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DUTCH SLOUGH TIDAL MARSH RESTORATION
CONCEPTUAL PLAN & FEASIBILITY REPORT

Prepared for

The California State Coastal Conservancy

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1. EXECUTIVE SUMMARY

1.1 INTRODUCTION

This study identifies a preferred conceptual restoration plan that will restore the 1,166-acre Dutch Slough former cattle grazing and dairy production site to freshwater tidal marsh, riparian, and sand dune habitat. The Dutch Slough Tidal Marsh Restoration Project is seen as a significant step in recovery of the ecological health of the Sacramento-San Joaquin Delta for two reasons. First, it is the largest tidal wetland restoration designed to recreate the dominant type of habitat present historically in the Delta – a mosaic of marshplain drained by a sinuous branching tidal channel network, with adjacent riparian habitats. Second, the restoration project is designed using an adaptive management framework intended to inform cost effective wetland restoration on subsided sites in the Delta to benefit native fishes and other native species. Lessons learned from monitoring the restoration will help inform key planning and design decisions for future large-scale freshwater tidal restoration proposed in the Delta.

The Dutch Slough Tidal Marsh Restoration is being planned by the Dutch Slough Management Team, which includes the California Department of Water Resources (DWR), the State Coastal Conservancy (SCC), the City of Oakley, and the California Bay-Delta Authority (CBDA). DWR is the land owner, having purchased the site in 2003 with funds from CBDA and the SCC. The SCC is leading the restoration planning with assistance from the Natural Heritage Institute (NHI) and the PWA (Philip Williams & Associates, Ltd.) consultant team. The City of Oakley is leading the public access and recreation planning components of the project, which are being documented separately. An Adaptive Management Work Group (AMWG) provided scientific input to the Dutch Slough conceptual restoration plan.

The preferred plan identified in this study will be evaluated for compliance with the California Environmental Quality Act (CEQA) and, as applicable, the National Environmental Policy Act (NEPA) in subsequent stages of planning.

1.2 LOCATION AND STUDY AREA

The Dutch Slough restoration site is located within the City of Oakley, in eastern Contra Costa County, California (Figure 1). The site was historically tidal marsh that adjoined sand dunes and the mouth of Marsh Creek. The site is currently diked and was, until recently, used primarily for cattle grazing and dairy production. The site slopes gently from higher areas in the south and southwest to lower areas in the north; elevations range from approximately -10 to +15 feet National Geodetic Vertical Datum of 1929 (NGVD), which is equivalent to approximately -12 feet to +13 feet relative to Mean Sea Level (MSL). The Dutch Slough site consists of three separate, similarly sized parcels. The restoration results can be compared between parcels, making the site particularly well suited to the design of adaptive management experiments. The site is bordered to the west by the channelized Marsh Creek, to the north by Dutch Slough, to the east by Jersey Island Road, and to the south by the Contra Costa Canal.

1.3 PROJECT GOALS AND OBJECTIVES

The three goals of the Dutch Slough Tidal Restoration Project are to:

1. Provide shoreline access, educational and recreational opportunities.
2. Benefit native species by re-establishing natural ecological processes and habitats
3. Contribute to scientific understanding of ecological restoration by implementing the project under an adaptive management framework.

This study addresses Goals 2 and 3. The public access and recreation features of the Dutch Slough project (Goal 1) are being developed in a separate master planning process, led by the City of Oakley, and are generally compatible with all the restoration alternatives considered in this study.

1.4 DESIGN APPROACH

Dutch Slough restoration alternatives were developed to provide both sustainable ecosystem restoration benefits and adaptive management experiments. Each restoration alternative includes habitat restoration features and adaptive management experiments. The restoration design features will create a mix of emergent freshwater tidal marsh, riparian, and upland habitats, which are expected to benefit a variety of native plants and animals, including several special status species. The adaptive management experiments at Dutch Slough will test different methods of wetland restoration and monitor the physical and ecological responses. Adaptive management is the process of learning from restoration and management actions, then using this knowledge to inform and adapt future actions. The adaptive management experiments at Dutch Slough are primarily intended to inform future restoration projects anticipated in the Sacramento-San Joaquin River Delta, but may also influence management actions at the Dutch Slough site after tidal restoration is implemented. The experimental and restoration features are not mutually exclusive. Many of the experimental features are expected to provide significant restoration benefits, and restoration features provide opportunities for experimentation.

The AMWG and PWA consultant team developed a conceptual model of wetland restoration (Appendix E) as the basis for recommending high priority experiments to test in the Dutch Slough project. The recommended experiments span various spatial scales. The small-scale experiments require only small areas (one or two acres) and can be readily accommodated within any given restoration alternative. The large-scale experiments require areas on the order of hundreds of acres. The project identified tidal marshplain elevation and marsh scale for large-scale testing. Marshplain elevation is considered important to test because lower vegetated marshes require less fill, but the habitat value is less well understood than for higher, natural marshes. Marsh scale (*i.e.*, size of the marsh drainage area) is considered important to test to guide the selection of future restoration sites. Small sites are generally more available for restoration than large sites, but may not offer the same benefits on a per-acre basis (*e.g.*, tidal channel complexity).

1.5 ALTERNATIVES CONSIDERED

Three restoration alternatives and the No Action Alternative were considered. Restoration alternatives for the Dutch Slough site were developed to meet the habitat restoration and adaptive management goals, with consideration of project cost. The alternatives represent different mixes of habitat, with different amounts of grading and imported fill to create these habitats. The alternatives are:

- No Action Alternative;
- Alternative 1: Low marsh and open water emphasis with minimal grading (Low cost alternative);
- Alternative 2: Mix of mid marsh, low marsh, and open water with moderate fill (Preferred alternative);
- Alternative 3: Mid marsh and low marsh emphasis with imported fill.

In Alternatives 2 and 3, Marsh Creek will be diverted into the Emerson parcel to restore a natural delta at the mouth of the creek, if feasible from a water quality perspective (Figure 11). All three restoration alternatives are consistent with providing high quality public access and restoration opportunities and provide for protection of existing infrastructure. Additional restoration approaches and preliminary alternatives were considered and not recommended because they do not meet the project goals.

1.6 PREFERRED ALTERNATIVES

Alternative 2 (Figure 12) is the preferred alternative selected for more detailed consideration in this feasibility study. Alternative 2 is expected to meet the project goals for habitat restoration and adaptive management in a cost-effective manner. Alternative 2 will create approximately 660 acres of marsh and tidal channel habitat and 80 acres of riparian, native grassland, and dune habitat using on-site grading (approximately 1,320,000 cubic yards), a moderate amount of additional fill (approximately 360,000 cubic yards), and re-vegetation techniques. Additional fill material will be imported or borrowed onsite from low elevation open water areas. The restored marsh will consist of low marsh and mid marsh areas with sinuous and branching tidal channel systems of varying scales. The key adaptive management experiments – testing of marshplain elevation and marsh scale – are major components of Alternative 2. Alternative 2 also includes features to protect existing infrastructure, ongoing maintenance, and monitoring to inform adaptive management.

Alternative 2 will allow for the option to divert Marsh Creek into the Emerson parcel to restore a natural delta at the mouth of the creek, if feasible from a water quality perspective. Studies of Marsh Creek water quality are in progress to inform this design decision. Alternate alignments for the potential Marsh Creek diversion are shown in Figure 11. Alternative 2 will also create areas of open water in each parcel (210 acres total), which will not be filled to reduce costs. There are several options for managing open water areas. The preferred options will be determined in future phases of the project.

The primary feasibility issues relate to water and sediment quality. The potential for wetlands to increase organic carbon production and mercury methylation are regional issues of concern for Delta wetland restoration. The processes driving the production, fate, and transport of these constituents are areas of developing science. According to the water and sediment quality assessment conducted for this project, it is not possible to characterize with a high degree of certainty the relative contributions of wetlands to dissolved organic carbon (DOC) and methyl mercury production compared to other land uses. The experimental design and monitoring at Dutch Slough are intended to contribute to ongoing research of organic carbon and MeHg so that the CBDA and others can make informed decisions about potential impacts and benefits associated with wetland restoration in the Delta.

The preliminary planning-level cost estimate for permitting, design, and construction of Alternative 2 is $25,200,000 to $29,400,000. The estimate includes an allowance of 30% for construction contingencies and 10% for planning and final design. The range in costs depends on the source of fill material needed to create marsh areas, which may be either imported or borrowed onsite. The estimate of average annual costs for ongoing site maintenance is $26,000 per year. Average annual costs for project performance monitoring (for environmental compliance) over the first 10 years after project construction are estimated to be $60,000. Costs are presented in 2005 dollars, and will need to be adjusted to account for price escalation for implementation in future years.

Several potential cost elements are not included in the cost estimate, such as restoration of a Marsh Creek delta, open water management options, small-scale adaptive management experiments, and adaptive management monitoring (*i.e.*, scientific research) (see Section 8.4.2 for further discussion). The above-mentioned items would increase project costs. It is assumed that the cost of monitoring large-scale adaptive management experiments and implementing and conducting small-scale experiments will be funded through individual scientific research initiatives. Further study, coordination, and design refinement are needed to assess other costs not included.

2. INTRODUCTION

2.1 STUDY PURPOSE AND SCOPE

This report summarizes the feasibility study for the Dutch Slough Tidal Marsh Restoration. The purpose of the study is to identify one or more feasible restoration plans that meet the project goals. Project feasibility is assessed in terms of physical, ecological, and economic considerations.

The feasibility study:

- Presents project goals and objectives;
- Describes physical and ecological site conditions;
- Evaluates opportunities and constraints for restoration;
- Presents a range of alternative plans and considers how well each meets the project goals;
- Recommends a potential restoration plan for further consideration;
- Provides additional planning and design detail for the selected plan.

The preferred plans identified in this study will be evaluated for compliance with the California Environmental Quality Act (CEQA) and, as applicable, the National Environmental Policy Act (NEPA) in subsequent stages of planning, as applicable.

2.2 SITE DESCRIPTION

The 1,166-acre Dutch Slough restoration site is located within the City of Oakley, in eastern Contra Costa County, California (Figure 1). The site was historically tidal marsh that adjoined sand dunes and the mouth of Marsh Creek. The site is currently diked and was, until recently, used primarily for cattle grazing and dairy production. The site slopes gently from higher areas in the south and southwest to lower areas in the north; elevations range from approximately -10 to +15 ft NGVD (from -12 feet to +13 feet relative to MSL). The Dutch Slough site consists of three separate, similarly sized parcels. The restoration results can be compared between parcels, making the site particularly well suited to experimental design. The site is bordered to the west by the channelized Marsh Creek, to the north by Dutch Slough, to the east by Jersey Island Road, and to the south by the Contra Costa Canal.

2.3 STUDY PARTICIPANTS

The Dutch Slough Tidal Marsh Restoration is being planned by the Dutch Slough Management Team, which includes the California Department of Water Resources (DWR), the California State Coastal Conservancy (SCC), the City of Oakley, and the California Bay-Delta Authority (CBDA). DWR is the land owner, having purchased the site in 2003 with funds from CBDA and the SCC. The SCC is leading the restoration planning with assistance from the Natural Heritage Institute (NHI) and the PWA (Philip Williams & Associates, Ltd.) consultant team. The City of Oakley is leading the public access and recreation planning component of the project.

One of the goals of the project is to contribute to scientific understanding of ecological restoration by implementing the project under an adaptive management framework. Within the context of the Dutch Slough project, adaptive management is the process of learning from restoration and management actions, then using this knowledge to inform future actions. Consistent with achieving this goal, an Adaptive Management Work Group (AMWG) was convened by NHI to provide scientific input to the Dutch Slough conceptual restoration plan. The AMWG consists of scientists with expertise in a broad range of physical and ecological topics relevant to tidal marsh restoration in the Sacramento-San Joaquin Delta. The AMWG met five times during the restoration planning to provide input and review on various aspects of the planning process, including goals and objectives, opportunities and constraints, and alternatives development. Study participants are listed in Section 11.

2.4 REPORT ORGANIZATION

The report is organized into the following sections:

- Section 3 Project Goals; Implementation Commitments, and Objectives;
- Section 4 Site Description; this section provides a discussion of site land uses, infrastructure, hydrologic and biologic conditions, and a brief summary of public use;
- Section 5 Opportunities and Constraints; for restoration;
- Section 6 Alternatives Development Approach; this section describes the approach for planning the restoration within an adaptive management framework and describes the restoration target habitats and design features;
- Section 7 Analysis of Alternatives; this section describes the range of alternatives considered and the alternatives evaluation that leads to selection of the preferred alternative considered in Section 8;
- Section 8 Preferred Alternative; this section describes the selected alternatives in further detail, including habitats created, preliminary engineering design, infrastructure protection, expected water quality, and planning-level construction methods and costs.

Following the main report are appendices documenting additional planning details and the technical studies completed for this plan and feasibility study.

3. PROJECT GOALS, IMPLEMENTATION COMMITMENTS, AND OBJECTIVES

The project goals, implementation commitments, and objectives were developed by the Dutch Slough Management Team with input from the Dutch Slough Restoration Committee (a forum of key agencies and stakeholders), the Adaptive Management Working Group, and PWA. Target species for the Dutch Slough restoration project are listed in Appendix A. While not explicitly identified as a project objective, the cost-effectiveness of project implementation was taken into account in the development of alternatives.

3.1 GOALS

The three project goals are to:

1. Provide shoreline access, educational and recreational opportunities.
2. Benefit native species by re-establishing natural ecological processes and habitats.
3. Contribute to scientific understanding of ecological restoration by implementing the project under an adaptive management framework.

3.2 IMPLEMENTATION COMMITMENTS

The implementation commitments are to:

1. Avoid, measure and mitigate degradation of drinking water quality.
2. Minimize the potential for mercury methylation and other water quality impacts.
3. Minimize the establishment of nuisance species through design and management.
4. Design and manage project to minimize negative affects on public health, such as conditions that promote the production of mosquitoes and associated diseases.
5. Avoid and/or mitigate impacts to existing infrastructure and easements on the project site.
6. Maintain existing flood protection on neighboring properties.

3.3 OBJECTIVES

Goal 1: Provide shoreline access, educational and recreational opportunities.

A. Provide and expand public access that is safe and consistent with the ecological goals of the project.
   1. Open trail around Emerson levee,
   2. Create a 55-acre community park,
   3. Provide public access to the Delta shoreline.

B. Create educational opportunities compatible with wildlife and habitat goals.

1. Create signage to educate public about restoration project,
2. Build wildlife viewing platforms,
3. Involve schools and community groups.

C. Create recreational opportunities compatible with wildlife and habitat goals.

1. Build non-motorized boat launch,
2. Create swimming opportunities for the public,
3. Create opportunities to canoe and kayak.

Goal 2: Benefit native species by re-establishing natural ecological processes and habitats.

A. Reestablish the hydrologic, geomorphic, and ecological processes necessary for the long-term sustainability of native habitats and the plant and animal communities that depend upon them.

1. Reestablish tidal connections to the site for exchange of water, sediments, and nutrients,
2. Contribute to primary productivity of the Suisun Marsh and San Francisco Bay through export of nutrients,
3. Create food supply for target species identified in Appendix A,
4. Seasonally inundate high marshplain for spawning and rearing by Sacramento splittail,
5. Re-route Marsh Creek, if feasible, to reestablish a supply of natural freshwater flows and fluvial sediments to the site.

B. Restore a mosaic of wetland and upland habitats.

1. Restore large areas of tidal emergent marsh and tidal channels. (invasives addressed separately in Objective 2C below),
2. Expand shaded riverine aquatic habitat along the sloughs and Marsh Creek,
3. Establish plant communities once common in the Delta but now rare such as the willow-lady fern community, sandmound riparian woodland, Antioch dune scrub, and perennial grasslands,
4. Create natural gradients between uplands and wetlands for the restoration of biologically rich transitional habitats (ecotones),
5. Restore a dynamic, natural creek delta at the mouth of Marsh Creek, if feasible.

C. Contribute to the recovery of endangered and other at-risk species and native biotic communities.

1. Focus restoration design to benefit tier 1 species, and adjust restoration to benefit tier 2 species. Maintain opportunities to benefit tier 3 species consistent with restoration of tier 1 species. Tier 1 species include juvenile Chinook salmon, Sacramento splittail, Delta smelt, and Antioch Dune Scrub species (see Appendix A for list of tier 1, 2, and 3 species).

D. Minimize establishment of and reduce impacts from non-native invasive species.

1. Design and manage the project to minimize the introduction of feral animals,
2. Design and manage the project to minimize potential for establishment of non-native submerged aquatic vegetation (*e.g.*, *egeria densa*),

3. Design and manage to prevent colonization and establishment of arundo donax, pepper weed and Phragmites,
4. Minimize human impacts to wildlife particularly nesting avian species.

Goal 3: Contribute to scientific understanding of ecological restoration by implementing the project under an adaptive management framework.

A. Establish technical review committees to review restoration design, management practices, and monitoring study design and results.

B. Articulate, test, refine, and grow understandings about natural and human systems. Conduct hypothesis based research on the ecological processes that shape and maintain ecosystems.

C. Establish and improve communication pathways between science, management, and public communities that will result in the sharing of knowledge developed in the course of the Dutch Slough Restoration Project.

D. Conduct long-term project monitoring to evaluate the effect of the restoration project on sensitive species, habitat value, and water quality.

4. SITE DESCRIPTION

4.1 SITE LOCATION AND LAND USE

The Dutch Slough restoration site is located within the City of Oakley, in eastern Contra Costa County, California (Figure 1). The site is bordered to the west by Marsh Creek, to the north by Dutch Slough, to the east by Jersey Island Road, and to the south by the Contra Costa Canal. Just northwest of Marsh Creek is Big Break, an existing shallow subtidal and freshwater emergent marsh.

Totaling 1,166 acres, the Dutch Slough site is divided into three separate parcels, the Emerson (438 acres), Gilbert (292 acres), and Burroughs (436 acres) parcels (Figure 1). Two internal sloughs separate the three parcels. The Emerson Slough divides the Emerson and the Gilbert parcels, and Little Dutch Slough divides the Gilbert and Burroughs parcels. Both Emerson and Little Dutch Slough dead end beyond the southern border of the site. Agricultural levees separate all three parcels from the surrounding Sloughs.

The Dutch Slough site is a former tidal marsh with relic dunes, historically surrounded by seasonal and riparian wetlands, and the Marsh Creek delta. The site was diked and drained for agriculture during European settlement, perhaps as early as the 1850s (NHI, 2004). From 1904 to 1910, Emerson, Little Dutch, and the eastern portion of Dutch Slough all were dredged for agricultural purposes. Few data exist on the extent and morphology of the natural historic channel network at the Dutch Slough site.

All three parcels at the Dutch Slough site have been used for dairy operations. The Emerson parcel remained a dairy from 1917 to 2003, and the Gilbert and Burroughs parcels remained dairies until they were converted to grazing lands in the mid-1970s (NHI, 2004). Contra Costa County and the Emerson, Gilbert and Burroughs families planned for housing developments at the Dutch Slough site as of 1997, but the City of Oakley subsumed this agreement, when it became incorporated in 1999 (NHI, 2004). Since DWR, SCC, and CBDA purchased the land in 2003, the Dutch Slough site remains as irrigated pasture for cattle grazing with some active and inactive gas production wells (see Section 4.2).

4.2 INFRASTRUCTURE

The Dutch Slough site is bordered to the south by the Contra Costa Canal, an artificial channel used to deliver water to many parts of Contra Costa County (Figure 2). The Contra Costa Canal is an open canal surrounded by earth embankments. The northern embankment separates the site from the canal. Agricultural levees separate the site from Dutch Slough, Emerson Slough, and Little Dutch Slough. The Marsh Creek flood control levee is the western site boundary and separates the site from Marsh Creek. Jersey Island Road and power and gas lines border the east side of the site, with the power lines and associated power towers on-site and Jersey Island Road considered off-site. Several other PG&E power and gas distribution lines are located on-site. Several buildings previously used for agriculture exist onsite. The buildings on the Gilbert and Emerson parcels, along with a small portion of land in the northeastern corner of the Burroughs property, are to be maintained by the City for use as public access at the restored site.

Natural gas wells exist on all three properties (Figure 2). The location and status of most of the wells have been confirmed (T. Hall, DWR, pers. comm.; ENGEO, 2003a). A map provided by PG&E identified several other gas wells on the Gilbert and Burroughs parcels; however, the location and status of these wells have not been verified. Further coordination with PG&E and well reconnaissance are recommended to confirm this. The confirmed gas wells on the Emerson and Gilbert properties are plugged and abandoned. Mineral and surface rights are reserved for the possible future operation of a single gas well on each parcel. The Burroughs property retains eight confirmed natural gas wells. Of the eight, two are plugged and abandoned, four are inactive, and two actively produce natural gas for commercial use. Storage tanks, concrete, and site contamination at the plugged and abandoned wells have been removed and cleaned up (DWR, 2003). Under terms of the land sale agreement, inactive gas wells must be plugged and abandoned on or before July 1, 2008.

