identified.

7.4 Next Steps

In order to make concrete progress in advancing tidal restoration in Suisun Marsh, there are a number of next steps:

- **Focused discussions with key stakeholders** to generate buy-in and revisions to this initial version of the Conservation Strategy. Many of these discussions have already taken place as of September 2011 and results incorporated into this first version of the Conservation Strategy.
    1) **Key entities likely to be involved in Suisun restoration implementation.** The Nature Conservancy, Department of Fish and Game, Department of Water Resources, the State and Federal Contractors Water Agency, the Suisun Resource Conservation District, Delta Conservancy, State Coastal Conservancy. The purpose of these discussions is to engage a broader discussion of the recommendations, make any adjustments deemed appropriate, and identify specific actions for moving forward.
    2) **Delta Plan.** The Delta Stewardship Council may consider incorporating elements of this Strategy into the Delta Plan. This discussion follows the DFG discussion.
    3) **Federal agencies.** The Fish and Wildlife Service and National Marine Fisheries Service will have an interest in terms of meeting their Delta smelt and salmonid Biological Opinion requirements, respectively. In addition, the Bureau of Reclamation would also be a participant in discussions related to how this Strategy relates to the Suisun Marsh Plan. These discussions may generate adjustments to the recommendations.
- **Develop first revision of this Strategy.** Once the input is gained through the above discussions, this Strategic Plan would be ready for its first revision.

- **Begin efforts to establish Restoration Coordination.** As the solution will be complex and thus take some time to develop, begin working on it now so it is ready when properties come into restoration planning.
- **Begin securing funding.** In the near term, focus on funding for acquisition, interim management, and restoration planning.
- **Begin preparing for longer term adaptive management.** Once the first agency-engaged revision to this Strategic Plan is completed, it should be subject to periodic review as new information is gained either through restoration implementation or through the advancement of other planning processes including the Delta Plan, Suisun Marsh Plan, and BDCP. This review should take place within a strong Adaptive Management Framework and the institutional structures need to be established for this purpose. That process should be directed by the Delta Science Program or an appropriate similar entity as it is about conduct of a regional adaptive management program.
- **Develop overall "budget" of multiple wetland and aquatic ecosystems needed to support full range of plant, fish and wildlife resources that utilize Suisun Marsh.** Suisun Marsh supports multiple plant, fish and wildlife species that have both complementary and distinct habitats. Restoration that benefits some species can impact other species. Examining the entirety of Suisun Marsh from the perspective of how all these diverse ecological functions are provided will be essential to the ecological effectiveness of tidal restoration efforts and the enhancement of managed wetlands. It will make substantial strides towards achieving cultural acceptance of the changes that will face Suisun Marsh. These efforts should involve the participation of public and non-profit ecologists, resource managers, and ecosystem restoration scientists, including participants from The Nature Conservancy, PRBO Conservation Science, California Waterfowl, Ducks Unlimited, Suisun Resource Conservation District, Department of Fish and Game, US Fish and Wildlife Service, National Marine Fisheries Service, US Geological Survey, UC Davis, and the Delta Science Program. Given the inherent scientific basis of this need, the importance of objective and thorough science, and its relevance to large scale ecosystem recovery, this effort would be very appropriately managed by the Delta Science Program.

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Appendix A

GIS Methods
Suisun Restoration Feasibility Analysis

The purpose of the analysis is to evaluate the tidal restoration feasibility of all diked lands in Suisun Marsh relative to a suite of feasibility criteria. This appendix describes the GIS methods used to perform the feasibility analysis.

Overview

- Start with base layer of Suisun properties (SRCD 2006)
- Break down property-level data to its three geomorphic components: diked, tidal, upland
- Calculate a suite of property-level feasibility parameters focused on the diked areas
- Build set of maps showing individual values of each feasibility parameter by property for all diked lands
- Identify restoration clusters geared primarily at joining properties so as to reduce or eliminate the need for tidal flood protection levees
- Build set of integrative maps synthesizing the individual feasibility parameters
- Generate two overall restoration feasibility maps: one for each club as a singular restoration parcel and a second for clusters of clubs

Foundation: Base GIS Data Set

- Data set name: SRCD Ownership 2006
- Topic: Wetland ownership
- Originator and Date: Suisun Resource Conservation District, 2006
- Description: GIS data set with polygons for each Suisun property (also termed duck club, or club), indicating public versus private land, owner name, club size,

Focusing on Diked Restorable Lands

- The SRCD Ownership data set contains one polygon for each property

- The subset of lands of interest for restoration are those at or below intertidal elevations, the 'diked' lands
- Some properties contain tidal marsh and/or uplands in addition to diked lands
- Some properties are entirely or mostly uplands (e.g., Potrero Hills)
- Adjustments to SRCD Ownership GIS data set:
    1) Flag all upland-only properties in new field as upland, for exclusion
    2) Subdivide all properties that contain mixed geomorphologies, as follows:
        a. Tidal marsh pieces cut using mix of EcoAtlas and air photos
        b. Upland pieces extracted using 2005 LiDAR data from DWR (suisun_topo_ft) and the 2010 NAIP
        c. Diked lands are remaining portion
- The modified SRCD Ownership data set will then have multiple entries for any properties that were subdivided: the original property plus the subdivisions

General Approach to Calculating Characteristics of Diked Portions of Suisun Properties

- All calculations for feasibility were then based on the diked portion of Suisun properties.
- Where a property was subdivided, the computational results are entered into the database records for the subdivided portion and into undivided original record, so that we retain the computational details while allowing Suisun-wide GIS analysis at the property level (which is the presumed acquisition unit)

Specific Property-Level Characteristics

Each set of attributes once calculated are tracked in a single GIS attribute table building upon the SRCD Ownership dataset. Each attribute's results are then mapped into five levels of suitability relative to restoration feasibility: high (green), medium-high (light green), medium (yellow), medium-low (orange), and low (red).

Recent history of change in property ownership

- **Data sources**
    1) Solano County Assessors Parcels GIS (Solano County, 2008)
    2) Solano County Assessors Parcels ownership data (Solano County, 2010)
- **Units:** date of property transfer

- **Method:** spatial overlay of parcels with SRCD Property dataset, assignment of property number to every APN, query on date of title transaction from County database and transfer result into land transaction date field in the SRCD Property dataset
- **Associated Dataset Fields:** analysis performed at the whole-club level (query: POLYEXTENT = 'WHOLE' or POLYEXTENT = 'MULTI-WHOLE")
    a) Original ownership data is in field [OWNERSHIP] and public owners were further described in field [Pub_Owner]
        - Feasibility ranking for this criterion is in field [OwnerClas]
    b) The year of the last transfer date if known and a private property is listed under field [lastTRANSFER]
        - Feasibility ranking for this criterion is in field [Trans_Rank]
- **Primary challenge:** distinguishing between intra-organizational change in legal ownership status (e.g., removing or adding a partner) vs. transfer of ownership. Method of resolution = case-by-case examination
- **Feasibility classification bins:**
    1) High: Before 2001 (longer term ownership)
    2) Medium: 2001-2007 (intermediate term ownership)
    3) Low: 2008-2011 (recent ownership change)