The Phase I site assessments also identified a dairy waste pond on the portion of the Emerson parcel that is being planned as a community park by the City of Oakley, which is not part of the Dutch Slough restoration site.

The Ironhouse Sanitary District uses treated wastewater to irrigate Jersey Island, to the north of Dutch Slough, and the Ironhouse parcel, to the west of the Emerson parcel. The restoration at the Dutch Slough site must not affect groundwater levels at Jersey Island and the Ironhouse parcel.

There are three drinking water intakes located near the Dutch Slough site: the Contra Costa Old River intake, Contra Costa Rock Slough intake, and the Harvey O. Banks intake.

4.3 SITE TOPOGRAPHY

Most potential restoration sites in the Delta have subsided below the appropriate elevations for colonization by emergent tidal marsh vegetation, and therefore are relatively difficult to restore (Orr and others, 2003). The Dutch Slough site is unique in that large portions of the site remain at high enough elevations for vegetation to colonize rapidly and for feasible restoration (Figure 3).

Existing topography at the Dutch Slough site was compiled by Carlson, Barbee, & Gibson (CBG) in 2000 using aerial photogrammetry. Ground surveys of the Emerson and Gilbert parcel levees were available from Green Mountain Engineering (2004). These data were collected in the NGVD. The tidal datums of mean higher high water (MHHW), mean high water (MHW), mean tide level (MTL), mean low water (MLW), and mean lower low water (MLLW) were measured by Wetlands and Water Resources (WWR) in lower Marsh Creek for the period of July 28, 2000 to March 9, 2002 (NHI, 2002). WWR also surveyed the elevation of the tidal datums relative to the NGVD datum, which provides a conversion between the NGVD land datum and tidal datums. PWA performed a limited elevation survey to confirm the datum of the topographic data and the conversion between NGVD and the tidal datums (Appendix B). Elevations in this study are reported in feet NGVD (ft NGVD). For certain restoration design features, elevations are reported both relative to the tidal datums (MHHW, MTL, or MLLW) and NGVD. The following section (Section 4.4.1) contains both the tidal datums and their NGVD conversions.

The top elevation of the agricultural levees on the Gilbert and Burroughs parcels range from approximately 8 to 11 ft NGVD. Most of the levees surrounding the Emerson parcel also range from 8 to 12 ft NGVD, however levees in the southwestern corner of the Emerson parcel are much higher (10 to 24 ft NGVD) in order to prevent overtopping by Marsh Creek.

Table 1. Site Acreages Relative to Dutch Slough Tidal Datums

Elevations	**Emerson** (Acres)	**Gilbert** (Acres)	**Burroughs** (Acres)
5 feet above MHHW to Highest (Potential Dune Habitat and Upland)	32	1	3
MHHW to 5 feet above MHHW (Potential Riparian)	133	33	31
MTL to MHHW (Potential High Emergent Marsh)	22	17	37
MLLW to MTL (Potential Low Emergent Marsh)	12	6	27
6.25 ft. Below MLLW to MLLW (Potential Low Emergent Marsh and Shallow Subtidal)	126	197	299
Lowest to 6 feet Below MLLW (Potential Deep Subtidal)	111	21	21
Total	436	275	418

Note: Potential habitats based on colonization elevation data from Orr and others, 2003. Total acreages differ from the totals in NHI, 2004 due to small differences in the digitized boundaries.

All three parcels slope downward to the north. The Emerson and Burroughs parcels retain the largest areas of relatively high elevation land, each containing 199 and 98 acres, respectively, above MLLW, which are suitable for emergent marsh colonization or riparian and upland habitats (Table 1). A large portion of each parcel (approximately 200 to 350 acres) still lies at subtidal elevations, presenting the biggest challenge for restoration. Only a small part of these subtidal areas would be expected to support emergent marsh at the current elevations.

4.4 HYDROLOGIC CONDITIONS

4.4.1 Tidal Characteristics

Tidal datums in Dutch Slough are published by the National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services (NOAA COOPS, 2003) for the recent tidal epoch (1983 to 2001). WWR measured tidal datums in lower Marsh Creek and surveyed the elevations of these datums relative to NGVD (NHI, 2002). Table 2 shows the NOAA tidal datums for Dutch Slough and the elevation of the datums relative to NGVD, using the conversion calculated by WWR. Tides (water levels) in Dutch Slough were also measured in NGVD from January 1, 1997 to February 28, 2003 by the U.S. Geological Survey (USGS) and are available through the Interagency Ecological Program (IEP). PWA estimated tidal datums from one year of this data set (2001), which showed close agreement with the tidal datums in Table 2. FEMA (1987) estimated the 100-year tide level.

Table 2. Dutch Slough Tidal Datums

	Dutch Slough Tidal Datums	
	Feet MLLW	**Feet NGVD**
100-year Tide Level	6.8	6.5
Mean Higher High Water (MHHW)	3.44	3.15
Mean High Water (MHW)	2.99	2.70
Mean Sea Level (MSL)	1.77	1.48
Mean Tide Level (MTL)	1.76	1.47
Mean Low Water (MLW)	0.52	0.23
Mean Lower Low Water (MLLW)	0.00	-0.29

Sources: NOAA COOPS (2003), WWR (NHI, 2002), and FEMA (1987)

4.4.2 Drainage and Flooding

Flooding in the vicinity of the Dutch Slough site may result from extreme water levels caused by low atmospheric pressure storm surges occurring at high tides, high outflows from Delta tributaries, the joint occurrence of these processes, or runoff and flood flows in Marsh Creek.

FEMA (1987) mapped the Dutch Slough site within the 100-year floodplain, with a base flood elevation of 7 ft NGVD. The FEMA 100-year floodplain extends south to the Contra Costa Canal and east and west beyond the Dutch Slough site. FEMA's analysis assumes that the agricultural levees around the Dutch Slough site and adjacent lands will not provide 100-year flood protection because these levees are not built to FEMA flood control levee standards. The embankments of the Contra Costa Canal are above the 100-year flood elevation and, though they were not designed as flood protection levees, FEMA (1987) shows the embankments as providing 100-year flood protection for areas south of the Dutch Slough project. Topographic data, however, indicate that there are gaps in the embankments located at the heads of Emerson Slough and Little Dutch Slough, where the canal is siphoned through underground pipes. Flooding of the area to the south of the canal could occur through the gaps in the embankments.

Water surface elevations in lower Marsh Creek adjacent to the site are generally tidally driven except during brief periods (approximately one week or less) in wet years, when high Delta outflow elevates water levels (PWA, 2004). Downstream of the Contra Costa Canal, Marsh Creek flood elevations are controlled by flood levels in Dutch Slough (FEMA, 1987). Immediately upstream of the Contra Costa

Canal, the 50- and 100-year flood elevations are approximately 9 to 10 ft NGVD. The 50, 100, and 500-year peak discharges in Marsh Creek are 4,000 cubic feet per second at the Atchison Topeka and Santa Fe Railroad, located approximately 10,000 feet upstream from the confluence with Dutch Slough. Peak flood flows at this downstream location are reduced due to bypassing and/or nonreturning overbank spills (FEMA, 1987).

The Marsh Creek watershed drains roughly 125 square miles. The Marsh Creek Dam was installed in 1963, and collects drainage from 38% of the total watershed. Examination of the flow record shows an increase in runoff following the major increase in urbanization in the Marsh Creek watershed from the early to mid-1900s to the present (NHI and others, 2003).

During the rainy season, precipitation collects in the Emerson, Gilbert, and Burroughs parcels as surface water and is pumped out into the sloughs. Areas to the south of the Dutch Slough site drain to Emerson and Little Dutch Sloughs. An open drainage culvert is located in Little Dutch Slough.

4.4.3 Groundwater

The existing groundwater elevation in the Dutch Slough site is estimated to be between +3 feet to -10 ft NGVD. The existing levees around the Dutch Slough project have allowed the groundwater to be artificially lowered within the project site by evapotranspiration in the summer and pumping in the winter. Many adjacent levee-protected properties also have lower groundwater levels than existed prior to reclamation. The aquifer beneath the site is being recharged in part from Dutch Slough, Little Dutch Slough, and Emerson Slough.

Groundwater levels around the site vary irregularly, most likely due to local groundwater withdrawal and/or infiltration. Regional topography and geology may cause a general pattern of groundwater flow in a northerly direction; however, local modifications to groundwater levels are likely to have a greater influence on the direction of groundwater flow than regional patterns.

4.4.4 Salinity

The United States Bureau of Reclamation measured daily salinities in Dutch Slough using electric conductivity measurements from January 1, 1964 to December 31, 1998 (IEP, 2005). Delta outflows affect the salinity regime at Dutch Slough, with more saline waters during drier years with less Delta outflow. Salinities in Dutch Slough rarely rise above one part per thousand (ppt), even during years with historically low Delta outflow (Figure 4).

4.4.5 Water Quality

Appendix C contains a detailed water quality assessment conducted by Brown and Caldwell for the Dutch Slough restoration. Potential on-site sources of water quality contamination identified in this assessment are summarized in this section.

A prominent water quality contaminant within the Bay-Delta region is mercury. Many abandoned mercury mines throughout the California Coastal Range, and silver and gold mines dispersed throughout the Sierra Nevada have been depositing mercury-laden sediments into the Bay-Delta for the past 150 years (IEP, 1999). Due to this continuous source of mercury, many rivers, streams, and reservoirs have elevated concentrations of mercury. The abandoned Mt. Diablo Mine is located in the upper Marsh Creek watershed and is a potential source of mercury to the Dutch Slough restoration site.

The Brentwood Waste Water Treatment Plant (WWTP) is located along the lower reaches of Marsh Creek, upstream of the Dutch Slough site. WWTPs are regulated via the National Pollutant Discharge Elimination System (NPDES) to ensure that constituents of concern do not reach hazardous concentrations. Even so, WWTP discharges do contain measurable concentrations of many regulated constituents, as well as some unregulated constituents such as endocrine disruptor compounds.

Three Phase One Site Assessments were conducted for the Dutch Slough site in 2003 (ENGEO, 2003b; ENGEO, 2003c; Sequoia, 2003), which evaluated the potential for pollution through a review of existing records, site history, and a site visit. Several potential sources of pollution were identified in the Phase One Site Assessments. Site-specific soil and groundwater testing associated with the purchase and sale agreements for the Dutch Slough Properties were completed (ENGEO, 2003d). Soil and groundwater testing on the Emerson dairy parcel indicated that nitrate and nitrite levels in the soil are well below residential and aquatic toxicity levels and the average nitrite and nitrate concentrations in the groundwater were well below state drinking water criteria. Soil testing at gas wells and an above ground service tank on the Burroughs parcel showed low levels of petroleum hydrocarbons; mercury levels were below the detection limit. Contaminated soil was excavated, removed, and replaced with clean fill (DWR, 2003).

4.5 SOIL CONDITIONS

4.5.1 Subsurface Soils

Sand lies beneath essentially the entire Dutch Slough property and extends laterally in all directions onto adjacent properties. The sand is derived from glacier outwash from the Sierra Nevada Range, washed downstream into the western portions of the Delta and then redistributed as windblown dune deposits. The top of the sand varies in elevation from about +2 to -16 ft NGVD. Few borings in the area penetrate the full thickness of the sand aquifer. The available data suggest that the base of the sand is between elevation of -30 and -50 ft NGVD. The sand is underlain by flood plain deposits consisting of silts and clays. Deeper sand units underlie the silts and clays. The lateral continuity of the silt and clay aquitard is not known.

At the south end of the Dutch Slough project area, the sands are overlain by silts and clays, probably derived as flood plain deposits from the Marsh Creek drainage. On the northern portion of the project, the sand is overlain by peat and/or organic silt. These materials were deposited during the last few thousand years as the sea level slowly rose during the Holocene glacier retreat and warming of the earth that has been continuing for the last 11,000 years. Prior to land reclamation that occurred about 100 years ago, the surface of the peat or organic silt was near elevation 2 ft NGVD. As the groundwater was lowered within the project site to allow ranching and farming, the organic materials oxidized and to a lesser degree were eroded by wind. This disappearance (deflation) of the peat is complete in some areas, exposing the underlying sands. In other areas, up to 10 feet of peat remain beneath the interior of the site.

4.5.2 Surface Soils

Soil composition and texture varies widely across the interior of the site, and the vegetation and habitat types associated with these soils are equally as variable. Eleven soil associations or series with a wide variety of surface textures have been mapped on the site, including Capay clay, Delhi sand, Rindge muck, Sycamore silty clay, Ryde silt loam, Sacramento clay, Piper loamy sand, Shima muck, Marcuse clay, Egbert Mucky Clay Loam, and Fluvaquents (Figure 5) (NRCD, 2004). With the few exceptions noted below, there appears to be little or no correlation between existing vegetation types and soils. This is most likely attributed to the fact that the site has been heavily manipulated over time for agriculture and other uses including sand mining. Native soils were removed, relocated, amended or otherwise altered, while native vegetation was removed and replaced with forage plants or crops.

Freshwater marsh in the northern portions of the site appear to be correlated with fine textured organic soils (Shima muck and Rindge muck). Similar to peat or histosols, these soils were formed by accumulations of decomposing tidal marsh vegetation and fine sediments over thousands of years under saturated conditions. Peat and muck soils throughout the Delta often support marsh and riparian vegetation because of an association with tidal inundation and/or high groundwater tables. A belt of Delhi sand, representing a portion of the historic Antioch dunes complex, ranges from northwest to southeast across the Emerson parcel. This correlates with remnant dune scrub vegetation and the occurrence of evening primrose.

4.6 BIOLOGICAL CONDITIONS

4.6.1 Existing Fish Habitat

Increased habitat and trophic support of important fisheries resources is a prominent goal of estuarine wetland restoration. This is particularly the case for wetland restoration in the Sacramento/San Joaquin Delta, where populations of threatened or endangered fish may benefit directly or indirectly from restoration of tidal marshes and floodplains. Shallow water habitat in brackish, oligohaline reaches of the western Delta currently provides only a small fraction of the historic spawning and rearing habitat for three of the most prominently listed fish species in the Bay-Delta: Delta smelt, Sacramento splittail, and Chinook salmon.

Delta smelt, *Hypomesus transpacificus*, is listed as threatened under both federal and state Endangered Species Acts (ESA). The Delta smelt is the only smelt endemic to California and is described as the only true native estuarine species found in the Sacramento-San Joaquin Delta (Moyle and others, 1989; Wang

1986; Wang, 1991). Although historically distributed broadly from Suisun Bay through the central Delta and upstream in both the Sacramento and San Joaquin Rivers (Moyle and others, 1989), that range is now more restricted depending upon life history stage and river discharge rates. Extensive congregations were previously documented in upper Suisun Bay and Montezuma Slough (Federal Register, 1993). Due to flow manipulation, the distribution of Delta smelt has more recently shifted to the Sacramento River channel (Moyle and others, 1992). Although concentrated along the northern margins of the western and central Delta, schools of Delta smelt have been observed on the intake screens of the Pittsburg and Contra Costa power plants (Wang, 1986). Delta smelt spawn in shallow, fresh or slightly brackish water upstream of the mixing zone, typically in tidal portions of backwater, sloughs and channel edge-waters in the western Delta (Wang, 1986; Wang, 1991; Moyle and others, 1992). Big Break is noted as a likely rearing region for Delta smelt, where shallow, protected, food-rich environments are maintained under the two psu isohaline.

Sacramento splittail, *Pogonicheilus macrolepidotus*, is listed as threatened under the federal ESA but is not listed under the state ESA. Native populations are concentrated in the central and western Delta, Suisun Bay, and several of the San Pablo tributaries, particularly the Napa River, and Petaluma River (Moyle, 1976). They are most abundant in the north and west portions of the Delta, although other areas are considered to be suitable for spawning (CDFG, 1995). Because splittail spawn on flooded vegetation in the lower reaches of rivers and the Delta, the decrease in riparian marshlands and floodable areas in recent decades is likely to be a major contributor to their decline (Federal Register, 1999).

Juvenile Chinook salmon, *Oncorhynchus tshawytscha*, migrate and rear in the western and central Delta. The Sacramento River winter run is listed as endangered under both federal and state ESAs. Spring, fall and late-fall runs are not listed but are of concern to both State and federal authorities. Juvenile Chinook are typically found along the margins of channels and shallow water habitats, where they feed on zooplankton (*Daphnia* spp.), epibenthic crustaceans (amphipods) and aquatic (Chironomidae) and surface insects (Simenstad and others, 2000). Based on the IEP survey results, the western Delta region could constitute a significant rearing area for these “ocean-type” Chinook when Delta outflows are high enough to depress the salinity regime to oligohaline conditions.

Delta smelt, Sacramento splittail, and Chinook salmon utilize shallow wetland habitats for feeding and refuge from predation. Perhaps one of the greater potential limitations on capacity and suitability of the Dutch Slough and Marsh Creek region in the present condition is the extensive submerged aquatic vegetation (SAV)-dominated areas that likely constitute a predation sink for small fishes attempting to utilize the area (Grimaldo and others, 2000). If SAV is left unaddressed, particularly the spread of invasive SAV, the three fish species of interest may seek to avoid the Dutch Slough site.

Striped bass, *Morone saxitalis*, are abundant in this region of the Delta and are presumed to have increased the predation pressure on Delta smelt by piscivorous fishes (Federal Register, 1993). In addition to these predators, non-indigenous fish such as the wagasaki, or Japanese smelt (*Hypomesus* *nipponensis*), or inland silverside (*Menidia beryllina*) may constitute competitors for copepod and cladoceran prey (Bennett, 1995).

Of particular relevance to the restoration of Dutch Slough are the non-indigenous piscivorous fishes associated with SAV, particularly centrarchids such as largemouth bass (*Micropterus salmoides*) that are associated with *Egeria densa* (*e.g.*, documented at Big Break; McGowan, 1999). Other non-indigenous fishes documented by McGowan (1999) at Big Break were bluegill (*Lepomis macrochirus*), red shiner (*Cyprinella lutrensis*), inland silverside, rainwater killifish (*Lucania parva*), mosquitofish (*Gambusia* spp.) and threadfin shad (*Dorosoma petenense*). The predominance of non-indigenous fishes in SAV-dominated ecosystems is typical for much of the Delta, as evidenced by the CALFED-funded Sacramento/San Joaquin Delta Breached Levee Wetland Study (BREACH) results (Simenstad and others, 2000).

Longfin smelt (Osmeridae, *Spirinchus thaleichthys*) is also a prominent and ecologically-important fish found in shallow water habitats of the Delta. McGowan (1999) also reported prickly sculpin (*Cottus asper*).

4.6.2 Existing Wetland and Terrestrial Habitats

4.6.2.1 Introduction and Methods

This section, along with Figures 6 and 7, is intended to serve as a baseline of existing biological conditions on the Burroughs, Gilbert, and Emerson parcels of Dutch Slough. It provides mapping and descriptions of habitats, plant communities, and cover types on the property. These terms are related, but are not synonymous. Habitats are natural areas of ground over which the environment is essentially uniform (Gleason and Cronquist, 1964). Plant communities are natural assemblages of plants that occur together in response to mutual tolerances of similar environmental and physical conditions such as climate and soils; in other words the association of plants that occur in a habitat. Because developed and disturbed areas are not natural environments and may not support vegetation, they do not fit either definition and are referred to here as "cover types."

The description of existing wetland and terrestrial habitats incorporates findings from a review and assessment of existing documents and other sources including the California Department of Fish and Game's (CDFG) California Natural Diversity Data Base (CNDDB) 2003; U. S. Fish and Wildlife Service (USFWS) Threatened and Endangered Species Database System (TESS) 2004; the Botanical assessment of the Dutch Slough Wetlands Restoration property, Oakley, Contra Costa County, California (DWR, 2005a); and the National Heritage Institute's *Dutch Slough Tidal Marsh Restoration Project Preliminary Opportunities and Constraints Report* (2004).

Plant communities, habitats, and cover types on the project site were mapped and described based upon existing literature, aerial photograph interpretation, and a reconnaissance level site visit by EDAW staff on March 30, 2004. These data were supplemented by surveys conducted by staff botanists from the

Division of Environmental Services, Department of Water Resources during summer and fall, 2004 (DWR, 2005a; DWR, 2005b). The area was traversed on foot during the site visit and habitats mapped using aerial photographs. Protocol surveys were not conducted and the following discussion identifies habitat and the few special status species observed; this section does not identify the presence/absence of the remaining special status species and only discusses the potential for these species to occur.

The USFWS and CNDDB identify a number of special-status species as having the potential to occur in the project area (USFWS, 2004; CNDDB, 2003). Many of these species were eliminated from further consideration because the project area is outside of the species' current range or because no suitable habitat is present in the project area. Plant community evaluation is based upon a general classification scheme, A Preliminary Description of the Plant Communities of California (CNDDB, 2003), with cross-references to the equivalent Manual of California Vegetation (Sawyer and Keeler-Wolf, 1995) series where possible.

4.6.2.2 Plant Communities/Habitats/Cover Types

General habitat types and cover types that occur on the project site are shown in Figure 6 and summarized below. Areas with high potential for sensitive species and/or high level of wildlife value (*e.g.*, freshwater marsh, interior dune scrub, etc) are discussed in more detail below.

Disturbed and Unvegetated Cover Types

The "developed" cover type consists of rock rip-rap, asphalt, concrete, structures and associated disturbed vacant land. It includes house pads, levee top dirt roads, armored levees, interior island dirt roads, blacktop paved roads, barns in various conditions of disrepair, and old concrete pads and is generally considered low value wildlife habitat.

"Pastures" occur on the site where other plant communities were displaced by clearing for agricultural activities. This is the dominant cover type on all of the parcels, and some of the pastures on site are being actively grazed by cattle. Higher elevation pastures are currently flood-irrigated, while others are naturally irrigated by high groundwater tables. The pastures with high groundwater tables include varying patches of seasonal wetlands (see description of alkali meadows below). Pastures are often utilized as foraging habitat by raptors, including Swainson's hawk (*Buteo swainsoni*) a federal species of concern (FSC) and listed by the State as threatened.

Ruderal or "weedy" areas on the site are dominated by an herbaceous layer of non-native grasses and forbs. Among others, ruderal areas often include extensive patches of invasive weeds including Himalayan blackberry (mapped as "blackberry" in Figure 6), milk thistle (*Silybum marianus*), artichoke thistle (*Cynara cardunculus*), tamarisk (*Tamarix* spp.), and perennial pepperweed (*Lepidium latifolium*). Artichoke thistle can be an aggressive invader, but mostly in coastal grassland areas. Perennial pepperweed (*Lepidium latifolium*) is aggressively spreading throughout disturbed areas in California, and once established can be very difficult to control (DWR, 2005a). Ruderal areas generally occur along the interior of levee banks, remnant sand dunes, abandoned developments, roadways, and some pastures. “Ornamental” vegetation occurs around developed areas and along adjacent roadways. Some of the more invasive ornamental species appear to be spreading to the other areas throughout the site.

Ponded open water and a seasonal pond on the Emerson parcel (Figure 6) are largely barren of terrestrial vegetation throughout most of the year.

Freshwater Marsh

Non-tidal freshwater marsh habitat occurs in perennially flooded or ponded, shallow (less than three foot deep) depressions and channels throughout the interior of the diked areas of the site (Figure 6). Tidal freshwater marsh habitat occurs along the outer edge of the diked areas, predominantly located along un-armored (*i.e.,* no riprap) levees, decrepit levees, narrow marsh or creek areas, and on in-channel islands in Dutch Slough. An extensive and high quality stand of tidal marsh exists in the abandoned channel of the former mouth of Marsh Creek along the north edge of the Emerson parcel. Tidal marsh supports nine stands of, Suisun marsh aster (Aster lentus), a special-status plant species, along the Marsh Creek and Emerson Slough levees (DWR, 2005a). Freshwater marsh habitat found on the site supports a variety of native species, including tules (*Scripus* spp.), common reed (*Phragmites communis*), spikerush (*Eleocharis* spp.), and narrowleaf cattail (*Typha angustifolia*). Non-native species are also found in this habitat type including species such as golden flag (*Iris pseudacorus*). Giant reed (*Arundo donax*) is an aggressive colonizer of tidal marsh habitat along levee banks and riparian areas. It can cause levee damage and competes with native vegetation (DWR, 2005a). All of the freshwater marshes on the three parcels were mapped as jurisdictional wetlands (Figure 7; DWR, 2005b).

Riparian Woodland and Willow Scrub

This plant community is typically characterized as narrow linear strips of trees and shrubs, in single to multiple story canopies. Some woodland may be characterized as willow scrub (mapped as “willows” in Figures 6 and 7), consisting primarily of shrubs and short trees such as sandbar willow (*Salix exigua)* and arroyo willow (*Salix lasiolepis*), while other areas are characterized as woodland with multiple canopy stands of shrubs and trees (mapped as “riparian”). Many woodland areas are infested with varying amounts of non-native Himalayan blackberry (*Rubus discolor*) thickets, which – although invasive – provide habitat for many songbirds and other wildlife. Riparian woodland generally occurs along the inside and outside of levees, ditches, and slough channels above the elevations that support freshwater marsh. Freshwater marsh and riparian woodland are often intermixed. Native woody plant species found on-site include Fremont cottonwood (*Populus fremontii*), Gooding’s willow (*Salix goodingii*), arroyo willow, shining willow (*Salix lucida*), sandbar willow, white alder (*Alnus rhombifolia*), button bush (*Cephalanthus occidentalis*), and California rose (*Rosa californica*). Invasive non-native species, such as California black walnut hybrid (*Juglans hindsii*), black locust (*Robinia pseudoacacia*), Himalayan blackberry, castor bean (*Ricinus communis*), eucalyptus (*Eucalyptus globulus*), giant reed (*Arundo donax*), tamarisk (*Tamarix* spp.), and edible fig (*Ficus carica*) are also found in this community type. A small stand of willows on the Emerson parcel was mapped as jurisdictional wetlands (Figure 7; DWR, 2005b).

Alkali Meadow

Most of the alkali meadows found on the site are closely associated with pastures that are seasonally flooded, and appear to have high summer groundwater tables supporting an abundance of hydrophytic plants. Some of the meadows are dominated by alkaline/saline species such as saltgrass (*Distichlis spicata*) and brass buttons (*Cotula coronopifolia*). Seasonal wetland habitat also occurs in some ditches that are inundated seasonally, but not inundated long enough to be dominated by emergent freshwater marsh species such as tules.

Native seasonal wetland plants that occur on-site in the meadows include buttercup (*Ranunculus* spp.), toad rush (*Juncus bufonius*), water plantain (*Alisma plantago aquatica*), saltgrass, brass buttons, narrowleaf cattail, spikerush, and meadow barley (*Hordeum brachyantherum*). Non-native species found in this habitat type include species such as Italian ryegrass (*Lolium multiflorum*), speedwell (*Veronica* spp.), Mediterranean barley (*Hordeum marinum* ssp. *gussoneanum*), vetch (*Vicia sativa*), and curly dock (*Rumex crispus*). Perennial pepperweed is widely distributed but is not yet a dominant invasive species. Portions of the alkali meadow community on the Emerson and Burroughs parcels were mapped as jurisdictional wetlands (Figure 7; DWR, 2005b). Special status species that have a potential to occur in this habitat type are listed in Appendix D.

Ruderal (relict sand dunes)

Interior dune scrub vegetation occurs within the Emerson and Gilbert parcels on isolated remnant dunes associated with the Antioch interior dune complex. Many of the former dune areas have been excavated for pasture conversion and development. The remaining remnant dunes are dominated by bush lupine (*Lupinus arboreus*) or support primarily non-native ruderal vegetation. The Gilbert parcel includes a remnant dune that is currently in a pasture grazed by cattle and dominated by primarily ruderal vegetation. The Emerson parcel includes a remnant dune that was planted with cultivated grapes. This 100-year-old vineyard is used to dry farm grapes ("vineyard" on Figure 6). Antioch Dunes evening-primrose (*Oenothera deltoides* ssp. *howellii*: federal endangered, state endangered and CNPS List 1B species) is endemic to Contra Costa and Sacramento counties on remnant river bluffs and sand dunes near the city of Antioch. A single plant similar in appearance to the Antioch Dunes evening-primrose was found by EDAW biologists during the March 30, 2004, survey on a remnant dune scrub area. Upon further investigation, the DWR botanical determination (T. Hall, DWR, pers. comm.) was that the characteristics of the single plant are not consistent with current taxonomic descriptions of the endangered Antioch dunes evening primrose based on the current literature references (Hickman, 1993; Munz and Keck, 1973) and species authorities that were contacted (R. Hurt, USFWS, pers. comm.). Raptors such as Swainson's hawk and white-tailed kite may forage for small mammals in this habitat type. Other special status species that have a potential to occur in this habitat type are listed in Appendix D.

4.6.2.3 Special Status Species

Special status species that were observed by EDAW staff within the freshwater marsh habitat include the Suisun song sparrow (*Melospiza melodia maxillaris*) and northern harrier (*Circus cyaneus*). A Swainson's hawk was observed within the mixed riparian woodland habitat, and a potential nest was identified in the central portion of Emerson Parcel. Black rail (*Laterallus jamaicensis coturniculus*) had been previously identified in tidal marshes on the site (NHI, 2004). The DWR surveys found evidence that Western pond turtles are reproducing in drainage ditches at the Dutch Slough property. As discussed above, nine stands of Suisun marsh aster (*Aster lentus*) were documented as occurring on levees along the east bank of Marsh Creek and Emerson Slough (DWR, 2005a). See Appendix D for the status of these species and a list of other special status plant and animal species that have a potential to occur in these habitat types.

4.7 PUBLIC USE

There are no existing, formal recreation facilities within the site with the exception of the Marsh Creek Bike Trail that runs along the western site boundary. Two areas owned by the City of Oakley are currently being proposed as park space for public recreation access (Figure 2). One area is being planned as the Dutch Slough Community Park. This area was recently used for dairy production, but is now closed. Some clean-up has taken place. The other area is being planned as a Delta Access Park, which may include a marina.

The proposed park and potential marina sites do not currently offer any public access. There are no shoreline access points from the site shoreline (T. Hall, DWR, pers. comm.). Shoreline access in the Delta is typically used for boat launching, swimming, windsurfing, and jet skiing, for example. The Delta is divided into six recreation areas by California Department of Parks and Recreation (DPR). The Dutch Slough site is located in the West Delta Recreation Area, as defined by DPR. Appendix D contains additional description of public use in the Delta region.

4.8 CULTURAL RESOURCES

DWR performed a cultural resources and archeological survey of the Dutch Slough restoration site in 2004. No archaeological resources were identified within any of the proposed project area, as documented in the DWR (2004) Negative Archeological Survey Report.

5. OPPORTUNITIES AND CONSTRAINTS

The Dutch Slough site offers the following opportunities and constraints for restoration. NHI (2004) provides additional detailed information on opportunities and constraints.

5.1 OPPORTUNITIES

Restore tidal inundation. Tidal inundation can be restored to the site by breaching to Dutch Slough, Little Dutch Slough, Emerson Slough and/or Marsh Creek. Tidal exchange will provide a source of water, sediments, nutrients, and colonizing plants and animals.

Restore a diversity of native habitats. Onsite topographic and soils diversity provide conditions suitable to restoring a diversity of habitats historically present in the Delta, including freshwater emergent marsh, riparian woodland, sand dunes, upland transitional habitat, and native grasslands.

Restore extensive areas of freshwater tidal marsh and channels. The large size of the site (1,166 acres) makes it possible to restore large contiguous areas of tidal marsh with dendritic channel systems. Marsh areas greater than approximately 30 to 50 acres are expected to sustain subtidal channel habitat.

Restore a natural transition from marsh to upland habitats. The gentle grade of the Dutch Slough site will allow restoration of a gradual transition from high marsh to upland with little or no grading.

Maintain and expand riparian woodland habitat. Riparian habitat exists within the Burroughs and the Emerson parcels. Raising groundwater levels (through tidal inundation) and planting above the high tide elevations will expand on these riparian areas and enhance habitat diversity.

Restore sand dunes on the Emerson Parcel. Remnant dunes on the Emerson Parcel can be restored to dune habitats (Antioch dune scrub) by excavating the top layer of imported organic soils and planting with native dune species.

Connect with Marsh Creek as a migration corridor and source of sediment. Marsh Creek provides perennial flows for a fish migration corridor. Marsh Creek is also expected to provide episodic delivery of sediment, useful for raising subsided site elevations to support marsh vegetation establishment.

Contra Costa Canal as a buffer. The Contra Costa Canal marks the southern border of the site, providing a useful buffer between the restored habitats and development associated with the City of Oakley. Plans under consideration by the Contra Costa Water District (CCWD) may eliminate this opportunity, however. The CCWD is considering filling the canal and replacing the open water channel with an underground culvert.

Connectivity with existing wetland at Big Break. Because it is near the Big Break Regional Shoreline, the Dutch Slough site can expand on an existing area of contiguous wetlands at Big Break Regional Shoreline.

Large-scale restoration experimentation. The large size of the site makes it possible to test different restoration approaches on a large-scale, which can then inform future large-scale restorations in the Delta. The three parcels at Dutch Slough (Emerson, Gilbert, and Burroughs) also provide an opportunity to replicate experiments on more than one parcel, allowing comparison between parcels.

Provide public access and opportunity for public education. Public access and education can be incorporated readily into the restoration design, meeting existing and expected future demand for public access and educational opportunities.

5.2 CONSTRAINTS

Subsided ground elevations. More than half the site is subsided below elevations at which emergent vegetation can survive once tidal inundation is restored. Onsite or imported fill will be required to raise ground elevations for extensive marsh restoration. Subsidence is a major constraint, though subsidence at Dutch Slough is less than at most other sites available for tidal marsh restoration in the Delta. Deposition of sediments from the water column is not expected to contribute significantly to raising ground elevations from subtidal to intertidal within the planning horizon of the project (50 years). Locally higher sedimentation rates are possible if Marsh Creek is routed onto the Emerson parcel (see opportunity above).

Rates and extents of natural vegetative recruitment. Natural vegetation recruitment cannot be relied upon to restore the non-marsh habitat types (*e.g.*, riparian habitats, dune habitats) within the planning horizon of the project. In addition, vegetation community development based on volunteer colonization would likely lead to the permanent domination of plant communities by invasive weeds because the primary propagules in the vicinity of the project area are invasive non-native species. The exception might be for emergent marsh vegetation, where recent experience at the Decker Island restoration site suggests that a diversity of native plant species can establish without planting (T. Hall, DWR, pers. comm.).

Drinking water quality. Tidal marsh restoration has the potential to increase levels of salinity and dissolved organic carbon in Delta waters. The project must be planned so as not to adversely affect the quality of drinking water exported from the Delta. In addition, the project must not result in tidal overtopping or increased groundwater seepage into the Contra Costa Canal, along the southern boundary of the site, since surface water and groundwater at the site may be more saline than waters in the canal. If the Contra Costa Water District proceeds with plans to replace the canal with an underground culvert, potential overtopping and seepage constraints will be eliminated.

Bioavailability of mercury and other contaminants. Mercury methylation resulting from tidal marsh restoration is an issue for all tidal marsh restoration projects in the Bay-Delta ecosystem. It is of particular interest at Dutch Slough because there is an abandoned mercury mine on upper Marsh Creek. Methylation makes mercury more biologically available. Mercury bioaccumulation in the food chain is harmful and potentially lethal to wildlife. Endocrine disruptors (released into Marsh Creek by an upstream wastewater treatment plant), and urban runoff pollutants are other contaminants of concern to wildlife that might use the restored site. The project will seek to minimize or avoid making contaminants more biologically available, and will monitor levels of mercury (in its various forms) and other contaminants as part of the adaptive management program.

Groundwater seepage to low lying offsite areas. The Dutch Slough project has the potential to raise groundwater levels in adjacent areas by increasing groundwater recharge. Without adequate mitigation measures, this could possibly affect the ability of the Ironhouse Sanitary District to use Jersey Island for wastewater infiltration and raise groundwater levels in areas currently being developed or considered for residential use east and south of the site.

Delta salinity. Increased tidal prism in the restoration site could make small incremental changes in Delta tidal hydrodynamics that might affect salt intrusion from the western Delta. If significant, these changes could affect water quality for drinking water (discussed above) and agricultural uses, and convert existing aquatic habitats from fresh to brackish.

Flooding and infrastructure. The restoration design must not adversely affect the maintenance or operation of existing infrastructure on and adjacent to the site (Figure 2). Existing infrastructure includes:

- *Ironhouse Sanitary District Pipeline*, located along the northwest corner of the site;
- *Active gas wells,* located on the Burroughs property;
- *Pacific Gas & Electric powerlines,* located on the northeastern corner of the site;
- *Adjacent levees,* Restoration of tidal flooding must not increase the potential for wave-induced erosion of adjacent levees, such as the Jersey Island levees north of Dutch Slough. Maintaining the levees along Dutch Slough will ensure that wind-waves generated on the site will not propagate offsite;
- *Jersey Island road,* The project must avoid increasing the risk of flooding on Jersey Island Road;
- *Residential inholding,* The project must avoid increasing the risk of flooding on the 1.36-acre residential inholding on the Burroughs parcel, adjacent to Jersey Island Road;
- *City property,* The project must coordinate with the City of Oakley to protect the proposed City park site from tidal flooding;
- *Local storm drainage,* areas south of the site gravity drain into Emerson Slough and Little Dutch Slough;

- *Other onsite infrastructure*, Pumps, inactive wells, and local power lines that are no longer needed with the restoration will be removed, closed, or demolished as part of site preparation.

Marsh Creek flood control channel. Lower Marsh Creek adjacent to the site is a flood control channel. Restoration actions must not reduce flood conveyance on the creek.

Conveyance capacity of Little Dutch Slough and Emerson Slough. The restoration will need to consider the conveyance capacity of Little Dutch Slough and Emerson Slough if these are to be used as tidal inlets to deliver water to the restoration.

Nuisance species. The restoration must be designed and managed to minimize the production of nuisance species such as mosquitoes and invasive plants and animals.

6. ALTERNATIVES DEVELOPMENT APPROACH

6.1 INTRODUCTION

Development of alternatives was guided by the project goals and objectives, existing site conditions, and opportunities and constraints. As presented previously, the project goals are to:

1. Provide shoreline access, educational and recreational opportunities (public access).
2. Benefit native species by re-establishing natural ecological process and habitats (habitat restoration).
3. Contribute to scientific understanding of ecological restoration by implementing the project under an adaptive management framework (adaptive management).

Formulation of the Dutch Slough restoration alternatives for the current study was driven primarily by goals 2 and 3. The public access and recreation features of the Dutch Slough project (goal 1) are being developed in a separate master planning process, led by the City of Oakley, and are generally compatible with all the restoration alternatives presented in this report.

In response to goals 2 and 3, the Dutch Slough alternatives were developed to provide both ecosystem restoration and adaptive management benefits. Each restoration alternative includes habitat restoration features and adaptive management experiments. The experimental and restoration features are not mutually exclusive. Many of the experimental features are expected to provide significant restoration benefits, and restoration features provide opportunities for experimentation.

The AMWG and PWA consultant team developed a conceptual model of wetland restoration (Appendix E) as the basis for recommending high priority experiments to test in the Dutch Slough project. The recommended experiments span small and large spatial scales. The small-scale experiments require only small areas (one or two acres) and can be readily accommodated within any given restoration alternative. The large-scale experiments – such as testing the effects of tidal marshplain elevation on fish growth and survival – require areas on the order of hundreds of acres. The restoration alternatives were formulated to test these large-scale experiments. Each restoration alternative also includes small-scale experiments. The alternatives were developed by the Dutch Slough Management Team with input from PWA and the AMWG.

The large-scale adaptive management experiments are designed to test hypotheses that predict the response of special status native fish to different methods of wetland restoration. Providing habitat for special status native fish species was the key objective of the adaptive management program that drove development of the large-scale adaptive management experiments. The conceptual model summarized below focuses on special status native fish species.

The CALFED Ecosystem Restoration Program Science Board provided feedback on the adaptive management framework in a May 2004 meeting, and the Dutch Slough Sub-committee of the Science Board provided additional input in a May 2005 meeting.

6.2 ADAPTIVE MANAGEMENT FRAMEWORK

Adaptive management is the process of learning from restoration and management actions, then using this knowledge to inform and adapt future actions (CALFED, 2000). Typically, these actions modify parts of a restoration that have already been implemented. Within the context of the Dutch Slough restoration, adaptive management also refers to informing actions for future restoration projects. This second type of adaptive management is sometimes referred to as "adaptive learning." Lessons learned at Dutch Slough are primarily intended to inform future restoration projects anticipated in the Sacramento-San Joaquin River Delta, but may also influence management actions at Dutch Slough after tidal restoration is implemented. The project will test different methods of wetland restoration, monitor the physical and ecological responses, and make these results available.

The process of adaptive management input to the design is as follows:

1. Define measurable ecological objectives. These are discussed above in Section 3.
2. Articulate a conceptual model (or models) of the process linkages that explain how the restoration actions address the ecological objectives.
3. Identify key uncertainties in the conceptual model(s).
4. Articulate hypotheses for each of the key uncertainties.
5. Design experiments to test the hypotheses. These are described in Section 7.
6. Implement a monitoring and adaptive management plan for the experiments and the restoration project.