Subregion

- **Data source:** boundaries established by Chris Enright and Stuart Siegel based on landscape ecology restoration principles
- **Units:** subregion number
- **Method:** in the SRCD Property data set, add subregion number to each property within an identified subregion.
- **Associated Dataset Fields:** analysis performed at the whole-club level as well as geographic portion level, but only on diked, restorable lands (query option 1, club-level: POLYEXTENT = 'WHOLE' or POLYEXTENT = 'MULTI-WHOLE" or query option 2, geographic unit level: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP")
    a) Field [SUBREGIONS] denotes the number of the subregion a club belongs to
        - Empty fields correlate to clubs not within a subregion or geomorphic units not appropriate to this criterion (e.g. upland)
        - Although subregion 4 has been retained in the data, only subregions 1 – 3 are currently being considered in anlysis

Average diked property elevation

- **Data source:** DWR 2005 LiDAR, 1.5ft lowering adjustment by DWR (vegetation interference compensation), levees then removed to retain elevations of only diked portion of each property
- **Units:** feet NAVD88
- **Method:** raster calculation of average elevation, join result to SRCD Property data set
- **Associated Dataset Fields:** analysis performed only on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP")
    a) Field [meanDikedE] denotes the averaged diked elevation for each club containing diked lands
        - '0' denotes a non-diked property or portion of property, depending on the feature extent
    b) A related field [DIKEDACRES] populates at the whole-club extent the corresponding diked acreage of each club
- **Feasibility classification bins:**
    1) High: 5-7 ft (centered around MHHW; roughly 'high' marsh)
    2) Medium-high: 3-5 ft(centered around MTL; roughly 'low marsh')
    3) Medium: 1-3 ft (MLLW to 2ft above MLLW; roughly below vegetation colonization elevation)
    4) Low-medium: -2 to 1 ft (shallow subtidal: 0-3 ft below MLLW)
    5) Low: < -2ft (deeper subtidal: more than 3ft below MLLW)

Extent of tidal flood protection needs

- **Data source:** NAIP 2010 aerial photo (USDA), LiDAR 2005 (DWR), EcoAtlas (SFEI 1998 as modified by WWR 2011)
- **Units:**
    1) **Distance requiring tidal flood protection**, to nearest 0.1 mile (mi) – describes total length of flood protection that must be addressed. Lower value improves feasibility.
    2) **Percent of diked property boundary requiring tidal flood protection** (%) – describes extent to which property is removed from the tidal waterways of Suisun Marsh. Lower value improves feasibility.
    3) **Ratio of distance requiring tidal flood protection to restoration area** (mi/ac) – describes "bang for the buck" of a restoration site. Lower value improves feasibility.

- **Method:** Analysis applies to the diked portion of each property; portions of properties that are uplands or tidal are excluded. For each diked property, rough digitized the perimeter, coding edge segments into four categories and recording length of each segment type: tidal, interior, natural upland, infrastructure upland. Distance and percent of edge calculated on these digitized length values. Length to area calculation utilizes area of the diked portion of each property. Digitizing done with tidal sloughs data set and NAIP 2010 air photo.
- **Associated Dataset Fields:** analysis performed on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP") as well as at the cluster level (query: POLYEXTENT = 'CLUSTER')
    a) Field [diked_mi] denotes the miles (minimum = 0.1mi) of diked edge of each diked geomorphic unit
        - Similarly, [dikedrd_mi] denotes the miles of diked roads within or bounding the potential restorable diked areas
        - A related field [DIKEDACRES] populates at the whole-club extent the corresponding diked acreage of each club
    b) For this analysis, field [pcnt_diked] yields miles of diked edge (including miles of diked road edge) as a percentage of the total diked area edge (e.g. if half of the diked geomorphic unit within club X is bordering other diked clubs while the other half borders natural uplands and tidal channels, than the [pcnt_diked] value for that diked unit will be 50)
    c) The ranking for this criterion was based on the percentage of diked edge yielding the rankings below. These rankings are presented in field [diked_rank]
- **Map: Percent of Boundary Requiring Tidal Flood Protection**
    1) High: (0%)
    2) Medium-high: (< 20%)
    3) Medium: (20-60%)
    4) Low-medium: (60-99%)
    5) Low: (100%)

Extent of natural upland edge

- **Data source:** same as for tidal flood protection boundaries above
- **Units:**
    1) Distance of natural upland edge (to nearest 0.1 mi) – describes how much transition edge habitat available
- **Method:** distance same as for tidal flood protection boundaries above.

- **Associated Dataset Fields:** analysis performed on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP") as well as at the cluster level (query: POLYEXTENT = 'CLUSTER')
    a) Field [upland_mi] denotes the miles (minimum = 0.1mi) of natural upland edge of each club's diked geographic unit
    b) The ranking for this criterion was based on the miles of upland edge yielding the rankings below. These rankings are presented in field [Uplnd_rank]
- **Feasibility classification bins:**
    1) High: 2.1 – 5.7 mi
    2) Medium-high: 1.1 – 1.8 mi
    3) Medium: 0.6 – 1 mi
    4) Low-medium: 0.2 – 0.5 mi
    5) Low: No upland edge

Extent of relic sloughs

- **Data source:**
    1) NAIP 2010 aerial photo, USDA
    2) LiDAR 2005, DWR
    3) Hydrographic, USGS
    4) Natural Community mapping, DFG
- **Units:** percent of diked properties covered by relic tidal sloughs
- **Method:** extract from existing data sets (hydrographic, DFG vegetation mapping) and digitize from air photo and LiDAR data.
- **Associated Dataset Fields:** analysis performed on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP")
    1) Field [RELICACRES] denotes the acres of diked relic tidal channels in each club's diked geographic unit
        - The field [PercentRel] yields the percent of relic tidal channel acres per total diked acres within each property
        - The ranking for this criterion was based on the percentage of relic acres per acre of diked acres within each property
    2) The ranking for this criterion is based on the percentage of diked relic tidal channels (acres) within the diked extent of each property. The rankings are listed below and presented in the dataset under field [RelicClass]
- **Feasibility classification bins:**
    1) High: >5 - 9%

2) Medium-high: >2 - 5%
3) Medium: >1 - 2%
4) Low-medium: >0 - 1%
5) Low: None

Dependency on adjacent properties for tidal connection

- **Data source:** Ownership (SRCD), tidal sloughs and bays (WWR from multiple sources)
- **Units:** Dependent/not dependent
- **Method:** Properties that do not border tidal sloughs directly are identified manually by examining location relative to tidal sloughs. Validated with above determination of percent of diked properties with tidal edge (0% tidal edge equates to a "land locked" property).
- **Associated Dataset Fields:** analysis performed on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP")
    1) Field [tidal_mi] denotes the miles (minimum = 0.1mi) of tidal edge of each diked geomorphic unit. If this value is greater than or equal to 0.1, than the property has the capacity to be tidally connected
    2) Tidal connection dependency is determined in field [TidConDep] where all properties with diked units are either ranked HIGH (can be tidally connected, independent of adjacent marsh restoration) or ranked LOW (cannot be tidally connected unless adjacent units are restored)
- **Feasibility classification bins:**
    1) Not dependent (green)
    2) Dependent (red)

Prevalence of Invasive Plant Species, *Lepidium latifolium* and *Phragmites australis*

- **Data sources:**
    1) Ownership (SRCD)
    2) DFG Vegetation data, 2006 (only *Lepidium* or *Phragmites* dominant strands were used for the analysis)
    3) Solano Land Trust, 2009
- **Units:** acres of invasive plant species cover; percent cover of entire property by invasive plant species
- **Method:** join spatial data of invasive plant species and perform a sum of total acres of invasive cover by each property boundary. (This method was repeated for each

Lepidium and *Phragmites* independently and will be included in the dataset, but not mapped.)