Adaptive management is an iterative process. Once monitoring results are available (from Step 6), the adaptive management process circles back to reassess the objectives (Step 1) and conceptual models (Step 2), etc. Steps 2 to 4 are summarized below. Step 6 is in progress and will be documented in the Dutch Slough Tidal Marsh Adaptive Management and Monitoring Plan (Adaptive Management and Monitoring Plan) (NHI, in progress). The Dutch Slough adaptive management process embedded within the overall restoration plan is more fully described in a draft memorandum to the AMWG (Cain, 2004) and will be documented in the Adaptive Management and Monitoring Plan.

6.2.1 Conceptual Model

The purpose of the Dutch Slough Tidal Marsh Restoration Conceptual Model (Appendix E) is to articulate the project's working assumptions about process linkages between specific restoration actions and the project's ecological objectives. It is understood that working assumptions are often uncertain, and may even be incorrect. Making these assumptions explicit, however, has value and is a necessary initial step in the adaptive management process. The conceptual model provides the framework for hypothesis testing and learning.

The Dutch Slough conceptual model articulates the process linkages between specific restoration actions and benefits (or drawbacks) to three special status fish species identified as “tier 1” target species for the project: Sacramento splittail (*Pogonichthys macrolipidotus*), Chinook salmon (*Oncorhynchus tshawytscha*) and Delta smelt (*Hypomesus transpacificus*) (see Appendix A). The elements of the conceptual model are organized into the categories: restoration actions, physical and vegetative processes, habitat structures, ecological processes, and functional responses (fish responses).

Restoration actions are required to recreate freshwater tidal marsh on leveed sites in the Delta that are presently subsided. These restoration actions allow physical and vegetative processes to occur and create habitat structures. Restoration actions are required because natural processes that formed ancient and historic freshwater tidal marshes over the last 10,000 years in the Delta are not expected to restore marsh habitat structures on a restored (or restoring[1]) subsided site within the desired timeframe. Restoration actions at Dutch Slough include: filling and grading marsh areas, excavating channels, managing or planting vegetation to favor native plant establishment (re-vegetation), diverting Marsh Creek, and breaching levees.

Generally, the physical processes part of the conceptual model predicts few significant geomorphic changes within several years to one or two decades after the site is constructed. Unlike its restoration counterparts in the more saline and sediment-rich parts of the estuary (San Francisco Bay) where sedimentation rates are higher, Dutch Slough is expected to experience slow rates of sedimentation in shallow subtidal and marshplain habitats, and likely limited formation of tidal channels through tidal scour. To achieve restoration and adaptive management goals within the planning horizon, it is therefore necessary to create restored marshes with features similar to equilibrium marshplain elevations and tidal channel networks, rather than relying on the evolution of equilibrium conditions through natural physical processes, in order to achieve the project goals within the planning horizons for restoration and adaptive management (50 years and from several years to one or two decades, respectively, as discussed in Section 7 of the Conceptual Plan and Feasibility Report). Constructed restoration features are expected to persist and evolve slowly over at least the next decade.

The ecological processes and functional response parts of the conceptual model focus on juvenile fish, including several species of concern, which preferentially occupy shallow water habitats in the Delta through transitory periods in their early life history (Moyle, 1976; Wang, 1986). The conceptual model is intended to illustrate how an adaptive management strategy can be used to identify and test functional relationships between fish performance and restored wetland structure, where structure includes composition, structure, and arrangement of various fish habitat elements. Performance measures for this

[1] The term “restoring” is sometimes used to indicate that restored marshes continually evolve.

strategy consist of juvenile Chinook salmon survival and growth, although similar mechanisms are expected to affect other fish using the restored wetlands, particularly Sacramento splittail.

A key feature of tidal marshes that influences juvenile salmon (and splittail) performance is the edge of vegetation along tidal channels. These fish feed predominantly at the marsh edge and are not expected to venture onto the vegetated marshplain. The opportunity for fish to access prey resources along the vegetated channel edge, and thus fish feeding rate and growth, is related most directly to the amount of time the fish have to access the channel edge over the tide cycle.

The conceptual model includes the fundamental assumption that short-term survival of juvenile salmon and splittail is greater in shallow subtidal channels than in either deep subtidal channels or intertidal channels. At low tide, shallow subtidal channels will provide refuge from predation by piscivorous birds for juvenile salmon and splittail, but will be too shallow to allow access for large, piscivorous fish predators. We also assume that juvenile fish that are feeding and growing well will be less susceptible to predation due to their increased vigor.

The conceptual model is discussed further in Appendix E.

6.2.2 Key Uncertainties, Hypotheses, and Experimental Design

The AMWG, PMT, and members of the PWA team identified key uncertainties, hypotheses for testing in the restoration design, and developed general restoration layouts to test these hypotheses. Key uncertainties are those that are considered most important (*i.e.*, high potential to affect the outcome) and most uncertain. Additional criteria were used to select key uncertainties, such as the implications for the future cost and feasibility of marsh restoration at Dutch Slough and elsewhere in the Delta. Design parameters related to the key uncertainties identified for testing at Dutch Slough are listed in Table 3. The testing spans small and large spatial scales.

Table 3. Summary of Parameters to Test in Adaptive Management Experiments

Experimental Scale	**Parameters**
Large scale	• Tidal marshplain elevation • Marsh scale
Small scale	• Dissolved organic carbon production • Mercury methylation and bioaccumulation • Maximum inundation regimes for emergent marsh vegetation survival and inundation regimes for minimization of invasive plants • Subsidence reversal (*e.g.*, biomass accumulation, addition of organic matter such as rice straw) • Vector control ponds • Rate and extent of formation of channels through tidal scour

The project identified tidal marshplain elevation and marsh scale as the key uncertainties for large-scale large scale experimental testing (Section 6). Marshplain elevation is considered important to test because lower vegetated marshes require less fill, but the habitat value may differ from that of higher, natural marshes. Marsh scale (*i.e.*, size of the marsh drainage area) is considered important to test to guide the selection of future restoration sites. Small sites are generally more available for restoration than large sites, but may not offer the same benefits on a per-acre basis (*e.g.*, tidal channel complexity). Both parameters have implications for the cost-effectiveness and feasibility of restoration, as filling restored marshes to higher elevations and acquiring larger areas for restoration are typically more expensive.

Hypotheses related to tidal marshplain elevation and marsh scale are:

- **Tidal marshplain elevation**. There is greater production of prey resources for juvenile salmon and splittail in lower elevation marshes than in higher elevation marshes, and thus greater potential for feeding, growth, and survival. The rationale behind this hypothesis is that a lower marshplain is inundated for a longer part of each tide cycle. A longer marshplain inundation period is expected to provide a more productive environment for fish prey (*i.e.*, dipteran fly larvae, pupae and adults; gammarid amphipods) because there is less stress (*i.e.*, less desiccation and exposure to high temperatures). Greater fine sediment and detritus accumulation in lower marshplain environments may also provide increased productivity.
- **Marsh scale.** Tidal channel networks in larger marshes provide shallow water refuge from predation throughout the tide cycle, whereas smaller channel networks in smaller marshes do not. Thus, larger marshes are expected to provide greater survival opportunities for juvenile salmon and splittail than smaller marshes. The rationales behind this hypothesis are that: (1) the size of the tidal channel network is related to marsh scale and (2) channels with shallow water depths at low tide limit predator access and provide refuge for juvenile salmon and spittail. In larger marshes, some portion of the channel network is expected to always have water depths suitable for refuge during low tide. In smaller marshes, channel depth at low tide is not expected to be sufficient to provide refuge for juvenile salmon and splittail, which will be “flushed” into deep subtidal Delta slough channels (external sloughs) that likely harbor predators. In addition, larger marshes are hypothesized to provide greater structural heterogeneity and diversity (*e.g.*, relief, vegetation assemblages and tidal channel sizes) and complexity (*e.g.*, larger tidal channel systems, greater tidal energy, more refugia) than smaller marshes, and thus greater refuge and survival opportunities.

Note that “lower elevation” and “higher elevation” marshes may be treated as distinct for adaptive management purposes, but are morphologically similar and not generally recognized as distinct habitat categories in the Delta as discussed in Section 4.3. For adaptive management purposes, the intent is to compare “lower” and “higher” marshplains that differ enough in elevation to show different ecological responses, while not making the “higher” marsh so high that it becomes fill-limited or cost prohibitive. Selection of the exact elevations to compare requires an application of judgment. The marshplain elevations selected for testing are described in Section 8.1.1.

The AMWG recommended testing a maximum of only one or two large-scale experimental parameters within any given alternative, to allow meaningful interpretation of the results. Other possible experimental design parameters were identified, but were not recommended for large-scale testing either because they were considered less important to ecosystem value or because more is known about them. Channel drainage density (length of channel per area of marsh) was considered for large-scale testing, with higher drainage density hypothesized to correlate strongly with higher benefits to fish. Despite the hypothesized strength of the correlation, channel density was not recommended for testing because the correlation was considered relatively well understood (low uncertainty).

The AMWG and the CALFED Ecosystem Restoration Program Science Board scientists agreed that experimental replication at the site is not feasible (as in most restored marsh environments) given the large number of samples required for statistical analysis, nor is it necessary, to yield useful information. Paired comparisons between study areas are expected to provide useful, if less definitive, data for hypothesis testing.

Several of the design features included in the restoration alternatives are intended to aid in the experimental comparison of marsh areas with different marshplain elevations and scales. For example, breach locations and channel networks are configured to drain different restored marsh areas to the same inlet channel (Little Dutch Slough) and are aligned to be opposite each other, as possible. Tidal channel systems in restored marsh areas will be constructed to be as similar to natural systems as possible, both in cross-section and plan form. Also, re-vegetation methods will be used to establish comparable coverage of tules on all marsh areas. Additional design considerations for the large-scale adaptive management experiments are discussed in Appendix E.

Other experimental parameters are expected to be tested at a small scale, generally one- to two-acre plots (Table 3). The small-scale experiments will be refined as the restoration plan is developed later in the design process.

6.2.3 Application of Adaptive Management

Findings from the Dutch Slough experiments will be applied to benefit future restoration in the Delta ("adaptive learning") and may be used to adjust select actions that will be implemented at Dutch Slough. Most habitat features at Dutch Slough are not expected to be subject to adaptive management actions once constructed. For example, the project team does not anticipate mass fill placement (or removal) to convert open water to marshplain (or vice versa) after construction. However, certain "reversible" actions could include changes to vegetation management and water management (for non-tidal areas), adjustments to the small-scale experiments, or breaching managed-pond areas.

6.3 TARGET HABITATS

The Dutch Slough project will restore a diversity of marsh, open water, and upland habitats. This section provides descriptions of the target habitats including plant species detail, fish and wildlife expected to use the habitats, and consideration of invasive species. Note that the low, mid, and high marsh habitats designations stem from the adaptive management experimental design.

6.3.1 Mid to High Marsh

Higher intertidal elevations (from MTL to MHHW) in each alternative will be appropriate for restoring mid to high tidal marshes. Based on observations of existing tidal freshwater emergent marshes in the Delta, this habitat type would be dominated by common tule (*Scirpus acutus*) but could also support California bulrush (*Scirpus californicus*) at lower elevations (Simenstad and others, 2000; Atwater and others, 1979; Atwater and Hedel, 1976). Depending on factors such as disturbance regimes, microtopography, nutrient availability, and planting plans; high tidal freshwater marsh habitat could also support a variety of other native species, including common reed (*Phragmites communis*), spikerush (*Eleocharis* spp.), and narrowleaf cattail (*Typha angustifolia*). Non-native species that could invade this habitat type include species such as golden flag (*Iris pseudacorus*) and giant reed (*Arundo donax*). The high marsh will provide only transitory fish habitat, during periods of high river discharge and spring tides when the marsh surface is flooding sufficiently to provide access to fish from tidal channels and low marsh. Under these conditions, small demersal species such as gobies (*e.g.*, yellowfin goby, *Acanthogobius flavimanus*, sculpins (*Cottus* spp., including prickly sculpin, *C. acutus*), mosquitofish (*Gambusia affinis*), rainwater killifish (*Lucania parva*), and small pelagic species such as inland silverside (*Menidia beryllina*) and the native cyprinid, California splittail (*Pogonichthys macrolepidotus*), would likely move transitorily into the high marsh but leave the marsh surface on the falling tide. High tidal marsh is also expected to provide nesting and/or foraging habitat for avifauna species such as marsh wren (*Cistothorus palustris*), saltmarsh common yellowthroat (*Geothlypis trichas*), pied-billed grebe (*Podilymbus podiceps*), eared-grebe (*Podiceps nigricollis*) and numerous species of diving ducks such as mergansers (*Mergus* sp.), canvasback (*Aythya valisineria*), and redhead (*Aythya americana*). Western pond turtle (*Emys marmorata*) would also be expected to forage in this habitat.

6.3.2 Mid to Low Marsh

Lower intertidal elevations for each alternative (from MTL to depths of 2 to 4 feet below MLLW) would be appropriate for restoring low tidal marshes. Based on observations of existing low freshwater emergent tidal marshes in the Delta, this type would likely consist of a monoculture of California bulrush, as that is apparently the only plant species that can survive long periods of deep inundation. Natural recruitment of these depths by bulrush would be slow and patchy, so revegetation methods are recommended. Fishes will commonly occupy the low marshplain when it is flooded, reflected by the species occurring in the high marsh, and some (*e.g.*, small sculpins and gobies) may even be able to persist in shallow depressions and pannes during low tide. Small, sub-yearling juvenile Chinook salmon (*Oncorhynchus tshawytscha*) may occupy lower order tidal channels in the low marsh, where they forage on larval (benthic) and adult (drift) insects. Wildlife species expected in high tidal marsh would also be expected to occur, at least some of the time, within low tidal marsh habitat. Species that are expected to occur more often within low tidal marsh are Suisun song sparrow (*Melospiza melodia samuelis*) and California black rail (*Laterallus jamaicensis coturniculus*).

6.3.3 Tidal Channels

A diversity of fish species are expected to penetrate into marshes (see above) and mudflats via the tidal channels, and occupy the system at low tides and water levels within channels that still retain water. Fish assemblages will likely be somewhat stratified by water depth, with juveniles of many species and adults of some maintaining their position in relatively shallow water, including in lowest order channels within vegetated marshes, and adults and larger juveniles found only in larger order, deeper channels. Common demersal species such as gobies and sculpins may be found throughout the tidal channel systems. Pelagic species such as inland silverside, California splittail and juvenile Chinook salmon will move dynamically in and out of the channels, although specific patterns of movement with tide stage is generally unknown. Evidence from other regions suggest that juvenile Chinook salmon may penetrate into lower order channels into marshes as long as they are unvegetated (Levy and others, 1979; C. Simenstad, University of Washington, and D. Bottom, NOAA, pers. comm.). Epibenthic species such as tule perch (*Hysterocarpus traskii*) and bluegill (*Lepomis macrochirus*) will also occupy the channels, but perhaps in greater densities concentrated among emergent and SAV and floating aquatic vegetation (FAV). Larger, more active predators, such as the non-native juvenile striped bass (*Morone saxatilis*) and largemouth bass (*Micropterus salmoides*), will likely move in and out of the larger channels with tidal fluctuation. Delta smelt (*Hypomesus transpacificus*) may spawn at the channel-marsh ecotone (Moyle, 1976).

6.3.4 Subtidal Open Water

The target vegetation community for shallow slow-moving open water habitat would be dominated by native rooted submergent aquatic vegetation (SAV), with low cover of non-native invasive SAV and FAV. The primary factor determining the presence, composition, and amount of all SAV is availability of propagules, intensity of available light for plant growth, and dominance by one or more species. Variations in salinity levels, water depth, nutrient availability, and substrate material also determine the species composition of a particular habitat (Cowardin and others, 1979). The target native vegetation include a mix of floating and submerged native pondweeds (*Potamogeton* spp.) such as shining pondweed (*P. illinoensis*), floating-leaved pondweed (*P. natans*), long-leaved pondweed (*P. nodosus*), and small pondweed (*P. pusillus*), and introduced pondweeds. Primary invasive SAV and FAV of concern in this habitat include Egeria (*Egeria densa*) and water hyacinth (*Eichhornia crassipes*).

6.3.5 Managed Pond and Marsh

Wildlife species that may be found within managed pond habitats would depend on the depth and size of the ponds. Larger deep ponds would provide foraging habitat for diving ducks, grebes, and western pond turtle. The creation of open, low vegetated islands within the larger ponds would provide loafing and resting habitat for numerous waterfowl species. Shallow managed ponds could provide foraging habitat for shorebirds (*e.g.*, sandpipers, plovers, pipets), sora, California black rail, American coot, and numerous waterfowl species (*e.g.*, ducks and geese). Large raptors such as red-tailed hawk and bald eagle (*Haliaeetus leucocephalus*) could also be found foraging within this habitat type. Western pond turtle would be expected to occur depending on availability of basking sites and adjacent suitable soil for nesting. Non-tidal managed marshes could be created through flood irrigation and planting with California bulrush rootstock anchored in straw mulch pillows. The bulrushes could then be grown to further accumulate organic matter as a treatment to reverse subsidence. Primary SAV plants targeted for restoration in this community include pond weeds listed in the subtidal open water community. Additional dominant native plants would be targeted for restoring along pond margins, including spikerush (*Eleocharis macrostachya*); sedges such as *Carex bolanderi*, *C. comosa*, *C. densa*; rushes such as toad rush (*Juncus bufonius*), *J. dubius*, and *J. phaeocephalus*; and other wetland plants tolerant of relatively constant water levels or frequency and duration of flooding. Fishes assemblages in the ponds, if any develop at all, would not be very species rich, and likely include three-spine stickleback and sculpins (*Cottus* spp.) unless other freshwater species are unintentionally introduced by artificial means.

6.3.6 Riparian Woodland

The target riparian community is a heterogeneous mix of multiple canopy and single canopy woodland or forest dominated by native riparian trees and shrubs. Riparian communities are expected to support a wide variety of resident and migratory native birds and other wildlife. They are also expected to provide shaded riverine aquatic (SRA) cover habitat along open water areas channels that may benefit native fish. The riparian woodland would vary from narrow corridors along channels to broad 500 foot or wider areas of continuous riparian habitat. Riparian woodland would be connected in a continuous band or network as much as feasible, in order to provide corridors for wildlife movement. The overstory canopy would consist of dominant native trees such as Goodding’s black willow (*Salix gooddingii*), Fremont cottonwood (*Populus fremontii*), and other species including those historically more abundant than exist today in the Delta. Mid-story canopies would include midsize trees such as shining willow (*Salix lucida*), arroyo willow (*Salix lasiolepis*), white alder (*Alnus rhombifolia*), Oregon ash (*Fraxinus latifolia*), and others. Lower canopy layers would include thickets of California blackberry and wild rose (*Rosa californica*), with lianas of California grape climbing through all levels. Plants near water channels would be dominated by a heterogenous mix of shrubs, trees and thicket-forming plants, including sandbar willow (*Salix exigua*), white alder, box elder (*Acer negundo*), California hibiscus (*Hibiscus californica*), and buttonbush (*Cephalanthus occidentalis*). Understory plants would include a mix of mostly native forbs, grasses and graminoids such as Barbara’s sedge (*Carex barbarae*), creeping wildrye (*Leymus triticoides*), meadow barley (*Hordeum brachyantherum*), umbrella sedge (*Cyperus eragrostis*), mugwort (*Artemisia californica*), and others. Riparian habitat has the potential to provide foraging and nesting habitat for raptors such as Swainson’s hawk, Cooper’s hawk (*Accipiter cooper;* foraging only), and red-tailed hawk. Riparian thickets of willows and blackberry also provide nesting and foraging habitat for numerous species of songbirds and other wildlife such as coast horned lizard (*Phrynosoma coronatum*). The woodland would support a variety of nesting songbirds, including those that nest in cavities, tree and shrub canopies, and on the ground.

6.3.7 Dunes

The higher sandy areas, especially on the Emerson parcel, could be treated and planted to restore a community similar to Antioch dune scrub. Sandy soils could be inverted to bury the surface layers which have higher levels of organic materials which would favor establishment of non-native grasses and weeds. Alternatively, dunes could be reconstructed with sterile sands if a source of non-organic sandy soils could be found. The dunes would be seeded and/or planted with containers (test plots could be used to determine the most effective method) of the following native species: Antioch dunes evening primrose (*Oenothera deltoides* ssp. *howellii*), Contra Costa wallflower (*Erysimum capitatum* ssp. a*ngustatum*), nude buckwheat (*Eriogonum nudum* var. *auriculatum*), broom snakeweed (*Gutierrizia sarothrae*), Douglas' groundsel (*Senecio douglasii*), telegraph plant (*Heterotheca grandiflora*), silvery bush lupine (*Lupinus chamissonis*), golden-aster (*Chrysopsis villosis*), and California croton (*Croton californicus*). Planting or seeding would require the permission of the US Fish and Wildlife Service because seed would have to be obtained from the Antioch Dunes National Wildlife Preserve, and some of the plant species are protected under the Endangered Species Act. Restoration would also require a major commitment to control of weeds such as ripgut brome (*Bromus diandrus*), and yellow starthistle (*Centaurea solstitialis*). Dunes would be expected to provide foraging habitat for several species of wintering passerines and potentially loggerhead shrike (*Lanius ludovicianus*), as well as globose dune beetle (*Coelus globosus*), Antioch multilid wasp (*Myrmosula pacifica*), and silvery legless lizard. The endangered butterfly, Lange's metalmark, could possibly be re-introduced to the restored site with USFWS permission.

6.3.8 Upland Transitional Habitat

Floodplain habitats that would be inundated only seasonally during periods of high tides and rainfall could support native grasses adapted to mesic habitats such as meadow barley (*Hordeum brachyantherum*), and creeping wildrye (*Leymus triticoides*). They could also support alkaline/saline species such as saltgrass (*Distichlis spicata*) and brass buttons (*Cotula coronopifolia*). Other native plants that could become established in seasonal floodplains include buttercup (*Ranunculus* spp.), toad rush (*Juncus bufonius*), water plantain (*Alisma plantago aquatica*), narrowleaf cattail, and spikerush. Non-native species that could invade this habitat type include Italian ryegrass (*Lolium multiflorum*), speedwell (*Veronica* spp.), Mediterranean barley (*Hordeum marinum* ssp. *gussoneanum*), vetch (*Vicia sativa*), and curly dock (*Rumex crispus*). Perennial pepperweed (*Lepidium latifolium*) could be an especially troublesome invader. Seasonal floodplains would be expected to provide foraging habitat for a wide variety of wildlife including California black rail, numerous shorebirds (depending on depth of tidal inundation and absence of vegetation), American wigeon (*Anas americana*), American coot, and raptors such as northern harrier (*Circus cyaneus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*Buteo swainsoni*). Potential nesting species within this habitat include California black rail, Suisun song sparrow, and northern harrier. Western pond turtle would be expected to occur within this habitat type depending on availability of basking sites and adjacent suitable soil for nesting.

6.3.9 Native Grasslands

Uplands above elevations suitable for riparian woodland and floodplain habitats that are not on sandy substrates would be most suitable for restoration of native grasslands. Restoration of native grasslands would require aggressive weed control, both initially, to deplete the soil bank of non-native seeds, and over the long-term, as ongoing management. The following native perennial grass species could be seeded or planted with plugs: purple needlegrass (*Nasella pulchra*), California brome (*Bromus californicus*), California fescue (*Festuca californica*), California oniongrass (*Melica californica*), and tufted hairgrass (*Deschampsia californica*). Annual wildflowers such as California poppy (*Eschscholzia californica*), lupines (*Lupinus* spp.), and gilias (*Gilia* spp.) could be seeded in after the grasses became established and broadleaved weeds were under control. Native grasslands would be expected to provide habitat for numerous songbirds and several common small mammal species such as voles and mice. Reptiles occurring in native grasslands would include lizards such as coast horned lizard and silvery legless lizard (*Anniella pulchra*). Several species of raptors have a potential to be found foraging in this habitat type including northern harrier, white-tailed kite (*Elanus leucurus*), and merlin (*Falco columbarius*). Potentially, northern harrier may nest within this habitat type.

7. ANALYSIS OF ALTERNATIVES

7.1 FORMULATION OF ALTERNATIVES

Restoration alternatives for the Dutch Slough site were developed to meet the habitat restoration and adaptive management goals, with consideration of project cost. The alternatives represent different mixes of habitat, with different amounts of grading and imported fill to create these habitats. The alternatives, shown in Figures 8 to 9, are:

- No Action Alternative;
- Alternative 1: Low marsh and open water emphasis with minimal grading (Low cost alternative);
- Alternative 2: Mix of mid marsh, low marsh, and open water with moderate fill (Preferred alternative);
- Alternative 3: Mid marsh and low marsh emphasis with imported fill.

Each alternative is described in Section 7.2 with respect to habitat restoration and design features and adaptive management experiments. Table 4 summarizes and compares the main differences between the alternatives. As discussed in Section 7.3, Alternative 2 has been selected for more detailed consideration. Restoration approaches and preliminary alternatives that were considered and not recommended because they do not meet the project goals are discussed in Section 7.4.

The “action” alternatives (Alternatives 1 to 3) vary the mix of restored habitats and the amount of fill used to create emergent tidal marsh. Alternative 1 will use minimal grading in all three parcels. Alternative 2 will use on-site grading (approximately 1,320,000 cubic yards) to create tidal marsh in all three parcels, and requires a moderate amount of additional fill (approximately 360,000 cubic yards). Alternative 3 will use a larger amount of grading and imported fill (approximately 3 million cubic yards total).

The following discussions assume a 50-year planning horizon, consistent with that used by other San Francisco Bay-Estuary restoration projects currently in planning. The relevant planning horizon for the adaptive management part of the restoration is shorter, on the order of several years to one or two decades, since experimental results are expected to be applied within this shorter timeframe.

Table 4. Summary of Dutch Slough Restoration Alternatives

Alternative	Marsh Creek Delta Restoration Option	Approximate Habitat Acreages[1]			Summary of Marsh Acreage		Adaptive Management Experiments[3]		Implementation Considerations			
		Open water	Marsh	Uplands	Low marsh	Mid marsh	Marshplain elevation	Marsh scale	Fill type	Fill amount	Construction costs	Managment costs[4]
No Action Alternative	Not applicable	See existing habitat acreages below[2]					Not applicable		None	None	None	High (levee maintenance)
Alternative 1: Low marsh and open water emphasis with minimal grading ***(Low cost alternative)***	No	480	440	180	340	100	No	Yes	Onsite borrow	Small	Low	Low
Alternative 2: Mix of mid marsh, low marsh, and open water with moderate fill ***(Preferred alternative)***	Yes	210	660	80	420	240	Yes	Yes	Imported material [5] *or* onsite borrow	Moderate	Medium[6]	Low - high[7]
Alternative 3: Mid marsh and low marsh emphasis with imported fill	Yes	110	830	80	480	350	Yes	Yes	Onsite borrow *and* imported material	Large	High[6]	Low

Notes:

1) Approximate habitat acreages are for the purpose of alternatives comparison only.
2) Existing habitat acreages are listed below for comparison and as an example of expected habitat acreages for the No Action Alternative.
3) Indicates the consistency with testing large-scale experimental variables
4) Indicates long-term or ongoing management and maintenance costs; does not include costs of monitoring adaptive management experiments
5) If available and cost effective
6) Depends on the type and cost of fill material
7) Depends on which open water management option is used

Existing habitat acreages (DWR 2005)	acres
freshwater marsh (diked)	54
alkali meadow	34.8
blackberry	1.7
developed	35.5
pasture	792.9
riparian	11.4
ruderal	118.7
ruderal (relict sand dunes)	18.9
seasonal pond	16.6
vineyard (relict sand dunes)	14.5
water	9.7
willows	0.5

7.2 DESCRIPTION OF ALTERNATIVES

7.2.1 Design Features Common to Alternatives

The alternatives have many features in common, including the restoration approach for native plant revegetation, marshplain microtopograhy, tidal channel networks, levee breaching and lowering, open water areas, infrastructure protection, and the accommodation of public access and recreation. These features are discussed below.

Restored habitats will be revegetated with native plant species to provide a diversity of habitat functions (shelter, food, nesting) for fish, birds, and other wildlife. Revegetation will also help the adaptive management experiments by providing more consistent vegetation types between parcels. Tules will be pre-established in restored low marsh and mid marsh areas prior to breaching by encouraging natural recruitment with flood irrigation, with limited supplemental planting of rhizomes using farm equipment and/or volunteers. The pre-establishment of tules will inhibit the invasion of non-native species such as egeria, golden flag iris, and arundo, especially at lower tidal elevations where natural colonization of tules is less likely to occur under tidal conditions. Planting high marsh and the ecotone (transition area) between marsh and riparian communities will be important to minimize the establishment of invasive weeds like perennial pepperweed and Himalayan blackberry. High marsh along the ecotone is expected to provide opportunities to restore rose-mallow and Mason's lilaeopsis, which are both special-status species. Riparian woodland will be planted with willow cuttings, cottonwood poles, acorns, herbaceous and woody plants (vines, shrubs, and trees), and a seed mix of grasses, graminoids and wildflowers.

In restored marsh areas, the topography of the marshplain will vary, generally sloping down towards the channels to facilitate drainage and up towards marsh drainage divides (see Section 8.1.1 for detail). Marsh drainage divides will support high marsh plant communities and provide boundaries to define marsh drainage areas for the purpose of adaptive management experiments. Prior to breaching, tidal channel systems will be excavated into the marshplain. The channel networks will be sinuous and branching, similar to the planforms of natural channel networks. The external levees of the parcels will be breached in several locations to restore tidal inundation to marsh areas. Portions of the levees will be lowered to create marsh and riparian woodland habitat.

A new levee will be constructed to protect on-site infrastructure, Jersey Island Road, and adjacent property to the east from flooding and groundwater seepage (using approximately 190,000 cubic yards of fill material). PG&E's on-site infrastructure crosses the northeast corner of the Burroughs parcel, which includes electric transmission line, high pressure gas line, and gas gathering line (see Section 8.3.4.2). This area (approximately 25 acres) will not be restored to tidal marsh and will remain diked behind the new levee. It may be possible to restore upland or other habitat in this area or incorporate the area with the adjacent Delta Access Park being planned by the City of Oakley. Further coordination with PG&E and the City is recommended to develop a plan for this area.

All three restoration alternatives include areas of open water, which will not be filled to reduce costs. There are several options for managing open water areas, which include breaching to create subtidal habitat planted with native submerged aquatic vegetation (SAV), managing open water pond habitat, growing tules as a subsidence reversal technique (biomass accumulation), and constructing wide marsh "berms" to form a "skeletal" tidal channel network. These options are discussed in Section 8.2.2. All of these options are compatible with Alternatives 1 to 3.

All three alternatives are consistent with providing high quality public access and recreation opportunities. The public access and recreation plan is being developed by the City of Oakley in a separate master planning process. Features of this plan will include the 55-acre Dutch Slough Community Park, a trail system with a loop trail encompassing the Emerson parcel, and the 8-acre Dutch Slough Access Park (Figure 10). All three alternatives include a footbridge over the Emerson parcel levee breach, and possibly a second footbridge over the inlet to the open water area on the Emerson parcel, to provide trail access. The need for a second footbridge will depend on the open water management option selected for the Emerson parcel open water area in later design phases (see Section 8.2.2). If the selected open water management option includes breaching the levee between the open water area and Emerson Slough to restore tidal action, then a footbridge will be required to provide trail access across this levee breach.

7.2.2 No Action Alternative

The No Action Alternative represents the most likely condition in the absence of a long-term restoration plan. The No Action Alternative is not being proposed by the Project, but is included for NEPA/CEQA compliance. For the No Action Alternative, there are several possible scenarios of future land use (T. Hall, DWR, pers. comm.). DWR and the project team may choose to lease or deed the land to a federal, state, or local agency to use for recreation, parks, wildlife reserve, or similar use. Alternately, the land may be fallowed to allow natural processes and vegetation recruitment to occur while managing for non-tidal habitats – such as seasonal (ponded or sub-irrigated) wetlands, freshwater marsh, riparian woodland, and native grasslands – and compatible public recreation. Any funds available from leasing the land would be transferred to the reclamation district and used to maintain the levees. A third option is that the land will be sold as "surplus property." If this occurs, the land will likely be developed for residential and commercial units. Figure 8 shows existing vegetation and habitat types for the No Action Alternative for comparison with the action alternatives.

7.2.3 Alternative 1: Low Marsh and Open Water with Minimal Grading (Low Cost Alternative)

Alternative 1 will create large areas of low marsh and open water habitats, smaller areas of mid marsh and high marsh, and upland habitats (riparian woodland, native grassland, dune, and marsh/upland transitional habitats) using only minimal grading in each parcel (Figure 8). Alternative 1 will have the lowest cost and uses minimal fill material.

7.2.3.1 Habitat and Design Features

As shown in Figure 8, the habitat gradient between open water, marsh, and upland will follow the existing site topography. Existing channels and irrigation ditches in the parcels will be enhanced to create tidal channels where possible. Additional tidal channels will be excavated to create sinuous and branching channel networks and to provide adequate tidal drainage. In the Burroughs parcel, irrigation ditches with existing riparian woodland habitat will be incorporated into the tidal channel system; however, it is uncertain whether these riparian communities will survive in the medium- to long-term once tidal inundation is restored (see Section 8.1.6.2).

7.2.3.2 Adaptive Management Experiments

To test the adaptive management hypotheses related to spatial scale, the Burroughs parcel will have low marsh areas drained by a large channel network (approximately 200 acres) and a small network (on the order of 10 acres), which can be compared to a medium sized channel network (approximately 60 acres) in the Gilbert parcel. The medium sized channel network in the Emerson parcel will provide an additional point of comparison for marsh scale. The testing of marshplain elevation hypotheses will not be possible because only small areas of mid marsh will be created. Small-scale adaptive management experiments (one to two acres) will be accommodated, though the exact locations of these experiments have not yet been decided.

7.2.4 Alternative 2: Mix of Mid Marsh, Low Marsh, and Open Water with Moderate Fill (Preferred Alternative)

Alternative 2 will create a mix of marsh, open water, and upland habitats (Figure 9). Alternative 2 will create these habitats using on-site grading (approximately 1,320,000 cubic yards) and a moderate amount of additional fill (approximately 360,000 cubic yards). Additional fill material will be imported or borrowed onsite from low elevation open water areas. Alternative 2 provides opportunities for marsh scale and marshplain elevation adaptive management experiments and the restoration of a natural delta at the mouth of Marsh Creek.

7.2.4.1 Habitat and Design Features

On-site grading and additional fill are needed to create marsh areas in Alternative 2 since relying on the existing topography would result in very small areas of mid to high marsh (and large areas of low marsh and open water as in Alternative 1), particularly in the Gilbert parcel. Marsh areas will be located in the higher areas of the parcels to reduce the amount of fill required and increase cost effectiveness. (In general, the higher elevation areas are located in the central and southern portions of each parcel.)

Marsh will be created by excavating approximately 1,320,000 cubic yards of material from higher areas and placing excavated material in lower-lying areas. Grading on the Emerson parcel will generate excess material (approximately 60,000 cubic yards), which will be used for fill in the Gilbert parcel. Additional fill material (approximately 360,000 cubic yards) will be needed for the Gilbert and Burroughs parcels. This additional material may be imported from off-site, if available or cost effective. Alternatively, additional fill material could be generated onsite by over-excavating the lower northern areas of the Gilbert and Burroughs parcels. Over-excavating onsite would deepen these areas, which is expected to limit open water management options (see Section 8.2.2). Therefore, the use of imported fill material is preferred over on-site borrow.

Portions of the higher areas on the Emerson and Burroughs parcels are currently designed to be left at existing grades to create islands of upland habitat within marsh areas, which are expected to provide refuge for upland species. It is possible that these upland areas may be excavated to create marsh and generate additional fill material if future phases of project planning determine that the value of preserving upland areas is outweighed by the cost of obtaining additional fill material.

In the Gilbert and Burroughs parcels, the marshplain topography of low marsh and mid marsh areas will vary as described in Section 7.2.2 (and detailed in Section 8.1.1). The average marshplain elevations of low marsh and high marsh will differ, with low marsh areas averaging MLLW (-0.3 ft NGVD) and mid marsh areas averaging MTL (1.5 ft NGVD). Each marsh area will have a distinct channel network defined by marsh drainage boundaries or divides, which will facilitate adaptive management experiments. In the Emerson parcel, a single large tidal channel network will connect topographically diverse habitats (low marsh, mid marsh, and upland).

The exterior levees of the Gilbert and Burroughs parcels will be breached along Little Dutch Slough to restore tidal action to restored marsh areas. Several marsh areas will be breached to the narrow southern reach of Little Dutch Slough. This reach of the slough will be dredged and the existing drainage culvert and road crossing will be removed to increase channel conveyance and allow for full tidal circulation to the marsh areas (see Section 8.3.1). The wider northern reach of Little Dutch Slough will also need to be enlarged, either through tidal scour or dredging, to provide full tidal circulation. The restored marsh on the Emerson parcel will be breached directly to Dutch Slough.

The restoration approach in the Emerson parcel will allow for the option to restore a natural delta at the mouth of Marsh Creek, if feasible from a water quality perspective (see Figure 11 and Section 8.2.1 for more detail). To restore the natural physical processes and ecological values of the creek, Marsh Creek may be diverted into the Emerson parcel through restored tidal marsh.

7.2.4.2 Adaptive Management Experiments

The marshplain and channel configurations of the Gilbert and Burroughs parcels will allow scientists to test the adaptive management hypotheses related to marshplain elevation and spatial scale. These experiments will compare low marsh and mid marsh areas drained by large channel networks (approximately 80 to 90 acres), medium sized channel networks (approximately 30 to 40 acres), and small networks (approximately 10 to 15 acres). Paired sampling of low and mid marsh will allow for comparison between low and mid marsh at different scales. A very large area of low marsh on the

Burroughs parcel (approximately 150 acres) will also be compared to the smaller paired-sample marsh areas. The scale of each marsh area and channel network may be refined in future design phases for the purpose of the adaptive management experiments.

The configuration of channel networks draining to the same inlet channel (Little Dutch Slough) is expected to aid in the comparison of results. Each marsh area and channel network will be drained by one breach to Little Dutch Slough. As possible, the channels draining paired sample areas will be located equidistant from the mouth of Little Dutch Slough. For example, breach channels will be aligned along Little Dutch Slough for the small marsh areas, medium marsh areas, and large and very large low marsh areas. The marsh drainage area for each channel network will be defined by high marsh drainage divides, which will minimize the potential for new channel connections to form between and connect marsh areas.

Until such time as Marsh Creek is diverted onto the Emerson parcel, should this occur, this parcel will provide an additional sample for the adaptive management experiments. In the Emerson parcel, the large area of "mixed" marsh could be compared to the very large area of low marsh on the Burroughs parcel to test the benefits of topographic diversity. The fact that the marsh will drain to different sloughs may complicate experimental comparison. If and when Marsh Creek is diverted onto the Emerson parcel, the marshes in this parcel would no longer be comparable to the other marsh areas due to the complicating factor of Marsh Creek.

As in Alternative 1, Alternative 2 will include small-scale adaptive management experiments (one to two acres).

7.2.5 Alternative 3: Mid Marsh and Low Marsh Emphasis with Imported Fill

Alternative 3 will use onsite grading and imported fill material (approximately 3 million cubic yards total) to create large continuous expanses of low marsh and mid marsh in the Burroughs and Gilbert parcels, respectively (Figure 10). Alternative 3 provides the largest area of restored tidal marsh and opportunities for large-scale adaptive management experiments. The Gilbert and Burroughs parcels will have the largest marsh areas and most complex (highest order) channel networks of all restoration alternatives; however, this will require the largest amount of fill and the highest cost. The restoration of the Emerson parcel in Alternative 3 is identical to Alternative 2.

7.2.5.1 Habitat and Design Features

Imported fill will be placed to mid marsh elevations in the Gilbert parcel. The Burroughs parcel will be graded to low marsh elevations using cut and fill of onsite material, with supplemental imported fill if necessary. Dredged material is the most likely source of imported fill and could be deposited onsite in a slurry. The marshplain topography of restored marsh areas in Alternative 3 is identical to Alternative 2. Restored marsh areas on the Gilbert and Burroughs parcels will be breached to the wider northern portion of Little Dutch Slough and slough channel dredging is not expected to be necessary.

7.2.5.2 Adaptive Management Experiments

Alternative 3 provides the largest and most continuous low marsh and mid marsh areas (on the order of 300 to 400 acres), so is well suited for both the marsh elevation and marsh scale adaptive management experiments. As in Alternative 2, Alternative 3 will include paired sample areas of low marsh and mid marsh in the Gilbert and Burroughs parcels. The large mixed marsh area in the Emerson parcel will be compared to the large low marsh and mid marsh areas in the Burroughs and Gilbert parcels; however, the same factors discussed for Alternative 2 may complicate this comparison. As in Alternatives 1 and 2, Alternative 3 will also include small-scale adaptive management experiments (one to two acres).

7.3 EVALUATION OF ALTERNATIVES

Table 4 summarizes and compares the main differences between alternatives. Alternative 2 is the preferred alternative selected for more detailed consideration in Section 8. Alternative 2 is expected to meet the project goals for habitat restoration and adaptive management in a cost-effective manner. Alternative 2 will create approximately 660 acres of marsh and tidal channel habitat and 80 acres of riparian, native grassland, and dune habitat. The key adaptive management experiments – testing of marsh scale and marshplain elevation – are major components of Alternative 2.