- **Associated Dataset Fields:** analysis performed on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP")
    a) Field [invsv_ac] denotes acres of invasive *Lepidium* and invasive *Phragmites* (summed) within each diked club unit
        - Similarly, [LEPIDIUM_ac] denotes acres of *Lepidium* only within each diked club unit and [PHRAGMITES] denotes acres of *Phragmites* only within each diked club unit
    b) Fields [pcnt_Lepid] and [pcnt_Phrag] denote the percentage of cover of each invasive species respectively per diked acres within each club
    c) The ranking for this criterion was based on the percentage of total invasive cover per diked acreage within each club, available under field [pcnt_invsv], and yields the rankings below. These rankings are presented in field [Invsv_Rank]
- **Feasibility classification bins:**
    1) High: Not present within property boundary
    2) Medium-high: < 2 %
    3) Medium: 2 – 10%
    4) Low-Medium: > 10%

Hydrology and Water Quality Constraints for Properties Adjacent to Peripheral Sloughs

- **Data source:** Suisun-tidal-sloughs (WWR 2011), SRCD properties, Railroad (WWR - digitized from NAIP)
- **Units:** Geographic position relative to railroads and long, small tidal channels
- **Method:** visual classification based on geographic position units
- **Associated Dataset Fields:** analysis performed on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP")
    1) The field [HYD_CNST] denotes the rankings for each diked club unit
- **Feasibility classification bins:**
    1) HIGH: Not subject to hydrologic or water quality constraints (adjoining major sloughs, bays, MIDS, or RRDS)
    2) MED-HIGH: medium-sized sloughs, some constraints (limited tidal mixing, high potential for DO)
    3) MEDIUM: smaller sloughs, more constraint (least tidal mixing, high potential for low DO)

4) LOW-MED: medium-sized sloughs west of railroad, moderate constraints (limited tidal mixing, high potential for low DO, tidal flow constrained)
5) LOW: smaller sloughs west of railroad, most constraint (limited tidal mixing, high potential for low DO, tidal flow constrained)

Presence/absence of infrastructure impediments (pipelines, transmission lines, etc.)

- **Data source:**
  1) Pipelines: Suisun Marsh Plan DEIR (USBR et al. 2010)
  2) Gas wells: Department of Conservation (March 2011 query)
- **Units:**
  1) Pipelines: presence/absence
  2) Gas wells: presence/absence and status where present
- **Method:**
  1) Pipelines: manual extraction from report figure
  2) Gas wells: plot location and status, add data to SRCD Ownership data set
- **Associated Dataset Fields:** analysis performed on the diked geographic portion (restorable lands) level (query: POLYEXTENT = 'PORTION' or POLYEXTENT = 'WP")
  1) Pipelines: the field [Pipeline] denotes the rankings pipeline rankings listed below for each diked club unit
  2) Gas wells: the field [GW_present] describes the 'worst-case scenario' present within the diked, restorable areas. All diked areas have either active wells (which may include new wells, idle wells, and/or cancelled wells), plugged wells only, or non wells at all.
     - The feasibility ranking for this criterion was determined by the type of wells present on the site (active = "Low", plugged only = "Medium", and none = "High"). The ranking of each restorable diked unit can be found under the field [GW_rank]
- **Pipelines classifications**
  1) Absent (High)
  2) Adjacent (Medium-High)
  3) Present (Medium)
- **Gas Wells classifications**
  1) High: None
  2) Medium: Plugged wells only
  3) Low: Active and other wells present

Benefits of linking to adjacent properties (Restoration Clusters)

- **Data source:** NAIP 2010 aerial photo (USDA), LiDAR 2005 (DWR), EcoAtlas (SFEI 1998 as modified by WWR 2011)
- **Units:** extent of necessary tidal flood protection (miles as percent of total restoration cluster perimeter); extent of natural upland edge (miles)
- **Method:** Analysis applies to the diked portion of each property; portions of properties that are uplands or tidal are excluded. For clusters of adjacent dike properties, used only cluster exterior digitized edges from the extent of tidal flood protection needs above to determine new cluster-based extent of tidal flood protection. Applied the same techniques for cluster-based analysis of natural upland edge.
- **Associated Dataset Fields:** integrated feasibility analysis performed on the *whole-club level only* (query: POLYEXTENT = 'WHOLE' or PLOYEXTENT = 'MULTI-WHOLE') but, as mentioned above, flood protection needs and natural upland edge analysis was performed at the *cluster level* (query: POLYEXTENT = 'CLUSTER')
    1) Field [IFR_Cluste] denotes the integrated restoration feasibility ranking for each property within a cluster – assuming all properties within the cluster are restored together
        - The related field [Notes_Clus] describes some of the major contributing attributes to each cluster's feasibility ranking
- **Feasibility classification bins – extent of flood protection needs (same as above):**
    6) High: (0%)
    7) Medium-high: (< 20%)
    8) Medium: (20-60%)
    9) Low-medium: (60-99%)
    10) Low: (100%)
- **Feasibility classification bins – upland (same as above):**
    1) High: 2.1 – 5.7 mi
    2) Medium-high: 1.1 – 1.8 mi
    3) Medium: 0.6 – 1 mi
    4) Low-medium: 0.2 – 0.5 mi
    5) Low: No upland edge

Appendix B

Restoration Feasibility Ranking Values

Table B-1 provides the restoration feasibility ranking values for each property across each of the 15 feasibility criteria. These data are mapped in the many feasibility maps included in this Conservation Strategy.

Table B-1. Restoration Feasibility Rankings for Each Restorable Diked Property in Suisun Marsh
Suisun Marsh Conservation Strategy

ID	NAME	Acreage	Owner	Restoration Subregion [1]	IFR Individual [2]	Individual Feasibility Notes	IFR Cluster Cluster Name [2]	Cluster Feasibility Notes	H1 TidConDep	H2 DikedEdge	H3 AvgElev	H4 Hydro/WQ	M1 GasWells	M2 Pipeline	M3 SMHM	M4 Owner	M5 RecDist	M6 InvsvPlants	M7 UplnEdge	M8 RelicChan	L1 Williamson	L2 TransDate
104		17	Private Land	WRR	LOW	levee needs, hydro/WQ, no relic chan			HIGH	MEDIUM	HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW-MED	LOW	HIGH	HIGH
105	Sweetwater Gun Club	170	Private Land	WRR	LOW-MED	hydro/WQ, levee needs, tx date			HIGH	MEDIUM	MED-HIGH	LOW	HIGH	MEDIUM	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	MED-HIGH	LOW	HIGH	LOW
106	Ornbaun Kennels	32	Private Land	WRR	LOW	No tidal connex			LOW	HIGH	HIGH	LOW	HIGH	MEDIUM	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	HIGH	HIGH
107		38	Private Land	WRR	LOW	No tidal connex			LOW	MEDIUM	HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	MEDIUM	LOW	HIGH	LOW
108		56	Private Land	WRR	LOW	No tidal connex			LOW	MEDIUM	HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	MEDIUM	LOW	MEDIUM	HIGH
109		144	Private Land	WRR	LOW-MED	hydro/WQ, levee needs, no relic chan			HIGH	MEDIUM	MED-HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	MEDIUM	LOW	HIGH	HIGH
110	Suisun Marsh Hunting Preserve	428	Private Land	WRR	LOW-MED	hydro/WQ, levee needs			HIGH	MEDIUM	MED-HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	HIGH	LOW-MED	MEDIUM	HIGH
112	Suisun Farms	199	Private Land	WRR	LOW-MED	Levee needs, hydro/WQ (Peytonia)			HIGH	LOW-MED	MED-HIGH	LOW	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	HIGH
113	Tule Farms Club	146	Private Land		LOW-MED	hydro/WQ, levee needs, gas wells, no upland			HIGH	MEDIUM	MED-HIGH	LOW	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	HIGH
115		17	Private Land	WRR	LOW	No tidal connex			LOW	MEDIUM	HIGH	LOW	HIGH	MEDIUM	NOT_ANAL	MEDIUM	HIGH	HIGH	MEDIUM	LOW	HIGH	LOW
116	Paoli Farms	96	Private Land	WRR	LOW-MED	hydro/WQ, levee needs, no relic chan, ltd upland			HIGH	MEDIUM	MED-HIGH	LOW	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW-MED	LOW	MEDIUM	MEDIUM
117	Mallard Inn Duck Club	312	Private Land	WRR	LOW-MED	hydro/WQ, levee needs, subsidence, no relic chan, ltd uplands			HIGH	MEDIUM	MEDIUM	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW-MED	LOW	MEDIUM	MEDIUM
118	Windsong Duck Club (118 amd 127)	94	Private Land	WRR	LOW	Levee needs, hydro/WQ			HIGH	LOW-MED	MED-HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	LOW
119	Suisun Marsh Hunting Preserve	31	Private Land	WRR	LOW	No tidal connex			LOW	LOW	LOW-MED	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	LOW	MEDIUM	HIGH
120		327	Private Land	WRR	LOW	Levee needs, subsided, hydro/WQ			HIGH	LOW-MED	LOW	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MEDIUM	MEDIUM	MEDIUM
121	Suisun Marsh Hunting Preserve	179	Private Land	WRR	LOW	Levee needs, hydro/WQ			HIGH	LOW-MED	MED-HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	LOW	MEDIUM	LOW
122	Gray Goose	201	Private Land	WRR	LOW-MED	hydro/WQ, levee needs, no relic chan, no upland			HIGH	MEDIUM	MED-HIGH	LOW	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	HIGH
123	Walnut Creek Gun Club	335	Private Land	CN	MEDIUM	Levee needs, hydro/WQ	Peytonia-Boynton HIGH	RR protection	HIGH	MED-HIGH	MEDIUM	MED-HIGH	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	MEDIUM	MEDIUM	LOW
124	Fat Hen Farm	682	Private Land		MED-HIGH	Ltd levee needs, ltd subsidence			HIGH	MED-HIGH	MED-HIGH	HIGH	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
125	North End Club	246	Private Land	WRR	LOW-MED	Subsidence, hydro/WQ			HIGH	MED-HIGH	MEDIUM	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	MED-HIGH	LOW-MED	HIGH	MEDIUM
126	Whistler Gun Club	72	Private Land	WRR	LOW	Levee needs, subsided, hydro/WQ			HIGH	LOW-MED	LOW-MED	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	LOW
128	Mrs. Murphy's Club	245	Private Land	WRR	LOW-MED	hydro/WQ, levee needs, no relic chan, no upland			HIGH	MEDIUM	MED-HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	MEDIUM
129	Suisun Marsh Hunting Preserve	470	Private Land	WRR	LOW	Subsidence, hydro/WQ,			HIGH	MEDIUM	LOW	LOW	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	HIGH
130		576	Private Land	WRR	LOW	Subsidence, hydro/WQ, levee needs			HIGH	LOW-MED	LOW	LOW	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	LOW
131	Jacksnipe Gun Club	83	Private Land	WRR	LOW	hydro/WQ, levee needs, subsidence, ltd relic chan, no uplands			HIGH	MEDIUM	LOW-MED	LOW	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW-MED	MEDIUM	MEDIUM
132	Hollywood Duck Club	111	Private Land		MEDIUM	Hydro/WQ			HIGH	HIGH	MEDIUM	MEDIUM	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	HIGH	HIGH
133	Shelldrake Duck Club	1009	Private Land		MED-HIGH	Ltd levee needs, subsidence			HIGH	MED-HIGH	MEDIUM	HIGH	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
136		7	Private Land	WRR	LOW	No tidal connex			LOW	MEDIUM	HIGH	LOW	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW-MED	LOW	MEDIUM	MEDIUM
202	Fairfield Suisun Sewer District	71	Fairfield Sewer		MEDIUM	Dredge disposal			HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	NOT_ANAL	HIGH	HIGH	MEDIUM	LOW	NOT_ANAL	HIGH	HIGH
207	Lang Tule Ranch	83	Private Land	CN	MEDIUM	Partially filled			HIGH	HIGH	HIGH	MEDIUM	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW-MED	LOW	MEDIUM	LOW
211	Wings Landing	276	Private Land	CN	MEDIUM	Levee needs, no upland, no relic chan	Peytonia-Boynton MED-HIGH	No relic chan	HIGH	MED-HIGH	MEDIUM	HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	MEDIUM
213	Rush Ranch Diked	80	Solano Land Trust	CN	HIGH	Upland edge, Land Trust ownership			HIGH	HIGH	HIGH	HIGH	MEDIUM	HIGH	NOT_ANAL	HIGH	HIGH	MEDIUM	MEDIUM	LOW	MEDIUM	MEDIUM
219	Volanti Duck Club	481	Private Land	CN	MEDIUM	Levee needs	Joice Island MED-HIGH	No levees; relic chan; subsided; proximity to invsv plants	HIGH	MEDIUM	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	HIGH	MEDIUM	HIGH

Table B-1. Restoration Feasibility Rankings for Each Restorable Diked Property in Suisun Marsh
Suisun Marsh Conservation Strategy