Alternatives 1 and 3 are not recommended for further consideration. Alternative 1 doesn't perform as well as Alternative 2 on the habitat restoration and adaptive management goals. Alternative 1 will create a smaller area of restored marsh compared to Alternative 2, and less mid marsh. Also, Alternative 1 does not provide the opportunity to test the marshplain elevation adaptive management experiment or the option to restore Marsh Creek on the Emerson parcel. The large amount of fill required for Alternative 3 makes this alternative more expensive than Alternative 2. In addition, implementation of Alternative 3 could be delayed significantly due to limited availability of imported fill. These drawbacks of Alternative 3 are not expected to be outweighed by corresponding habitat benefits.

7.4 ADDITIONAL ALTERNATIVES CONSIDERED AND NOT RECOMMENDED

Phased breaching of each parcel. Phased breaching of the Emerson, Gilbert, and Burroughs parcels – for example, breaching the Gilbert parcel first, followed by the Burroughs parcel several years later, then the Emerson parcel after Burroughs – was considered early in alternatives development. An advantage of this approach is that it allows the flexibility of phasing the funding required for construction; full funding for all three parcels is not required at one time. Another advantage is that it allows adaptive management lessons from the early phases to benefit planning for the later phases. However, implementing restoration on different parts of the site at different times greatly complicates comparison of results between parcels. The parcels would be different "ages" and would be subject to different environmental conditions during site evolution. Another disadvantage of this alternative is that, in order to allow learning between phases, the phases would need to be at least several years apart, and possibly much more, delaying full implementation. The project team discussed the pros and cons of this approach with the CBDA Ecosystem Restoration Program Science Board (CBDA ERP Science Board, 2004), who advised that simultaneous implementation was preferred to a phased approach. The Project will consider restoring the Gilbert and Burroughs parcel in one phase and the Emerson parcel in a separate phase (see Section 8.4.5).

Continuous high marsh in all parcels. Although this alternative would restore a marsh system most similar to a natural historic Delta marsh, presumably with great restoration benefits, it has two major drawbacks. It would not meet the adaptive management goal because it would not allow testing of different marshplain elevations. In addition, continuous high marsh in all parcels is probably not feasible because of the large amount of fill it would require.

Equal areas of mid marsh, low marsh, and open water in the Gilbert and Burroughs parcels. This alternative could provide "pseudo-replication" of large-scale experimental results by comparing large areas of low marsh in both the Gilbert and Burroughs parcels with large areas of mid marsh in both parcels. This concept was rejected because the AMWG decided that testing a range of small, medium, and large marsh scale was a priority over pseudo-replication. The rejected concept did not allow for medium scale marsh areas.

Continuous low marsh or mid marsh in Emerson Parcel. Filling the Emerson Parcel to create continuous low marsh or mid marsh was rejected because a limited amount of fill is expected to be available. Priority is given to filling the Gilbert and Burroughs parcels to marshplain elevations for adaptive management experiments.

8. PREFERRED ALTERNATIVE

This section provides details on the restoration design features; restoration options; feasibility assessment; planning-level construction volumes, methods and costs; and site maintenance and monitoring for the preferred alternative, Alternative 2 (Figure 12).

8.1 RESTORATION DESIGN FEATURES

Restoration design features for the preferred alternative are shown in Figures 12 and described below.

8.1.1 Marshplain Grading

Fill material will be used to raise existing ground elevations up to marshplain elevations suitable for the growth of native emergent freshwater marsh plant communities. Some high elevation areas will be graded down to marshplain elevations.

Average design elevations for marshplain grading are:

- Low marsh: MLLW (-0.3 ft NGVD)
- Mid marsh: MTL (1.5 ft NGVD)

Design elevations will vary by up to 0.5 feet above and below the average design elevation, with marshplains generally sloping towards the channels to facilitate marshplain drainage. Mixed marsh areas with channel networks draining both low marsh and mid marsh will gradually slope from approximately -0.8 ft NGVD to +2 ft NGVD. A grading tolerance of 0.5 feet will be allowed in construction to reduce construction costs and create microtopography on the marshplain, which is expected to have habitat benefits.

The minimum low marsh elevation (approximately -0.8 ft NGVD or 0.5 feet below MLLW) is within the elevation range where tule vegetation is observed to transition to unvegetated mudflat in Delta marshes (Figure 13). PWA surveyed the elevation of the tule/mudflat edge in Little Dutch Slough (Appendix B) and compiled data from the BREACH study (Simenstad and others, 2000). Based on available data, tules are expected to dominate an area at -0.8 ft NGVD, with some areas of unvegetated mudflat interspersed. Because tules will be pre-established at the Dutch Slough site, a somewhat greater probability of tule cover is expected than in the sites represented in the data set.

To reduce costs, fill will be placed on higher elevation areas. Typical depths of marsh fill will range from 0 to 4 feet, with a maximum depth of fill of approximately 8 feet. In Alternative 2, marsh areas are generally located to avoid areas with low existing elevations and peat soils shown in the soils map (Figure 5). Near the Emerson parcel breach, 8 feet of fill material will be placed in the location of historic peat soils. Available soil borings suggest that the peat layer may be up to 7 feet thick in this location. A total of approximately 10 feet of fill will need to be placed to achieve a net 8-feet depth of fill due to the settlement of the underlying peat, which is expected to be approximately 2 feet (Appendix F-2).

8.1.2 Marsh Drainage Divides

The perimeter of marsh drainage areas will be constructed to gently slope up to the elevation of MHHW to create marsh drainage divides. Marsh drainage divides are expected to support native freshwater marsh plant species and provide high marsh habitat. During high tides, marsh drainage divides will be tidally inundated and tidal exchange between adjacent marsh areas may occur. For the purposes of adaptive management experiments, marsh drainage divides will define drainage areas for the small, medium, and large low marsh and mid marsh channel systems to facilitate the comparison between different marsh areas. As an example, marsh drainage divides will be necessary for monitoring fish and water quality in different marsh areas. For open water management options that will use water control structures to lower water levels below tide levels, higher marsh drainage divides may be necessary between marsh and open water areas to prevent frequent overtopping and the potential for scour.

8.1.3 Breaches

Breaches will be sized to provide full tidal exchange between the sloughs and the restored marsh and open water areas. Empirical channel relationships (hydraulic geometry) for Delta marshes can be used to size the breaches in proportion to the restored tidal prism (Simenstad and others, 2000; Williams and others, 2002; PWA, 2003). For large marsh areas (approximately 230 acres), breaches are expected to be approximately 60 to 80 feet wide at MHHW and 15 feet deep below MHHW. Hydrodynamic modeling could be used to confirm the breach sizing in subsequent phases of the design.

8.1.4 Tidal Channel Networks

Tidal channel systems in the three parcels will be excavated into the marshplain. The channel networks will be sinuous and branching, similar to the planforms of natural channel networks in freshwater marshes. The design length of tidal channels will be based on channel densities in historic or mature freshwater marshes, which are expected to be approximately 100 feet per acre (SFEI, 2004). The radius of curvature, meander wavelength and amplitude, and bifurcation ratios of the tidal channel networks will also mimic natural freshwater marshes. Channel cross-section dimensions will be based on empirical hydraulic geometry relationships for tidal channels in Delta marshes and constructability considerations (PWA, 2003; Williams and others, 2002). Channel side slopes will be constructed as steep as possible to mimic natural channel banks. It may be feasible to construct side slopes of 2:1 (horizontal:vertical) or steeper, depending on the type of soil used for marsh fill.

The dimensions of the main tidal channels in large marsh areas are expected to be similar to the breach dimensions discussed above. Large channel systems (marsh drainage areas on the order of 150 acres) are expected to be 4^{th} or 5^{th} order channel systems, which means the main channels will branch into smaller channels four to five times before reaching the smallest channels in the system. The collection of additional data on tidal channel dimensions and plan form relationships to marsh area in Delta marshes is recommended in future phases of the project to reduce the uncertainty in designing and predicting fish response to tidal channel morphology.

8.1.5 Habitat Levees

The existing levees surrounding the Emerson, Gilbert, and Burroughs parcel will be restored to provide a mix of high marsh, riparian woodland, and native grassland habitats. Portions of the existing levees will be planted with riparian woodland to provide woody aquatic habitat, if levees soils are suitable for planting. These habitat levees are expected to provide shaded riverine aquatic (SRA) cover habitat along the water's edge with benefits to native salmonids and other native fish. Other portions of the levees will be lowered to marshplain elevation to provide high marsh habitat and allow for high tide flows and fish access to restored marsh areas.

Riparian habitat levees are shown as upland habitat in Figure 12. Portions of the existing levees surrounding the Gilbert and Burroughs parcels along Emerson Slough and Little Dutch Slough will be lowered to elevations ranging from 6 to 8 ft NGVD, where the roots of riparian woodland plantings can reach the groundwater table. The existing elevations of levees around the Emerson parcel and along Dutch Slough in the Gilbert and Burroughs parcel will be maintained for two purposes. The existing levee elevations along Dutch Slough will be maintained to reduce overtopping and the possibility of exposing Jersey Island levees to wind-waves generated in open water areas on-site. The existing levee elevations around the Emerson parcel will be maintained to provide access for the public trail and the Ironhouse Sanitary District's pipeline (see Section 8.3.4.1).

Habitat levees will be planted with alder, box elder, and sandbar willow. If the levees are very compacted or low in nutrients, the soils may need to be ripped and amended with slow release fertilizer. Soil tests are recommended to determine exact treatments. Invasive weeds such as Himalayan blackberry will need to be removed. Riparian woodland may be interspersed with non-woody canopy openings (*e.g.*, 100 foot long or greater areas along levees), particularly in locations above the zone of inundation or natural sub-irrigation (*i.e.*, the tops of habitat levees along Dutch Slough and around the Emerson parcel). These openings or clearings are expected to add diversity by supporting native riparian herbaceous vegetation, such as creeping wildrye, Barbara sedge, and native grasses and forbs. These herbaceous habitats are also expected to provide opportunities to restore special-status plant species such as Delta tule pea, Suisun marsh aster, Suisun thistle and rose-mallow.

Figure 14 shows a conceptual schematic for a typical cross-section of a habitat levee planted with riparian woodland. Riparian woodland plantings will extend down to 3.2 ft NGVD (MHHW) on the outboard or slough side of the habitat levees and 5.0 ft NGVD on the inboard side. It may not be necessary to remove existing rip-rap on the outboard side of the levee; however, the rip-rap may be moved around to allow for interspersed planting. Retaining the existing rip-rap along Dutch Slough is expected to provide an effective and low cost method of protecting the levee from boat-wake erosion. On the inboard side of the levee, a gently sloping levee bench (5:1 horizontal: vertical or flatter) will be constructed from 5.0 ft

NGVD to existing grade using fill material. Measures to protect the inboard slope of the levee from erosion due to wind-waves over the open water fetch may depend on the open water management option (see Section 8.2.2). In locations where habitat levees adjoin restored marsh areas, slope protection will not be necessary. The design of the habitat levees and slope protection may be detailed and optimized in future design phases through the assessment of potential wind-wave erosion.

For open water management options that create tidal open water areas, the inboard levee slope will be revegetated with tule and high marsh plant species. This will create a wide tule edge (approximately 30 feet minimum width) that is expected to protect the levee slope from wave erosion and provide marsh and transitional habitat. Tules will be established on the levee slope prior to breaching. The proposed method is to encourage natural recruitment through flood irrigation and water management, with limited supplemental planting of rhizomes. To revegetate the levee slope, tules will first be established at the lowest elevations in the open water areas. Water levels will be gradually increased to allow tules to spread to higher elevation areas through natural recruitment and rhizomal extension until the vegetation reaches the levee slope. Tules established in lower elevation areas are not expected to survive as inundation depths increase; however, a sufficient width of tule at the open water edge is expected to provide short-term protection from wind waves and erosion, allowing for quiescent conditions suitable for tule establishment at higher elevations.

Habitat levee plantings and slope protection are expected to help protect against complete levee failure, except in the case of an earthquake. In some locations, the habitat levees may settle, scour, or be overtopped by extreme water levels, which have the potential to cause unintentional breaches. Breaches will be repaired where habitat levees surround managed open water areas or where breaches lead to new tidal openings that will complicate adaptive management experiments. Otherwise, breaches of habitat levees surrounding tidal areas will be allowed to remain.

Other portions of the levees along Little Dutch Slough will be lowered to provide high marsh habitat and allow for high tide flows and fish access to the marshplain. The design elevation of the lowered levees will be 3.2 ft NGVD (MHHW) or slightly higher. The lowered levee will be overtopped by up to approximately half of the diurnal high tides. As the existing levee elevation is approximately 8 to 10 ft NGVD, lowering the levee will provide a source of fill material. The material excavated from the lowered levees may be sidecast into the parcels as marsh fill.

8.1.6 Revegetation

The Project will revegetate restored tidal marsh, riparian, native grassland, and dune scrub habitats with native plant species. With active restoration of desired native plant species, including control of invasive weeds during the establishment period, native plants are expected to dominate most plant communities, potentially providing habitat for both common and sensitive wildlife and plants. Once established, native plant species may outcompete invasive non-native species. Without active revegetation in upland habitats, plant community development based on volunteer colonization would likely lead to the dominance of invasive weeds in many plant communities because the propagules of invasive non-native upland species are abundant in the vicinity of the project area. Invasive plant species are considered to have reduced value to many native wildlife and fish species.

Planting methods are summarized below and described in detail in Appendix G. Additional planting methods for habitat levees are discussed in the section above.

8.1.6.1 Tidal Marsh

To maximize native species establishment and minimize colonization by non-target invasive species, tules will be established prior to breaching the site. The pre-establishment of tules will allow for the experimental comparison of vegetated marsh areas immediately after breaching. This will avoid an initial period of natural colonization under tidal conditions and increase comparability by providing more consistent vegetation cover between locations. Water management will be used to encourage natural recruitment by periodically flooding and then drawing down water levels in marsh areas (*i.e.*, flood irrigation). A limited amount of tule rhizomes will be planted on a large scale, possibly using farm equipment or volunteer labor, and will supplement natural recruitment.

The pre-establishment of tules will inhibit the establishment of and competition with invasive species such as non-native SAV in lower areas of marsh (below MTL) and golden flag iris and arundo in higher areas of marsh (above MTL). The pre-establishment of tules is also expected to limit widespread establishment of cattails and common reed. Although cattails and common reed are considered native, they can also be undesirable as they can quickly dominate a site and limit species diversity.

Areas of high marsh will provide opportunities to restore rose-mallow, a special-status species, along the ecotone (transition area) with riparian communities. Mason's lilaeopsis, another special-status plant, can also be restored in even small (*e.g.*, less than 100 sq-feet) unvegetated saturated mudflat areas in the ecotone with riparian communities.

8.1.6.2 Riparian

Riparian uplands and habitat levees will be planted with native woody species to maximize the ultimate extent and diversity of native riparian plant communities and hasten the process of volunteer establishment. Riparian woodland plantings will include Fremont cottonwood, willows, box elder, Oregon ash, California blackberry, wild rose, buttonbush and others. Following initial control of weeds, a seed mix of native riparian grasses, sedges, and wildflowers will be drilled on areas within appropriate elevations. Cuttings from native riparian trees and shrubs will be collected from the project vicinity and installed in the riparian zones. Areas within the elevation range of 3.2 to 16.5 ft NGVD (MHHW to 15 feet above MTL) are expected to be suitable for riparian vegetation. Low elevation moist areas will be planted with water tolerant species such as alders and sandbar willow, while intermediate and higher riparian zone areas will be planted with deep-rooted riparian species such as cottonwoods, valley oaks, and Oregon ash. In higher elevation areas, (above 6.5 ft NGVD or 5 feet MTL), long "pole" cuttings will be planted in deeply augured holes so as not to rely on irrigation. Riparian trees and shrubs could also be field grown and transplanted in the winter as bare root stock, as appropriate.

Without active restoration, volunteer establishment of native woody and herbaceous riparian plants would likely be minimal due to the lack of adjacent existing native riparian plant communities to provide a source for colonization. Instead, there would be a high potential for establishment of invasive non-native species currently abundant in the vicinity, including Himalayan blackberry, perennial pepperweed, Bermuda grass, milk thistle, Italian ryegrass, vetch, and curly dock. Volunteer establishment of native plants would probably be limited to areas adjacent to existing native riparian plant communities, and would likely take decades to succeed beyond initial willow scrub phases to cottonwood-willow forests.

Existing riparian communities above 3.2 ft NGVD (MHHW) may survive after the levees are breached. Riparian communities not tolerant of inundation, such as cottonwoods and red willows, may die out over time and be replaced by species that do tolerate inundation, such as sandbar willow and alder. The elevation of the well developed riparian woodland along the drainage channel in the southern half of the Burroughs parcel is uncertain, as only limited spot elevation data are available (one spot elevation at 4 ft NGVD). Detailed elevation surveys and further assessment of inundation tolerance are recommended in future phases of the project to evaluate the potential for the existing riparian woodland to survive. In Alternative 2, portions of the existing riparian woodland along the drainage channel would be retained as part of the marsh drainage divide between the mid marsh and low marsh areas on the Burroughs parcel.

8.1.6.3 Native Grasslands

Areas of native grasslands and native herbaceous floodplain vegetation will be restored with a mix of competitive (creeping wildrye, deergrass, and meadow barley) and other native grasses (blue wildrye, purple needlegrass, California brome, and California melic). Following initial weed control, these native grasses will be seeded and mulched on clay soils in upland areas of the site above approximately 8.2 ft NGVD (5 feet above MHHW). The seed mix will also include native wildflowers such as California poppies and lupines. Native grasses will also be a component of transitional habitats between high marsh, riparian communities and native grasslands. Sandy soils in the higher elevations will be seeded with a mix of grasses such as one-sided bluegrass and forbs such as lupines and asters adapted to dry coarse soils. Native grassland plant communities are not expected to develop without planting even in the long-term because of the extremely limited existing sources of native seed and propagules, and competition from non-native annual grasses and other invasive species.

8.1.6.4 Dune Scrub

Native dune habitat will be restored in the Emerson parcel by planting and/or seeding with a mix of native dune scrub plants (Antioch dunes evening primrose, Contra Costa wildflower, naked buckwheat, broom snakeweed, etc.) following initial weed control. As with native grasslands, native dune habitat is not expected to develop without planting even in the long term. Because of the limited experience with Antioch dune scrub restoration, various planting techniques will be tested in small-scale experiments prior to full scale planting. In the experiments, seeding could be compared to container planting, various types of mulching could be compared to no mulching, and planting of untreated Delhi sand soils could be compared to excavation of soils to expose subsoils with low organic matter.

8.2 RESTORATION OPTIONS

The restoration options are flexible parts of the conceptual design. The final configuration of restoration options will be based on information to be developed during future phases of the project.

8.2.1 Marsh Creek Delta Restoration Options

Alternative 2 allows for the option to restore a delta at the mouth of Marsh Creek. If feasible from a water quality perspective, Marsh Creek may be diverted onto the Emerson parcel to restore the physical processes and ecological values of a natural creek delta. Water quality in Marsh Creek will be monitored to determine if conditions are suitable for diverting the creek on-site (see Section 8.3.5). If conditions are determined to be suitable prior to final design, the implemented project will include the restored delta in the Emerson parcel. If it is not possible to determine the suitability prior to final design, the plan will allow for the possibility of diverting and restoring Marsh Creek after project implementation. If monitoring results indicate that routing Marsh Creek through a restored marsh delta will negatively impact native plant and wildlife species or degrade the water quality of creek discharge to the Delta, the current alignment of Marsh Creek will be maintained as shown in Figures 12. Marsh Creek water quality is discussed further in Section 8.3.5.3. A coordinated project, the Marsh Creek Delta Restoration (Appendix J), proposes to divert Marsh Creek onto the Ironhouse Sanitary District's parcel to the west of Marsh Creek and the Dutch Slough site.

If Marsh Creek is diverted onto the Emerson parcel, it will connect with the tidal channel network, flowing through the restored marsh to Dutch Slough and creating a system of backwater channels. Flows in Marsh Creek will deliver sediment to the marshes, recreating natural deltaic processes and features that are expected to benefit native fish and wildlife. Over time, Marsh Creek deposition will raise ground elevations within low marsh areas. Further study of the sediment yield from Marsh Creek is recommended in future design phases to estimate the potential deposition rate in the restored creek delta.

Marsh Creek will be diverted onsite in one of several potential locations (see Figure 11). The existing Marsh Creek channel will be blocked below the diversion to re-direct flow into the restored delta. A vehicle-accessible bridge will span the Marsh Creek diversion to allow for a trail and maintenance of the Ironhouse Sanitary District pipeline. The Ironhouse pipeline currently crosses over Marsh Creek and into the Emerson parcel at an existing footbridge and will be moved into the Marsh Creek levee (see Section 8.3.4.1). If the creek is diverted onsite downstream of the existing pipeline crossing, the pipeline may need to cross the creek diversion at the new bridge. The Marsh Creek restoration options are flexible and allow for Marsh Creek to be diverted through both the Ironhouse parcel and the Emerson parcel, potentially providing a larger restored delta at the creek mouth.