ID	NAME	Acreage	Owner	Restoration Subregion [1]	IFR Individual [2]	Individual Feasibility Notes	IFR Cluster [2] Cluster Name	Cluster	Cluster Feasibility Notes	H1 TidConDep	H2 DikedEdge	H3 AvgElev	H4 Hydro/WQ	M1 GasWells	M2 Pipeline	M3 SMHM	M4 Owner	M5 RecDist	M6 InvsvPlants	M7 UplnEdge	M8 RelicChan	L1 Williamson	L2 TransDate
220	Joice Island Mallard Farms	389	Private Land	CN	LOW-MED	Levee needs	Joice Island	MED-HIGH	No levees; relic chan; subsided; proximity to invsv plants	HIGH	LOW-MED	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	HIGH
222	Peidmont Rod and Gun Club (222 and 22	258	Private Land		MEDIUM	Levee needs, subsided				HIGH	MEDIUM	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
302	Pickleweed Ponds	184	Private Land	NE	MEDIUM	Levee needs, hydro/WQ				HIGH	MEDIUM	MED-HIGH	MEDIUM	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	HIGH	HIGH	MEDIUM	HIGH
303	Potrero Duck Club	526	Private Land	NE	MEDIUM	Levee needs, hydro/WQ, subsided	Denverton Slough	MED-HIGH	Ltd levees, extensive land manipulation	HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	MED-HIGH	HIGH	MEDIUM	LOW
304	Denverton Land Company (304 and 306)	629	Private Land	NE	MEDIUM	Levee needs, hydro/WQ	Denverton Slough	MED-HIGH	Ltd levees	HIGH	MEDIUM	MED-HIGH	MED-HIGH	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM
313		5	Private Land	NE	LOW	No tidal connex				LOW	MEDIUM	HIGH	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW-MED	LOW	HIGH	
318	Brass Button (includes 317 uplands)	48	Private Land	NE	MED-HIGH	No levees, upland edge, hydro/WQ				HIGH	HIGH	MED-HIGH	MEDIUM	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	MEDIUM	LOW	HIGH	MEDIUM
319	Stolte Farms	66	Private Land	NE	HIGH	No levees, ltd subsidence, relic chan				HIGH	HIGH	MEDIUM	MED-HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW-MED	MEDIUM	MEDIUM	HIGH
320	Tule Meadows Club	73	Private Land	NE	MED-HIGH	Levee needs	Hastings Slough	HIGH	No levees, no relic chan	HIGH	MEDIUM	MED-HIGH	MED-HIGH	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW-MED	LOW	MEDIUM	MEDIUM
321	Greenhead Duck Club	559	Private Land	NE	MEDIUM	Gas well, ltd levee needs, tx date	Hastings Slough	MED-HIGH	No levees, gas well	HIGH	MED-HIGH	HIGH	MED-HIGH	LOW	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	MED-HIGH	MED-HIGH	MEDIUM	LOW
322	Overlook Club	159	Private Land	NE	MEDIUM	Levee needs, subsided, some upland, some relic chan	Bradmoor Island	HIGH	No levees, better tidal cnx	HIGH	MEDIUM	MEDIUM	MEDIUM	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW-MED	MEDIUM	MEDIUM	MEDIUM
323	Duck & R	232	Private Land	NE	HIGH	Extensive upland, no levees				HIGH	HIGH	HIGH	MEDIUM	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	HIGH	LOW	MEDIUM	HIGH
326	Tonnesen Ranch	111	Private Land	NE	MED-HIGH	No levees, upland edge, hydro/WQ				HIGH	HIGH	MED-HIGH	MEDIUM	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	MEDIUM	LOW	MEDIUM	HIGH
329	Flying D	119	Private Land	NE	MEDIUM	Levee needs, subsided, some upland, some relic chan	Bradmoor Island	HIGH	No levees, better tidal cnx	HIGH	MEDIUM	MEDIUM	MED-HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	MEDIUM	LOW	MEDIUM	MEDIUM
330	Wildwing Duck Club	198	Private Land	NE	MED-HIGH	Ltd levee needs, subsided, some upland, some relic chan	Bradmoor Island	HIGH	No levees, better tidal cnx	HIGH	MED-HIGH	MEDIUM	MED-HIGH	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	MEDIUM	LOW	MEDIUM	LOW
402	Golden Gate Duck Club	230	Private Land	WRR	LOW-MED	Hydro/WQ				HIGH	MED-HIGH	MEDIUM	LOW-MED	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	MEDIUM	MEDIUM	LOW
404	Cordelia Gun Clug	614	Private Land	WRR	LOW-MED	Hydro/WQ, levee needs				HIGH	MEDIUM	MED-HIGH	LOW-MED	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	HIGH
405	Sunrise Duck Club	298	Private Land	WRR	LOW-MED	Hydro/WQ, subsided, recent land TX				HIGH	HIGH	LOW-MED	LOW-MED	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	LOW
406	Teal Duck Club	449	Private Land	WRR	LOW-MED	Hydro/WQ, subsided, recent land TX				HIGH	HIGH	LOW-MED	LOW-MED	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	LOW	HIGH	LOW
407	Ibis Duck Club	136	Private Land	WRR	LOW	Hydro/WQ, subsided, levee needs, recent land TX				HIGH	MEDIUM	LOW-MED	LOW-MED	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	MED-HIGH	MEDIUM	LOW
408	Franciscan Marshview (408 and 409)	153	Private Land	WRR	LOW	Hydro/WQ, subsided, levee needs				HIGH	MEDIUM	LOW-MED	LOW-MED	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	LOW	MEDIUM	HIGH
410	Gibson's Horseshoe Club	276	Private Land	WRR	LOW	Hydro/WQ, subsided, levee needs, recent land TX				HIGH	MEDIUM	LOW-MED	LOW-MED	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	LOW	MEDIUM	LOW
411	Greenlodge Club	206	Private Land	WRR	LOW	Hydro/WQ, subsided, levee needs, recent land TX				HIGH	MEDIUM	LOW-MED	LOW-MED	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	MED-HIGH	HIGH	LOW
412	Tule Hilton	164	Private Land	WRR	LOW-MED	Hydro/WQ, subsided				HIGH	MED-HIGH	LOW-MED	LOW-MED	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	LOW	MEDIUM	MEDIUM
413	Sprig a Teal	205	Private Land		MEDIUM	Levee needs, subsided, recent land tx				HIGH	MEDIUM	LOW-MED	MED-HIGH	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	LOW
414	Roos Duck Club	246	Private Land		MEDIUM	Levee needs, subsided, recent land tx				HIGH	MEDIUM	LOW-MED	MED-HIGH	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	HIGH	LOW
415	Arnold Ranch	456	Private Land		MEDIUM	Levee needs, subsided				HIGH	MEDIUM	LOW-MED	HIGH	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
416	Tule Belle Club (416, 417, 421)	973	Private Land	WRR	LOW-MED	Hydro/WQ				HIGH	MED-HIGH	MEDIUM	LOW-MED	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW-MED	MEDIUM	MEDIUM
418	Cygnus Gun Club	169	Private Land		MEDIUM	Levee needs, subsidence				HIGH	MEDIUM	MEDIUM	HIGH	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	MEDIUM
419	Miramonte Gun Club	311	Private Land		MEDIUM	Levee needs, subsidence				HIGH	MEDIUM	MEDIUM	HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	MEDIUM
420	Antioch Golden Eye	288	Private Land		MEDIUM	Levee needs, subsidence				HIGH	MEDIUM	MEDIUM	HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	MEDIUM
423	The Family Gun Club	226	Private Land		MED-HIGH	No levees (RR); ltd subsided; invsv plants				HIGH	HIGH	MEDIUM	MED-HIGH	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	LOW-MED	LOW	NOT_ANAL	MEDIUM	LOW
424	Dean Witter-Harvey Sorensen Marshland	761	SRCD	CN	HIGH	No levees, some relic chan, public ownership				HIGH	HIGH	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	HIGH	HIGH	MEDIUM	LOW	LOW-MED	HIGH	HIGH
425	California Farms	160	Private Land		MEDIUM	Levee needs, subsided				HIGH	MEDIUM	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
426	Tip End Gun Club	237	Private Land		MEDIUM	Levee needs, subsidence				HIGH	MEDIUM	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	HIGH	HIGH
501	The Island Club	648	Private Land		LOW-MED	Levee needs, subsided, no upland, gas well				HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
502	Grizzly Duck Club	183	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH

Table B-1. Restoration Feasibility Rankings for Each Restorable Diked Property in Suisun Marsh
Suisun Marsh Conservation Strategy

ID	NAME	Acreage	Owner	Restoration Subregion [1]	IFR Individual [2]	Individual Feasibility Notes	IFR Cluster Name	[2]	Cluster Feasibility Notes	H1 TidConDep	H2 DikedEdge	H3 AvgElev	H4 Hydro/WQ	M1 GasWells	M2 Pipeline	M3 SMHM	M4 Owner	M5 RecDist	M6 InvsvPlants	M7 UplnEdge	M8 RelicChan	L1 Williamson	L2 TransDate
503	Montezuma Gun Club	524	Private Land		LOW-MED	Levee needs, subsided, no upland, recent land TX				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	LOW
504	Gum Tree Farms	479	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
505	DUXRUS	235	Private Land		LOW-MED	Levee needs, subsided, no upland, recent land TX				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	LOW
506	Four Winds Duck Club	65	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
507	Grizz/Fizz Club	57	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
508	Little West Wind Duck Club	43	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	MEDIUM	MEDIUM
509	Garben Ranch	77	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	NOT_ANAL	MEDIUM	LOW
510	Honker Farms	134	Private Land		LOW-MED	Levee needs, no upland, aband gas well				HIGH	LOW-MED	MEDIUM	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	MEDIUM	MEDIUM
513	Grizzly King Gun Club	194	Private Land	SE	LOW-MED	Levee needs, no relic chan, no upland	Grizzly Island	MEDIUM	Levees, large, better if restore S of RRDS	HIGH	LOW-MED	MEDIUM	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	HIGH	MEDIUM
514	Tree Slough Farms	305	Private Land		MEDIUM	Levee needs, subsided				HIGH	MEDIUM	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	HIGH
515	Long Point West Club	201	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	NOT_ANAL	HIGH	HIGH
516	Bent Barrel Gun Club	142	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
517	Wild Turkey	58	Private Land		LOW	No tidal connex, levee needs				LOW	LOW	MEDIUM	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
518	Mendoza Gun Club	139	Private Land		LOW-MED	Levee needs, subsided, aband gas well, no upland, recent tx				HIGH	LOW-MED	MEDIUM	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	MEDIUM	LOW
520	Grizzly Ranch	923	Private Land		LOW-MED	Levee needs, subsided, no upland, recent land TX				HIGH	LOW-MED	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	LOW
525	Balboa Farms	188	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
526	Flatlander Duck Club - South	258	Private Land	NE	MED-HIGH	Ltd levee needs	Cross Slough	HIGH	No levees, no relic chan	HIGH	MED-HIGH	MED-HIGH	HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	HIGH	HIGH
526	Flatlander Duck Club - North	372	Private Land	NE	MED-HIGH	Levee needs	Hastings Slough	HIGH	No levees	HIGH	MED-HIGH	MED-HIGH	MED-HIGH	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	MED-HIGH	MEDIUM	HIGH	HIGH
527	Delta King Ranch	270	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
528	Grizzly Fairview Farms	170	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	HIGH
529	Sprigsville Ranch	150	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
530	Bul-Rush Farms	115	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
531	Gang Bang Duck Club	108	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	NOT_ANAL	MEDIUM	HIGH
532	Windmill Farms	130	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	NOT_ANAL	MEDIUM	HIGH
536	Marsh Club	96	Private Land		LOW	No tidal connex, subsided, levee needs				LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
537	Westwind Duck Club	534	Private Land		LOW-MED	Levee needs, subsided				HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	MEDIUM
538	Merganser Farms	55	Private Land		LOW	Levee needs, gas well				HIGH	LOW-MED	MEDIUM	NOT_ANAL	LOW	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	NOT_ANAL	MEDIUM	MEDIUM
539	Tule Red	295	Private Land	SE	MEDIUM	Levee needs	Grizzly Island	MEDIUM	Levees, large, better if restore S of RRDS	HIGH	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	LOW-MED	LOW	LOW-MED	HIGH	MEDIUM
601	Can-Can Duck Club	209	Private Land	NE	MED-HIGH	Ltd levee needs, recent land TX	Cross Slough	HIGH	No levees, no relic chan	HIGH	MED-HIGH	MED-HIGH	HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	LOW	MEDIUM	LOW
604	Blacklock Ranch	175	Private Land	NE	HIGH	No levees, upland edge				HIGH	HIGH	MEDIUM	MED-HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	MEDIUM	MED-HIGH	HIGH	LOW
605	The Duck Club	325	Private Land	NE	MED-HIGH	Gas well, pipeline				HIGH	HIGH	MEDIUM	MED-HIGH	LOW	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	HIGH	MED-HIGH	MEDIUM	MEDIUM
607	Duck-A-Go-Go	81	Private Land		MEDIUM	Levee needs, subsidence				HIGH	MEDIUM	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
608	Shur Shot Gun Club	86	Private Land		MEDIUM	Levee needs, subsidence				HIGH	MEDIUM	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
609	Black Dog Gun Club	126	Private Land		LOW-MED	Levee needs, subsided, no upland				HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
610	Westwind Duck Club	296	Private Land		LOW-MED	Levee needs, subsided				HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM

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ID	NAME	Acreage	Owner	Restoration Subregion [1]	IFR Individual [2]	Individual Feasibility Notes	IFR Cluster [2] Cluster Name	Cluster Feasibility Notes	H1 TidConDep	H2 DikedEdge	H3 AvgElev	H4 Hydro/WQ	M1 GasWells	M2 Pipeline	M3 SMHM	M4 Owner	M5 RecDist	M6 InvsvPlants	M7 UplnEdge	M8 RelicChan	L1 Williamson	L2 TransDate
611	The Sleeping Pintail	90	Private Land		LOW	No tidal connex, subsided, levee needs			LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
612	Meridian Gun Club	229	Private Land		LOW	No tidal connex, subsided, levee needs			LOW	LOW	LOW	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
613	Kirby Hills	85	Private Land	NE	HIGH	No levees, upland edge			HIGH	HIGH	MED-HIGH	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	MEDIUM	LOW	MEDIUM	MEDIUM
618	Hidden Cove	535	Private Land		LOW-MED	Levee needs, subsided, no upland			HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	NOT_ANAL	MEDIUM	MEDIUM
619	Schafer Farms (619 and 620)	151	Private Land		LOW	No tidal connex, subsided, levee needs			LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	LOW
621	Stone Duck	108	Private Land		LOW	No tidal connex, subsided, levee needs			LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	LOW
623	Frost Slough Rod and Gun Club	85	Private Land		LOW	No tidal connex, subsided, levee needs			LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	HIGH
625	Pintail Ranch	375	Private Land		LOW-MED	Levee needs, subsided			HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	NOT_ANAL	MEDIUM	LOW
627	Honneger Ranch	74	Private Land	NE	HIGH	Upland, no levees			HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	MEDIUM	LOW	MEDIUM	LOW
631	Meins Landing	647	DWR	NE	MED-HIGH	Ltd levee needs, upland+riparian edge, public ownership, pipelines			HIGH	MED-HIGH	LOW-MED	NOT_ANAL	MEDIUM	MEDIUM	NOT_ANAL	HIGH	HIGH	MED-HIGH	MED-HIGH	LOW	HIGH	MEDIUM
632	Sheriff Pond	73	Private Land		LOW	No tidal connex, subsided, levee needs			LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	NOT_ANAL	MEDIUM	LOW
633	Boles Pond	132	Private Land		LOW	No tidal connex, subsided, levee needs			LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	HIGH
634	Grizzly Hilton	189	Private Land		LOW	Major levee needs, subsidence			HIGH	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	NOT_ANAL	MEDIUM	HIGH
701	Goodyear Club	105	Private Land	CN	LOW	hydro/WQ, no tidal connex			LOW	MED-HIGH	MED-HIGH	LOW	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	MEDIUM	LOW	HIGH	MEDIUM
702	Morrow Island Land Company	690	Private Land	CN	MEDIUM	Levee needs, recent land TX, some relic chan	Morrow Island	MED-HIGH No levees, subsuded	HIGH	MEDIUM	LOW-MED	MED-HIGH	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	MEDIUM	HIGH	LOW
703	The Friendly Godfather	128	Private Land	CN	LOW-MED	Levee needs	Morrow Island	MED-HIGH No levees, subsuded	HIGH	MEDIUM	LOW-MED	MED-HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW	LOW	HIGH	HIGH
705	Mulberry Land Company	452	Private Land	CN	LOW-MED	Levee needs, subsided, no upland, some relic chan	Morrow Island	MED-HIGH No levees, subsuded	HIGH	LOW-MED	LOW-MED	MED-HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	MED-HIGH	MEDIUM	LOW
706	Mallard Haven	101	Private Land	CN	LOW-MED	Hydro/WQ, levee needs			HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	LOW	MEDIUM	LOW
707	Goodyear Land Development	406	Private Land	CN	LOW-MED	Levee needs, recent land TX, hydro/WQ	Morrow Island	HIGH No levees; invsv plants but salt	HIGH	LOW-MED	MEDIUM	MEDIUM	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	MEDIUM	LOW	MEDIUM	HIGH	LOW
709		39	Private Land	CN	LOW	No tidal connex			LOW	MED-HIGH	HIGH	LOW	HIGH	MED-HIGH	NOT_ANAL	MEDIUM	HIGH	HIGH	LOW-MED	LOW	HIGH	LOW
715	Fleetside Farms	445	Private Land	CN	MEDIUM	Levee needs, hydro/WQ, less subsided	Morrow Island	HIGH No levees; invsv plants but salt	HIGH	MED-HIGH	MED-HIGH	MEDIUM	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	LOW-MED	LOW	LOW	HIGH	HIGH
721	Silver Sprig	148	Private Land	CN	LOW-MED	Levee needs, subsided, no upland	Morrow Island	MED-HIGH No levees, subsuded	HIGH	LOW-MED	LOW-MED	MED-HIGH	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	MED-HIGH	LOW	LOW-MED	MEDIUM	MEDIUM
802	Rich Island, Inc.	1007	Private Land	SE	MEDIUM	Levee needs, subsided	Simmons Island	MEDIUM RRDS levee, relic chan	HIGH	MEDIUM	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	LOW
803	St. Germain Duck Club	768	Private Land	SE	MEDIUM	Levee needs, subsided, relic chan, no upland, recent land TX	Simmons Island	MEDIUM RRDS levee, relic chan	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	HIGH	MEDIUM	LOW
804	Sprig Farm	508	Private Land	SE	LOW	No tidal connex	Simmons Island	MEDIUM RRDS levee, relic chan	LOW	LOW	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	HIGH
805	Grey Island (805 and 806)	143	Private Land	SE	LOW-MED	Levee needs, subsided, no upland, no relic chan	Simmons Island	MEDIUM RRDS levee	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	LOW	MEDIUM	MEDIUM
807	Wheeler Island	997	Private Land	SE	MEDIUM	Levee needs, subsided, relic chan, no upland	Simmons Island	MEDIUM RRDS levee, relic chan	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	MEDIUM
902	Atlantis Gun Club	122	Private Land	SE	MEDIUM	Levee needs	Honker Bay	MEDIUM Ltd levees, RRDS	HIGH	MEDIUM	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	HIGH	LOW
903	Blue Bird Club	128	Private Land	SE	LOW-MED	Levee needs, subsided, no upland, no relic chan	Honker Bay	MEDIUM Ltd levees, RRDS	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	LOW	MEDIUM	MEDIUM
904	Wingnuts	80	Private Land	SE	LOW-MED	Levee needs, subsided	Honker Bay	MEDIUM Ltd levees, RRDS	HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	MEDIUM	MEDIUM	MEDIUM
905	Mallard Farms	254	Private Land	SE	LOW-MED	Levee needs, subsided	Honker Bay	MEDIUM Ltd levees, RRDS, pipeline	HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	MEDIUM	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	LOW
906	Wreck Slough	129	Private Land	SE	LOW-MED	Levee needs, subsided, no upland, no relic chan	Honker Bay	MEDIUM Ltd levees, RRDS	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	LOW	MEDIUM	MEDIUM
907	River Dog Retreat	380	Private Land	SE	LOW	Levee needs, subsided, inactive gas well, no upland, relic chan	Van Sickle Island	MEDIUM Subsided, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MED-HIGH	MEDIUM	MEDIUM
908	Montezuma Ranch	247	Private Land	SE	LOW	Levee needs, subsided, gas well, no upland, min relic chan	Van Sickle Island	LOW-MED Gas well, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	LOW	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	LOW-MED	HIGH	MEDIUM

Table B-1. Restoration Feasibility Rankings for Each Restorable Diked Property in Suisun Marsh
Suisun Marsh Conservation Strategy