The location and sizing of the Marsh Creek diversion and channel will be determined in future design phases. The design of the Marsh Creek diversion and delta restoration will need to maintain or improve the existing level of flood protection provided by the Marsh Creek flood control channel. Restoring a large marsh floodplain has the potential to lower flood levels in Marsh Creek. Hydraulic modeling and consideration of sediment dynamics are recommended to evaluate potential changes in flood risk.

8.2.2 Open Water Management Options

There are several options for managing open water areas on the three parcels. Potential management options are summarized in Table 5 below. The management of open water areas will be detailed and determined in later design phases with consideration of habitat restoration and adaptive management objectives (with input from the AMWG), implementation and management costs, and compatibility with the method of fill.

If feasible, subsidence reversal through biomass accumulation is the preferred management option for the open water area on the Gilbert parcel. The open water area on the Gilbert parcel is the largest and least subsided and provides the best opportunity for subsidence reversal.

Several of the open water management options are experimental and could be adaptively tested on small-scale plots before application to large-scale areas. Open water management could be treated as a reversible adaptive management action. The success of different open water management options could be compared to each other. If comparison indicates that one option is more successful (*e.g.*, provides more habitat value), this option could then be applied to other open water areas. For example, if experimental results show that subtidal areas planted with native SAV provided significantly less habitat value than marsh areas, the subtidal area could be closed to tidal action and managed for subsidence reversal.

The costs of the management options have not been estimated, but relative costs are discussed qualitatively below. If imported fill material is not available or cost-effective, onsite fill material will be excavated from deep borrow areas within the open water areas. The only option that is expected to be compatible with on-site borrow is deep subtidal open water. It may be possible to confine the deep borrow areas to smaller areas within the open water areas, leaving shallow open water areas that could be managed with any of the options. Shallow open water areas are expected to be compatible with all other management options. If one of the tidal options is selected for the open water area on the Emerson parcel and the levee is breached to Emerson Slough, an additional footbridge will be required to provide trail access across the breach.

Marsh drainage divides will separate open water areas from marsh areas (see Section 8.1.2). For options that will manage water levels below tide levels, berms that are higher than the elevation of marsh drainage divides (MHHW) may be needed to prevent overtopping from marsh areas, which may lead to scour and channel cutting between open water and marsh areas. Open water areas may be internally partitioned with berms to allow the application of different management options within a single parcel or to facilitate water management.

Certain types of open water management may limit water circulation, such as managed pond, subsidence reversal through biomass accretion, and deep subtidal. Poor circulation could potentially lead to water quality problems related to anaerobic conditions and depth stratification. The managed pond and subsidence reversal options will require vector control measures (see Section 8.3.7).

Table 5. Summary of Open Water Management Options

Open Water Management Option		Expected Habitat[1]	Adaptive Management	Implementation Costs	Ongoing Management Costs	Compatible Fill Method
Tidal	Shallow subtidal with native SAV planting	Native SAV, higher proportion of native fish than without planting	Small-scale experiment or large-scale comparison	Med	Low - High	Import
	Deep subtidal	Predominantly non-native fish	Limited, could be used as a reference site (similar to breached site not optimized for habitat)	Low	None	On-site borrow
	Skeletal channel network	Marsh edge/ tidal channel bank, intermediate between subtidal and marsh (experimental)	Small-scale experiment or large-scale comparison	High	None	Import (possibly on-site borrow)
Managed	Managed pond	Waterfowl or shorebird	None	Low - Med	Med - High	Import
	Subsidence reversal through biomass accretion	Future tidal marsh (long-term)	Small or Large-scale experiment	Low - Med	Med - High	Import

8.2.2.1 Subtidal with Native Submerged Aquatic Vegetation (SAV) Planting

Breaching open water areas to allow full tidal exchange would create subtidal open water habitats. If fill material is imported and open water areas are not excavated to provide on-site borrow, the existing elevations of the open water areas (approximately -10 to -3 ft NGVD) will provide shallow subtidal habitat (less than approximately 8 to 12 feet below MTL). Native SAV species such as pondweed could possibly be pre-established in open water areas by planting and gradually inundating shallow subtidal areas prior to breaching. Native SAV is expected to provide desirable habitat for the benefit of native fish and invertebrates within the first few years of establishment. The pre-establishment of native SAV may provide competition to minimize establishment of non-native SAV; however, on-going management would likely be required to control for non-native SAV. This experimental approach has not been tested previously. It may first be tested on a small-scale through an adaptive management approach prior to large-scale application. Without planting to pre-establish native species, shallow open water areas are expected to be invaded by non-native FAV (*i.e.*, water hyacinth) and SAV (*e.g.*, *Egeria densa*) within a few years of breaching.

Optimal depths for planting native SAV are expected to range from -3.5 to -1.5 ft NGVD (-5 to -3 feet MTL) and to depend on light penetration (L. Anderson, USDA, pers. comm.). As an alternative option to planting, natural recruitment of native SAV may be possible if non-native SAV is removed and controlled for and if a seed bank of native SAV exists within the vicinity of the project (L. Anderson, USDA, pers. comm.).

Management costs for controlling invasive SAV and FAV are expected to range from approximately $500 to $1,000 per acre per year to initially establish native SAV (L. Anderson, USDA, pers. comm.). If the initial, more intensive management is successful in keeping out the invasive species, management costs could drop to as low as $150 per acre per year.

8.2.2.2 Deep Subtidal

If fill material is borrowed from the open water areas, they may be excavated to a depth of up to approximately -10 to -12 ft NGVD (11.5 to 13.5 feet below MTL). Subtidal open water areas below -10.5 ft NGVD (-12 feet MTL) are not expected to support SAV due to limited sunlight. Areas of deep subtidal open water breached to tidal action would not be suitable for planting native SAV and may not be invaded by non-native SAV.

8.2.2.3 Skeletal Channel Network

A “skeletal” tidal channel network could be created within subtidal open water areas by constructing a network of vegetated channel banks with fill material. This experimental concept, which has not been tested previously, was suggested by the AMWG and is depicted in Figure 15. In high marsh habitat, native fish are expected to primarily use the channel bank and marshplain a short distance from the channel. Creating a skeletal tidal channel network may provide some of these benefits while avoiding the need to fill the entire marsh area.

Tidal channel banks would be constructed to an elevation of up to 3.2 ft NGVD (MHHW). The width of marshplain adjacent to the channel bank would be sufficient to provide habitat functions and fill stability.

A sinuous and branching tidal channel network similar to natural marshes would be constructed. Subtidal areas surrounding the skeletal network would drain through separate breaches. The subtidal areas would be expected to be invaded with non-native SAV and FAV, if these species are not controlled. Some tidal exchange between the skeletal channel network and subtidal areas would occur during overmarsh tides and possibly through the ends of the channel network. The cost, construction feasibility, and long-term sustainability of a skeletal channel network have not been assessed. Analysis of the feasibility and sustainability would be necessary in future design phases.

8.2.2.4 Managed Pond

In managed non-tidal open water ponds, water levels would be managed with control structures to provide waterfowl or shorebird habitat. Topographic high points in managed pond areas would become islands, which are expected to provide loafing and resting habitat for waterfowl species. Managed ponds may also provide habitat for large raptors and the Western pond turtle, depending on factors such as the depth and size of the ponds and the availability of basking sites and adjacent suitable soil for nesting. Fish assemblages in the ponds, if any develop, would not be very species rich, unless freshwater species are unintentionally introduced by artificial means.

This option would require on-going management of water control structures and levee maintenance. Managed ponds are not expected to be compatible with on-site borrow because deep ponds will not be desirable avian habitat and it may not be feasible to manage for shallow water levels in deep borrow areas. A higher berm will be necessary to prevent high tide overtopping areas into the managed ponds from adjacent restored marsh areas.

8.2.2.5 Subsidence Reversal Through Biomass Accumulation

Non-tidal managed marshes could be created and managed to raise subsided ground to marshplain elevations through either biomass accretion and/or the use of rice straw. Tules could be planted and grown through flood irrigation to accumulate organic matter (biomass). Once the accumulated biomass reaches marshplain elevations, the areas may be breached to create a tidal marsh. Subsidence reversal through biomass accretion is being tested in a USGS demonstration project at Twitchell Island. The use of rice straw is being evaluated in a separate CALFED-funded project with DWR involvement. For the Dutch Slough restoration project, these experimental subsidence reversal techniques may be tested through adaptive management on a small-scale prior to large-scale application. Subsidence reversal areas may be sub-divided with berms to allow for internal gravity drainage. Subsidence reversal techniques are expected to require active management for a number of years before the managed areas can be breached.

8.3 FEASIBILITY ASSESSMENT

This section assesses the feasibility of Alternative 2 with respect to tidal circulation, flood hazards, groundwater seepage, infrastructure protection, water quality, and vector control. The feasibility assessment addresses the implementation commitments and other potential constraints to tidal marsh restoration.

8.3.1 Tidal Circulation

Full tidal drainage in restored marsh areas is important for restored tidal marsh function at Dutch Slough. If significant tidal damping occurs, low marsh vegetation may be stressed due to water-logging. Tidal damping is a decrease in tidal range at a given location due to frictional losses as the tide travels to this location. Tidal damping occurs to a small degree in natural marshes due to the upstream dissipation of tidal energy in natural tidal channel systems and over-marsh flow. Damping may be more pronounced in restored marshes if conveyance from the tidal source is constricted.

With full tidal drainage at the Dutch Slough restoration site, the depth and frequency of tidal inundation are expected to be approximately the same for all marsh areas breached to Little Dutch Slough, which will facilitate comparison for adaptive management experiments. The existing drainage culvert and road crossing in Little Dutch Slough will be removed to provide unrestricted tidal drainage and fish access to the large mid marsh area on the Burroughs parcel in Alternative 2. Full tidal drainage is also important to avoid potential drainage impacts to the area south of the Dutch Slough project, which drains to Little Dutch Slough and Emerson Slough.

PWA assessed the potential for tidal damping in Little Dutch Slough for Alternative 2 using hydraulic modeling (MIKE11), which is documented in Appendix H. Model results indicate that Little Dutch Slough is undersized compared to the restored tidal prism from open water and marsh areas. Limited conveyance in Little Dutch Slough is expected to result in initial short-term tidal damping, unless Little Dutch Slough is dredged or until tidal scouring enlarges the slough. With the existing channel dimensions, initial tidal damping may lower high tide water levels and elevate low tide water levels by approximately 0.7 feet on average, with damping on the low tides ranging from approximately 0.3 to 1.3 feet. Low tide damping would likely stress low marsh vegetation and impede drainage into Little Dutch Slough. If the open water areas on the Gilbert and Burroughs parcels are managed (*i.e.*, non-tidal), model results indicate that initial tidal damping may still occur, but to a lesser degree than if the open water areas are tidal.

To achieve full tidal drainage, Little Dutch Slough will need to be enlarged, either by dredging or allowing the channel to scour in response to the restored tidal flows. PWA modeled scenarios to assess the effect of enlarging Little Dutch Slough. Based on model results, enlarging the wider downstream (northern) reach of Little Dutch Slough is expected to allow full tidal drainage in marshes draining to this reach and improve tidal drainage in marshes draining to the narrow upstream (southern) portion of Little Dutch Slough. Additional enlargement of the narrow upstream (southern) portion of Little Dutch Slough is expected to be necessary to achieve full tidal drainage in marshes draining to this reach.

At other restored tidal marshes where initial tidal damping occurred due to the constriction of tidal flows through an undersized channel, monitoring results showed that restored tidal flows scoured and enlarged the undersized channel over time (Williams and others, 2002). At these sites, channel scour increased conveyance of tidal flows and improved tidal drainage, offsetting the temporary initial tidal damping. Based on these results, Little Dutch Slough is expected to scour and enlarge over time, eventually allowing for adequate tidal drainage.

The expectation that Little Dutch Slough has the potential to scour is supported by predictions of equilibrium channel dimensions from hydraulic geometry relationships and modeled flow velocities (see Appendix H). PWA has developed hydraulic geometry relationships that are regressions between marsh area or tidal prism and channel dimensions for mature marshes (Williams and others 2002, Simenstad and others 2000). These relationships provide a geomorphic design tool to assess the potential for tidal channel scour. For Little Dutch Slough, channel dimensions predicted to be in equilibrium with the potential restored tidal prism are larger than existing channel dimensions. This indicates the potential for Little Dutch Slough to scour.

Hydraulic modeling results show that restored tidal flow velocities in Little Dutch Slough are higher than velocities modeled for existing conditions and are within the range of scouring velocities. The peak velocities modeled for initial damped conditions in the wider downstream reach of Little Dutch Slough are approximately 2 ft/s on a typical tide cycle, which is within the range of threshold velocities for erosion available in the literature (approximately 1 to 4 ft/s, Delft 1989). Actual channel scour will depend on the critical shear stress for erosion of the substrate in Little Dutch Slough, which is not known. Peak modeled velocities for damped conditions in the narrower upstream reach of Little Dutch Slough are approximately 1 ft/s on a typical tide cycle. These results indicate that channel scour in the narrow upstream reach may be delayed. Flow constriction in this undersized reach of the channel and the resulting tidal damping in restored marsh areas may limit velocities and the rate of channel scour for an extended period of time, as observed at Sonoma Baylands (Williams and others 2002).

Dredging the narrow upstream reach of Little Dutch Slough is recommended due to the limited potential for this reach to scour. It may be possible to avoid dredging the wider downstream reach of Little Dutch Slough by allowing this reach to scour. Monitoring experience from similar restoration projects in San Francisco Bay suggests that channel scour may occur within several years after breaching (Williams and others 2002). Further assessment of the rate of channel scour and the resilience of low marsh vegetation to partial drainage is recommended in future design phases to assess whether or not it is necessary to dredge the entire length of Little Dutch Slough. For the purpose of the cost estimate, it is assumed that only the narrow upstream portion of Little Dutch Slough will be dredged.

If the open water area on the Emerson parcel is managed (*i.e.*, non-tidal), Alternative 2 is not expected to change tidal drainage in Emerson Slough because restored marsh areas will not be breached to this slough. If the open water area on the Emerson parcel is breached to Emerson Slough, further study of the potential for tidal damping and channel scour is recommended to assess the potential to impede drainage through the culverts at the upstream end of Emerson Slough.

8.3.2 Flood Hazards

8.3.2.1 New East Levee

A new levee will be constructed along the east boundary of the Burroughs parcel to provide flood protection for areas to the east once the parcel is restored. The new levee will be located immediately west of Jersey Island Road and the PG&E easement for on-site power and gas transmission lines (Figure 2). The new levee will also be constructed around the inholding for a private house and easement for the privately-operated active gas well along Jersey Island.

The new levee will provide "in-kind" replacement of the existing levee that currently surrounds the Burroughs parcel along Dutch Slough and Little Dutch Slough. The new in-kind replacement of the existing levee will not change flood protection for the Hotchkiss Tract, which is subject to flooding from the north along Dutch Slough (FEMA, 1987). It is assumed that upgrading the levee to FEMA urban levee standards to protect the proposed development on the Hotchkiss tract will not be the responsibility of the Dutch Slough project. The new levee could be constructed to FEMA urban levee standards or upgraded to these standards after construction through cost-sharing with the responsible parties.

Hultgren-Tillis Engineers developed conceptual criteria for a new in-kind levee replacement, upgrade from the in-kind levee to a FEMA urban levee, and a FEMA urban levee, which are detailed in Appendix F-1. For the purpose of the cost estimate, it is assumed that a new in-kind levee replacement will be constructed with a crest elevation of 9 ft NGVD, a minimum crest width of 16 feet, a waterside slope of 2:1, and a landside slope of 3:1 (Figure 16). The existing levee around the Burroughs parcel range in elevation from 8.8 to 10.5 ft NGVD.

Slope protection on the waterside of the new levee could consist of either biotechnical or rock slope protection. Although biotechnical protection is preferred, rock slope protection is assumed for cost estimating purposes at the conceptual planning stage. We anticipate that biotechnical slope protection can be provided at an equal or lesser cost. Biotechnical slope protection may require using a more gradual slope or constructing a wide levee bench, which is not included in the cost estimate.

The new levee would be constructed of lean clay, which could be imported or excavated from onsite (see Section 8.4). Peat will need to be excavated from beneath the planned levee alignment to expose the underlying sand or stiff clay soils. As peat soils may underlay the existing Dutch Slough levee (to remain), a transition section of the new levee near its connection with the existing levee will likely have wide berms to maintain stability of the new section and to aid in controlling levee settlement induced by lateral creep.

8.3.2.2 Southern Site Boundary

The Contra Costa Canal and the City of Oakley's planned Dutch Slough Community Park border the Dutch Slough project to the south. Residential developments are planned for the area to the south of the

Contra Costa Canal. The existing agricultural levees around the Dutch Slough site provide some measure of flood protection for areas to the south; however, these levees are not expected to protect against the 100-year flood, according to FEMA (1987). Restoring the Dutch Slough site to tidal action will move the existing line of flood defense provided by levees (less than 100-year) to the existing and restored uplands along the southern site boundary. The uplands will be at the same or higher elevations than the existing levees.

The restoration is expected to have only a small effect on flood hazards, if any, because measures to protect against the existing flood hazard are being planned for areas to the south of the project site. The project will coordinate with other ongoing flood protection planning in progress for areas south of the Dutch Slough site.

Contra Costa Canal. The Contra Costa Canal is an open canal surrounded by earth embankments. The embankments are above the 100-year flood elevation and, though they were not designed as flood protection levees, FEMA (1987) shows the embankments as providing 100-year flood protection for areas south of the Dutch Slough project. Topographic data, however, indicate that there are gaps in the embankments located at the heads of Emerson Slough and Little Dutch Slough, where the canal is siphoned through underground pipes. Flooding of the area to the south of the canal could occur through the gaps in the embankments.

The Contra Costa Water District plans to encase the Contra Costa Canal in a pipe (D. Briggs, CCWD, pers. comm.). The pipe will be installed and buried in the existing canal and the canal embankments will be re-graded. With the encasement of the canal in a pipe, any potential increase in flood hazards for the canal due to the Dutch Slough project are not expected to be a concern.

In the event that the Contra Costa Canal is not encased in a pipe at the time the Dutch Slough restoration project is implemented, the project will need to consider the potential effects of flooding the canal embankment. The Dutch Slough restoration project will remove the existing flood storage provided by the Dutch Slough site. However, restored marsh and upland areas are expected to protect the canal embankments from potential wave runup and erosion during extreme flood events in which the Dutch Slough site would be flooded. The net effect on flood potential has not been assessed in detail, but is expected to be small. Any increase in flood potential could be offset by raising the elevation of uplands along the southern boundary of the Dutch Slough site. Additional study would be required to identify and design any mitigation features.

Planned residential developments to the south. Residential developments are planned for the area south of the project and north of Cypress Road. In 2005, a new flood control levee was built south of the Contra Costa Canal to provide 100-year flood protection for one of the developments south of the Emerson parcel (Cypress Grove). Other developments south of the Dutch Slough site (Dutch Slough Properties) will construct similar levee systems to provide 100-year flood protection (City of Oakley, 2005). This new system of flood control levees will address any potential increase in flood hazards due to the Dutch Slough restoration project. In the event that the flood control levees and residential developments are not constructed at the time the Dutch Slough restoration project is implemented, the project will need to consider potential mitigation features, as discussed above for the Contra Costa Canal.

Dutch Slough Community Park. Further coordination with the City of Oakley is recommended to determine the level of flood protection required for the Dutch Slough Community Park, which is being planned by the City as part of the Dutch Slough project. Low elevation areas of the Dutch Slough site surrounding the park will be raised to restore upland habitats. These areas could be designed to provide the desired level of flood protection for the park in future design phases. The cost estimate assumes that these areas will be raised to elevations that will provide 100-year flood protection. We understand that buffers may be built as part of the Park project (P. Miller, 2M Associates, pers. comm.), which could also be designed to provide flood protection.

8.3.2.3 Marsh Creek

The levee along the west side of Marsh Creek provides flood protection for the Ironhouse Sanitary District's property to the west of the Dutch Slough restoration site. The restoration project is not expected to effect this levee or flood protection for this property. The levee along the east side of Marsh Creek, adjacent to the Emerson parcel, will not be needed for flood protection once the Emerson parcel is restored to tidal marsh. However, the eastern Marsh Creek levee will be retained to provide access to Ironhouse Sanitary District's pipeline and a public trail.