ID	NAME	Acreage	Owner	Restoration Subregion [1]	IFR Individual [2]	Individual Feasibility Notes	IFR Cluster [2] Cluster Name	Cluster	Cluster Feasibility Notes	H1 TidConDep	H2 DikedEdge	H3 AvgElev	H4 Hydro/WQ	M1 GasWells	M2 Pipeline	M3 SMHM	M4 Owner	M5 RecDist	M6 InvsvPlants	M7 UplnEdge	M8 RelicChan	L1 Williamson	L2 TransDate
910	Dante Farms	262	Private Land	SE	MEDIUM	Levee needs	Chipps Island	MED-HIGH	No levees; no relic chan; extensive cover by invsv plants	HIGH	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	HIGH	LOW-MED	LOW	LOW	MEDIUM	LOW
912	Honker Bay Farms	292	Private Land	SE	LOW	Levee needs, subsided, aband gas well, no upland	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	LOW	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MEDIUM	HIGH	MEDIUM
913	Hook n' Trigger	201	Private Land	SE	LOW	Levee needs, subsided, no upland, relic chan	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MEDIUM	HIGH	MEDIUM
915	Delta Shoots (915 and 941)	348	Private Land	SE	MED-HIGH	All but relic chan	Chipps Island	MED-HIGH	No levees; no relic chan; extensive cover by invsv plants	HIGH	HIGH	HIGH	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	HIGH	LOW-MED	LOW	LOW	MEDIUM	MEDIUM
916	A & B Duck Club	61	Private Land	SE	LOW	Levee needs, subsided	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	MEDIUM	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	HIGH	MEDIUM
917	Island Gun Club	29	Private Land	SE	LOW	No tidal connex, subsided, levee needs	Van Sickle Island	MEDIUM	Subsided, many properties	LOW	LOW	LOW	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	HIGH	LOW
918	Blue-Winged Teal	90	Private Land	SE	LOW	Levee needs, subsided	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	LOW	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	LOW	HIGH	HIGH
923		11	Private Land	SE	LOW	Levee needs	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	LOW	HIGH	MEDIUM
926	Webfoot Duck Club	108	Private Land	SE	LOW	Levee needs, subsided, no upland, no relic chan, trans date	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	HIGH	LOW
927	Spoonbill Club	50	Private Land	SE	LOW	No tidal connex	Van Sickle Island	MEDIUM	Subsided, many properties	LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	MED-HIGH	HIGH	HIGH
928	Hi Gunner Club	71	Private Land	SE	LOW	No tidal connex	Van Sickle Island	MEDIUM	Subsided, many properties	LOW	LOW	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	LOW-MED	MEDIUM	HIGH
929	Riverside Gun Club	32	Private Land	SE	LOW	No tidal connex, subsided, levee needs	Van Sickle Island	MEDIUM	Subsided, many properties	LOW	LOW	LOW	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	HIGH	LOW	LOW-MED	HIGH	LOW
930	Hit & Miss Club	44	Private Land	SE	LOW	Levee needs, subsided, no upland, no relic chan, trans date	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	HIGH	MEDIUM
931	Delta Farms	309	Private Land	SE	LOW	Levee needs, subsided, gas well, no upland, min relic chan	Van Sickle Island	LOW-MED	Gas well, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	LOW	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	LOW-MED	MEDIUM	HIGH
932	Concord Farms	384	Private Land	SE	LOW	Levee needs, subsided, inactive gas well, no upland	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	MEDIUM	HIGH	HIGH
933	Mallard Farms II	191	Private Land	SE	LOW-MED	Levee needs	Honker Bay	MEDIUM	Ltd levees, RRDS, pipeline	HIGH	LOW-MED	MEDIUM	NOT_ANAL	HIGH	MEDIUM	NOT_ANAL	MEDIUM	MEDIUM	MED-HIGH	LOW	LOW	MEDIUM	LOW
934	934, 935, 936, 937, 938, 939	17	Private Land	SE	LOW	Levee needs, subsided, no upland, no relic chan	Van Sickle Island	MEDIUM	Subsided, many properties	HIGH	LOW-MED	LOW-MED	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	LOW-MED	LOW	LOW	HIGH	HIGH
940	Spinner Island	61	Private Land	SE	MEDIUM	Levee needs, ltd subsidence	Van Sickle Island	MED-HIGH	Little subsidence, many properties	HIGH	MEDIUM	MED-HIGH	NOT_ANAL	HIGH	HIGH	NOT_ANAL	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	MEDIUM	LOW
1000	Gold Hills Unit	59	CDFG Land	WRR	LOW-MED	hydro/WQ, levee needs, pipeline				HIGH	MEDIUM	HIGH	LOW	HIGH	MED-HIGH	NOT_ANAL	HIGH	HIGH	HIGH	LOW-MED	LOW	HIGH	MEDIUM
1001	Beldons Landing FA	13	CDFG Land	CN						HIGH	MED-HIGH	HIGH	NOT_ANAL	HIGH	HIGH	NOT_ANAL	HIGH	HIGH	MEDIUM	LOW-MED	LOW	HIGH	HIGH
1002	Island Slough Unit	514	CDFG Land		LOW-MED	Levee needs, subsided				HIGH	LOW-MED	LOW	NOT_ANAL	HIGH	HIGH	LOW-MED	HIGH	HIGH	MED-HIGH	LOW	NOT_ANAL	HIGH	HIGH
1003	Crescent Unit, GIWA	164	CDFG Land		LOW-MED	Levee needs				HIGH	LOW-MED	MEDIUM	NOT_ANAL	MEDIUM	HIGH	LOW-MED	HIGH	HIGH	MEDIUM	LOW	NOT_ANAL	HIGH	MEDIUM
1004	Crescent Unit, GIWA	92	CDFG Land		LOW	No tidal connex				LOW	LOW	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	HIGH	HIGH	MED-HIGH	LOW	NOT_ANAL	HIGH	HIGH
1005	Crescent Unit	150	CDFG Land		LOW	No tidal connex, levee needs, SMHM, no upland				LOW	LOW	MEDIUM	NOT_ANAL	HIGH	HIGH	LOW-MED	HIGH	HIGH	LOW-MED	LOW	NOT_ANAL	HIGH	HIGH
1006	West Family Unit	186	CDFG Land	WRR	LOW	No tidal connex, hydro/WQ, no upland, no relic chan				LOW	MEDIUM	MEDIUM	LOW	HIGH	MED-HIGH	NOT_ANAL	HIGH	HIGH	MEDIUM	LOW	LOW	HIGH	HIGH
1007	Goodyear Slough Unit	314	CDFG Land	CN	MEDIUM	Hydro/WQ				HIGH	MED-HIGH	MEDIUM	MEDIUM	HIGH	MED-HIGH	NOT_ANAL	HIGH	HIGH	LOW-MED	LOW	LOW	HIGH	HIGH
1008	Joice Island Unit	1644	CDFG Land	CN	MEDIUM	Levee needs, public ownership	Joice Island	MED-HIGH	No levees; partial subsided; proximity to invsv plants	HIGH	MEDIUM	MEDIUM	NOT_ANAL	HIGH	HIGH	NOT_ANAL	HIGH	HIGH	MEDIUM	LOW	LOW-MED	HIGH	HIGH
1011	Grizzly Island Unit -R	4876	CDFG Land	SE	LOW-MED	Levee needs	Grizzly Island	MEDIUM	levees; large; better if restore S of RRDS; invsv plants	HIGH	LOW-MED	MEDIUM	NOT_ANAL	MEDIUM	MEDIUM	LOW-MED	HIGH	HIGH	MEDIUM	LOW	MEDIUM	HIGH	HIGH
1011	Grizzly Island Unit -N	3810	CDFG Land		LOW-MED	Levee needs, land use, inactive gas well, pipelines				HIGH	LOW-MED	LOW-MED	NOT_ANAL	MEDIUM	MEDIUM	LOW-MED	HIGH	HIGH	MEDIUM	LOW	NOT_ANAL	HIGH	HIGH
1014	Garabaldi Unit	388	CDFG Land	WRR	LOW-MED	Hydro/WQ				HIGH	HIGH	MEDIUM	LOW-MED	HIGH	MED-HIGH	NOT_ANAL	HIGH	HIGH	HIGH	MED-HIGH	LOW-MED	HIGH	HIGH
1017	Hill Slough Unit	743	CDFG Land	CN	MED-HIGH	Ltd levee needs, ltd subsidence, public ownership				HIGH	MED-HIGH	MED-HIGH	HIGH	HIGH	HIGH	MED-HIGH	HIGH	HIGH	MEDIUM	LOW-MED	MEDIUM	HIGH	HIGH

Table B-1. Restoration Feasibility Rankings for Each Restorable Diked Property in Suisun Marsh
Suisun Marsh Conservation Strategy

ID	NAME	Acreage	Owner	Restoration Subregion [1]	IFR Individual [2]	Individual Feasibility Notes	IFR Cluster Name [2]	Cluster Feasibility Notes	H1 TidConDep	H2 DikedEdge	H3 AvgElev	H4 Hydro/WQ	M1 GasWells	M2 Pipeline	M3 SMHM	M4 Owner	M5 RecDist	M6 InvsvPlants	M7 UplnEdge	M8 RelicChan	L1 Williamson	L2 TransDate

NOTES

1 Subregion Codes: SE = Southeast; NE = Northeast' CN = Central; WRR = West of Railroad
2 IFR = Individual Feasibility Ranking of the diked portion of property
H1 TidConDep = Tidal Connection Dependency on adjacent lands
H2 DikedEdge = Percent of diked portion of property that adjoins other diked lands requiring tidal flood protection
H3 AvgElev = Average land surface elevation of diked portion of property, based on DWR-adjusted 2005 LiDAR
H4 Hydro/WQ = Hydrologic and water quality constraints
M1 GasWells = Gas wells present on site and their use status (active, inactive, abandoned)
M2 Pipeline = Pipeline crossing or along margin of diked portion of property
M3 SMHM = Salt marsh harvest mouse conservation area on diked portion of property
M4 Owner = Ownership type (private, public)
M5 RecDist = Reclamation District
M6 InvsvPlants = Invasive plants (*Phragmites, Lepidium*)
M7 UplnEdge = Natural upland edge adjoining diked portion of property
M8 RelicChan = Relic tidal channel intact on diked portion of property
L1 Williamson = Williamson Act contract for property
L2 TransDate = Transfer Date of property title on record with Solano County