8.3.3 Groundwater Seepage

As described in the existing conditions section (Section 4.4.3), groundwater levels in the Dutch Slough site are artificially lowered by evapotranspiration and pumping. Restoration of tidal inundation will recharge the groundwater aquifer beneath the site, raising groundwater levels. The elevation of groundwater beneath the project site is expected to average approximately MTL (1.5 ft NGVD) and fluctuate with the tides. In the absence of appropriate control measures, increases in groundwater beneath the restoration site have the potential to cause groundwater to flow laterally through the aquifer from the project area outward to adjacent properties, raising groundwater elevations for those properties. Generally, groundwater levels can affect vegetation survival, septic tank operations, below-ground dampness in residential properties, and seepage into buried utilities such as sewer lines. Control measures must be included in the restoration plan to minimize the effects of potential groundwater increases on adjacent properties. This section summarizes the groundwater seepage assessment performed by Hultgren-Tillis Engineers. Additional detail is presented in Appendix F-1.

8.3.3.1 Control Measures

The two common approaches to controlling groundwater seepage are described below. These primarily passive systems for controlling groundwater are preferred over actively pumping individual wells because they require less costly operation and maintenance.

Cut-off wall. A cut-off is a barrier used to stop groundwater flow from leaving an area. Cut-off walls need to fully penetrate the aquifer. A common approach for constructing deep cut-off walls is to excavate and backfill a slurry trench. A cut-off wall is expected to be a viable method of controlling groundwater seepage for the Dutch Slough project, however further site-specific assessments of groundwater flow and aquifer depths are necessary.

Collection system. A groundwater collection system is intended to artificially lower the groundwater at or near the boundary between the two properties to control the elevation of the groundwater leaving the site and entering a neighbor's property. Methods for collecting groundwater include ditches, subdrains, and relief wells. Excavated collection ditches are commonly seen at or near the toes of levees in the western Delta. To be effective, the ditches need to extend through the peat and/or clay overburden and into the sand aquifer. Collection ditches require routine maintenance. Some pumping is generally required to "lift" the collected groundwater to a discharge point, which can typically be accommodated by surface water drainage systems for low lying areas.

8.3.3.2 Potential Project Effects

The potential effects of the restoration project on groundwater seepage were assessed by analyzing available topographic, soil, and groundwater data (see Appendix F-1). The assessment considers potential effects to adjacent properties: Jersey Island to the north, the Ironhouse Sanitary District's property to the west, land proposed for development to the south along Cypress Road (Cypress Grove and Dutch Slough Properties), and the Hotchkiss tract to the east.

Jersey Island. The Ironhouse Sanitary District currently irrigates Jersey Island with treated effluent, a practice that is sensitive to groundwater elevations. However, the Ironhouse Sanitary District has proposed to modify their water treatment operations on Jersey Island such that treatment will not rely on groundwater infiltration (J. Cain, NHI, pers. comm.). With the modified water treatment operations in place, Ironhouse Sanitary District operations on Jersey Island should not be affected by the Dutch Slough restoration project.

In the event that the modified treatment operations are not in place at the time the Dutch Slough restoration project is implemented, the project will need to consider the potential effects of groundwater seepage on Jersey Island. Based on the groundwater assessment, these potential effects are expected to be small. Existing data suggest that the sand aquifer may be continuous beneath Dutch Slough between the Dutch Slough project site and Jersey Island. However, seepage onto Jersey Island is currently dominated by infiltration from the Dutch Slough channel. Infiltration from the Dutch Slough restoration project will likely create only a small increase in seepage to Jersey Island. Monitoring of groundwater elevations on Jersey Island are recommended to check whether, or to what extent, increased seepage occurs after restoration. The installation of new ditches on Jersey Island, or deepening existing ditches, would likely mitigate any increased seepage. Disposal of the seepage water may create a small added load for Ironhouse Sanitary District on Jersey Island.

Ironhouse Sanitary District property to the west of the Dutch Slough site. As at Jersey Island, the Ironhouse Sanitary District currently irrigates their property west of the Dutch Slough site with treated effluent, but proposes to modify their future water treatment operations such that treatment will not rely on groundwater infiltration (J. Cain, NHI, pers. comm.). The Ironhouse Sanitary District proposes the Marsh Creek Delta Restoration Project for a portion of the land immediately west of Marsh Creek (Appendix J; J. Cain, NHI, pers. comm.). This project is related to the Dutch Slough project and plans to restore tidal marsh. With the modified water treatment operations and the Marsh Creek Delta Restoration in place, Ironhouse Sanitary District operations on their property west of the Dutch Slough site should not be affected by the Dutch Slough restoration project.

In the event that the modified treatment operations are not in place at the time the Dutch Slough restoration project is implemented, the project will need to consider the potential effects of groundwater seepage on the Ironhouse Sanitary District's operations. Based on the groundwater assessment, these potential effects on are expected to be small under most conditions. The existing Marsh Creek channel is likely creating a partial recharge and drainage boundary condition between the Ironhouse property and the Dutch Slough project site. The existing ground elevation of the Ironhouse property is approximately 5 ft NGVD and coring data indicate that groundwater elevations are generally near MTL (1.5 ft NGVD). Restoring the Dutch Slough project site is expected to increase the amplitude of tidally driven variations in groundwater levels beneath the Ironhouse property, making high groundwater levels higher and low groundwater levels lower, and increase groundwater levels during floods and tide surges. During brief periods of high Delta water levels, on the order of a few days, net seepage increases are expected. Adding water load from groundwater seepage during these times would likely be undesirable for Ironhouse Sanitary District because the property is already fully committed to the irrigation of treated effluent. The quantities of groundwater seepage, however, are expected to be small relative to the Ironhouse Sanitary District's irrigation capacity.

Residential properties to the south. The Dutch Slough restoration has the potential to increase groundwater seepage onto the planned residential properties to the south, along Cypress Road. Groundwater levels in this area range from slightly above MTL to about 4 feet below MTL. The Contra Costa Canal is an unlined channel and infiltration from the canal is locally recharging groundwater in the planned residential areas. In areas where ground water levels are low, seepage from the restored Dutch Slough project site has the potential to raise groundwater by several feet to near MTL. Higher groundwater levels could affect dampness around buildings as well as the success of various types of landscaping. This will be a particular concern if the houses are constructed in low-lying areas, at or below MTL. Proposed construction grades for the new residential developments are not known.

Further coordination with the County and/or developers is recommended to develop a plan for controlling the potential increase in groundwater seepage to the south of the Dutch Slough project. The preferred approach may be to integrate measures to control seepage from the Dutch Slough project with the control system that the development will require to deal with existing seepage. Possible measures could include a collection ditch, relief wells, or a cut-off wall (slurry trench).

Contra Costa Canal. As noted above, the Contra Costa Canal is currently unlined, with infiltration from the canal locally recharging groundwater in adjacent areas. The Contra Costa Water District (CCWD) plans to replace segment of the canal adjacent to the restoration site with an enclosed pipe (D. Briggs, CCWD, pers. comm.) (see Section 8.3.2.2). The pipe would isolate the CCWD water from adjacent groundwater, such that any groundwater changes associated with any restoration seepage would not affect water conveyance operations.

In the event that the proposed pipe line is not in place at the time the Dutch Slough restoration project is implemented, the project will need to consider the potential effects of groundwater seepage on the Contra Costa Canal. With the restoration project, daily variations in groundwater levels may increase in amplitude and net seepage may increase during floods and tide surges. This could affect the quality of the water and result in increased maintenance in the canal.

Further coordination with the CCWD is recommended to integrate or develop plans for controlling the potential increase in groundwater seepage to the south of the Dutch Slough project. If the canal remains an unlined channel, possible measures could include a collection ditch, relief wells, or a cut-off wall (slurry trench).

Hotchkiss Tract. The Dutch Slough project will include measures to control groundwater seepage onto the Hotchkiss tract to the east of the restoration project, across Jersey Island Road. Seepage control measures will be incorporated with the design of the new east levee along Jersey Island Road. A cut-off wall (slurry trench) through the aquifer is proposed for controlling groundwater seepage from the project site. A drainage ditch could also be installed beyond the toe of the new flood control levee, requiring some pumping and maintenance. Alternatively, measures to control groundwater seepage from the Dutch Slough restoration project could be integrated with the seepage control system for the Hotchkiss tract development. Without control measures, groundwater seepage is expected to occur from the restoration project toward the low ground area across Jersey Island Road.

The implementation of groundwater seepage control measures for the Dutch Slough project could potentially lower groundwater levels in adjacent properties. While the previous discussion has focused on the potential effects of raising groundwater elevations, lowering groundwater elevations can have effects as well. Lowering groundwater in any remaining peat areas in the Hotchkiss tract may cause peat consolidation and ground surface subsidence. A more detailed evaluation of this area will be needed for preliminary design.

8.3.4 Infrastructure Protection

8.3.4.1 Ironhouse Sanitary District Pipeline

The Ironhouse Sanitary District's pipeline will be relocated from the toe of the levee between the Emerson parcel and Marsh Creek (Marsh Creek levee) to near the top of the Marsh Creek levee (Figure 14). The existing alignment of the pipeline is shown in Figure 2. The pipeline is currently buried in the

Emerson parcel just beyond the toe of the Marsh Creek levee. As this area will be restored to tidal marsh, a new pipeline will be installed in the top of the levee to preserve access for service and maintenance. The top of the levee will be lined with gravel to provide an all-weather access road. The existing top width and elevation of the Marsh Creek levee (approximately 20 feet and 11 ft NGVD, respectively) will be adequate for access requirements. The new pipeline will be buried two feet below the top of the levee. The new pipeline will be installed with flexible joints to prevent potential shearing of the pipeline due to levee settlement. As the Marsh Creek levee has existed for some time, the amount of settlement is expected to be small. The existing pipeline will be removed or abandoned once it is replaced by the new pipeline.

The eastern side slope of the Marsh Creek levee adjacent to the Emerson parcel will be protected to reduce levee scour and to protect the Ironhouse pipeline. Further coordination with Contra Costa County Flood Control District (CCCFCD) is recommended to determine if it is possible to protect the Marsh Creek levee slope using biotechnical approaches, such as planting riparian woodland or native grasses on the slope. Alternative slope protection measures may include erosion control fabric or rip rap. However, biotechnical approaches that provide habitat are preferred.

This plan assumes that the CCCFCD will allow the pipeline to be relocated into their levee. Further coordination with the CCCFCD is recommended to confirm this plan. This portion of the levee will no longer provide flood control as the Emerson parcel will be restored to tidal action.

8.3.4.2 Power and Gas Facilities

The alignment of the new east levee on the Burroughs parcel will protect and preserve access to PG&E's electric transmission line, high pressure gas line, and gas gathering line. These PG&E lines all cross the northeast corner of the Burroughs parcel, which will not be restored to tidal marsh. The new levee will be located immediately west of the easement for PG&E's electric transmission line and will preserve the existing level of flood protection for the area northeast of the new levee. The new levee will also protect the two privately-operated active gas wells along Jersey Island Road (Figure 2). The remaining privately-operated inactive gas wells on the three parcels must be plugged and abandoned by the owners of the gas wells (Marquez Energy) on or before July 1, 2008, per the land sale agreement.

Further coordination with the PG&E is recommended to develop a plan and costs for moving or decommissioning PG&E's gas distribution lines and power distribution lines, equipment, and transformers.

8.3.5 Preliminary Water Quality Assessment

Brown & Caldwell prepared a technical assessment of potential water and sediment quality concerns related to dissolved organic carbon (DOC), mercury, diverting Marsh Creek onto the Emerson parcel, and onsite soils. The assessment used available existing data to identify potential onsite, watershed, and tidal sources of contaminants and to calculate preliminary loads that could be delivered to the Dutch Slough site. Additional data needs to be obtained to reduce the uncertainty regarding these preliminary import load calculations and to predict export loads that could be expected from the restoration project. The water and sediment quality assessment is documented in a technical memorandum in Appendix C-1 and is summarized here. The Dutch Slough Water and Sediment Quality Monitoring Plan (Appendix C-2) identifies monitoring station locations, sampling frequency, and sampling methods to develop more robust baseline water and sediment quality conditions, assess project implementation, and provide data necessary to adaptively manage the Dutch Slough site.

The potential for wetlands to increase organic carbon production and mercury methylation are regional issues for Delta wetland restoration. Knowledge of the processes and factors driving the production, fate, and transport of these constituents is a developing science. There are ongoing and proposed studies and monitoring programs to learn more about these processes and factors, which may provide useful information in both predicting export water quality from wetlands as well as in designing a wetland to minimize export of organic carbon and methylmercury (MeHg).

8.3.5.1 Dissolved Organic Carbon (DOC)

Organic carbon, while generally good for ecosystem productivity, is a concern in the Delta because it can negatively affect drinking water quality. The restored wetlands at Dutch Slough have the potential to generate and export DOC (Bergamaschi and others, 2003). If DOC levels are too high, water treatment facilities that use source waters from the Delta may not be able to meet drinking water regulatory standards.

DOC is a disinfection byproduct precursor for methods used to treat drinking water taken from the Delta (American Water Works Association, 1999). Disinfection byproducts form during water disinfection when chlorine reacts with certain organic materials to create trihalomethanes, including chloroform in particular. Toxicological studies undertaken on chloroform suggested that it was carcinogenic to laboratory animals, although at levels much higher than those found in drinking water.

The results of the preliminary assessment, based on limited available data, suggest that the restoration may increase the amount of organic carbon in the vicinity of the drinking water intakes and may exceed the CALFED record of decision target of 3.0 mg/l at the source. A more detailed assessment of mixing and transport processes using regional hydrodynamic and DOC transport modeling could be used to refine these results. There are limited data on DOC generation, especially as compared to other land uses (such as agriculture and urban development). The project will provide valuable information by monitoring DOC. As part of the Dutch Slough adaptive management plan, small-scale adaptive management experiments may be designed to test the potential for different restoration approaches to reduce DOC export from the site.

8.3.5.2 Mercury

Mercury is a prominent water quality contaminant within the Bay-Delta. Wetlands are known to convert mercury into methylmercury (MeHg) (Marvin DiPasquale and others, 2003), which is a bioavailable form that can accumulate in the food chain and adversely affect the health and fitness of fish and birds. Elevated MeHg levels in fish can also result in mercury exposure in humans who consume contaminated fish (National Research Council Committee on the Toxicological Effects of Methylmercury, 2000).

The study of mercury methylation in wetlands is an emerging, complex science. Based on our assessment of the limited available data on mercury methylation for Delta wetlands (Appendix C-1), it is not possible to conclude whether the restoration will be a net source or net sink of MeHg. It is also not possible to characterize with a high degree of certainty the relative contribution of mercury to the site from local (Marsh Creek) or regional (Delta) sources.

Currently there are limited aqueous mercury data available for Marsh Creek. One sample was collected in lower Marsh Creek during high flow of March 1995 for analysis of total mercury, dissolved mercury, and mercury adsorbed to suspended solids (Slotton and others, 1996; Slotton and others, 1998). If the suspended load concentrations sampled during March 1995 were representative, a local watershed source of mercury would be present for the production of MeHg. However, the concentrations and loads from this one sampling event are not representative of seasonal and annual variations. Due to the limited available data, no significant conclusions can be drawn regarding mercury in Marsh Creek.

Additional data and scientific studies are necessary to predict import and export loads that could be expected from project implementation. Data collection methods proposed as part of the Dutch Slough restoration are described in the Dutch Slough Water and Sediment Quality Monitoring Plan (Appendix C-2).

8.3.5.3 Potential Marsh Creek Diversion

Diverting Marsh Creek onto the Emerson parcel to restore a natural creek delta could benefit ecological diversity, but it also has the potential to adversely affect the restored habitat by introducing mercury (discussed above) and urban runoff and wastewater treatment effluent pollutants onto the site. The water and sediment quality assessment evaluated potential water and sediment issues associated with the Marsh Creek diversion. The assessment concluded that diversion of Marsh Creek should remain an option in the design until additional data and information can be collected to more accurately assess the import and export water quality associated with the proposed Dutch Slough tidal wetland (Appendix C-2).

In general, wetlands function to filter pollutants, particularly for constituents such as nutrients, metals, biological oxygen demand, total suspended solids, and some pathogens. Diverting Marsh Creek may improve downstream water quality for typical urban runoff pollutants at the expense of accumulating pollutants in the restored habitat.

The wastewater treatment plant effluent could be a source of endocrine disrupting chemicals and pharmaceuticals and personal care products. Endocrine disruptors are exogenous compounds that alter the synthesis, secretion, transport, binding, action, or elimination of natural hormones in organisms that maintain homeostasis, reproduction, development, and/or behavior (EPA, 1997). Currently there are not any Marsh Creek data available for these chemicals; however, the concerns they present should be considered given the location of the Brentwood Waste Water Treatment Plant on Marsh Creek.

Urban and agricultural runoff present additional concerns during dry weather months. The low flows during dry weather periods may become concentrated with pollutants from runoff and other discharges. At times, creeks in urban areas are subjected to illegal discharges (such as water containing oil/grease, solvents, cleaning chemicals, pesticides, and chlorinated water from swimming pools). During low flow periods, there is less water available in the creek to dilute these constituents, which may create a risk to the receiving ecosystem. This will be less of a concern in parts of the Marsh Creek channel that are well-mixed with tide waters from the Delta.

The proposed sampling design in the Dutch Slough Water and Sediment Quality Monitoring Plan includes recommendations for additional water sampling to better define the water quality of Marsh Creek (Appendix C-2). The sampling design also includes analysis of metals to assess possible toxicity to aquatic organisms.

8.3.5.4 Onsite Soil Quality

Potential sources of onsite soil contamination that could affect the quality of the restored wetland include legacy mercury deposited by Marsh Creek, hydrocarbons, and barium, though there is insufficient information to confirm the presence of any of these potential sources on the site. Data showing concentrations of constituents of concern in on-site sediments are not available. High levels of nitrates from the dairy operations are not anticipated to be a significant problem for the restoration, since wetlands can usually take up nitrates at relatively high levels. The Dutch Slough Water and Sediment Quality Monitoring Plan (Appendix C-2) describes a soil and source sediment sampling design and analysis that will provide information that is necessary for the re-use of dredged or excavated material and a better understanding of background concentrations of mercury in soils.

8.3.6 Delta Salinity

The Dutch Slough restoration project could potentially cause small increases in salinities in the Delta by increasing tidal flows from the Bay. Increased Delta salinities could negatively impact the quality of water diverted from the Delta for drinking and irrigation. The analysis of the potential to increase Delta salinities was outside the scope of this study. The project will model tidal flows and salinities in the Delta during future design phases to assess this potential impact.

8.3.7 Vector Control

Members of the Dutch Slough project management team and PWA met with representatives of the Contra Costa Mosquito and Vector Control District (CCMVCD) to discuss methods for minimizing mosquito production with the proposed restoration. Mosquitoes pose a nuisance to residents of urban areas and certain types of mosquitoes are vectors for the West Nile Virus. Different types of land use (agricultural, urban, wetland) pose different risks for mosquito production. Tidal wetlands can generally be readily designed and managed to pose a low risk of mosquito production. Managed wetlands – such as the proposed subsidence reversal experiments and other types of managed open water treatments – require additional design features and management.

There are two basic approaches to minimizing mosquito production: (1) avoiding the creation of mosquito habitat and (2) spraying pesticides. The first approach is preferable and has been incorporated into the design as possible. The primary mosquito habitat of concern is shallow, stagnant, standing water. Deeper water (which supports mosquito-eating fish), waves, and currents will deter mosquito production. Spraying is used as a back-up measure, and requires land access for CCMVCD vehicles.

Tidal restoration generally does not create mosquito habitat, since tidal areas flood and drain on a twice-daily cycle (no standing water). CCMVCD staff monitor the adjacent Big Break tidal wetland and generally find conditions to be acceptable at that location (K. Malamud-Roam, CCMVD, pers. comm.). Sometimes poorly drained areas along the upper edge of a tidal wetland can pond water for up to two weeks between high tide cycles. At the suggestion of the CCMVCD, the upper edge of the Dutch Slough wetlands will be graded with a moderate to steep slope (greater than or equal to 0.5%) to allow for good drainage. In addition, the upland edge will be checked periodically as part of ongoing maintenance to remove any obstacles to drainage, such as build up of debris (*e.g.*, woody debris, rack). The CCMVCD had no objection to the channel drainage density proposed at Dutch Slough (modeled on a natural wetland drainage density) and noted their preference for a drainage density on the high end of the natural range.

The managed wetland (non-tidal) areas of the site will require additional design features and management. Of concern are shallow continuously-ponded areas, particularly those with dense vegetation. Vegetation dampens wave energy and limits access by mosquito-eating fish. To limit mosquito production, the project will use a steeper slope around the edge of the managed water areas, design for rapid drainage on an as needed basis (if possible), and allow access for spraying. Note that the need for spraying in managed pond areas may affect adaptive management experiments and will need to be taken into account in the experimental design.

8.4 PLANNING-LEVEL CONSTRUCTION METHODS, VOLUMES AND COSTS

8.4.1 Uncertainties

The conceptual plan described in this report will be refined in future design phases after refinement of design objectives, gathering geotechnical and additional topographic data, and further design development. Design refinements may result in lower quantities and costs.

Formal investigation of geotechnical conditions will be required for subsequent design phases. For this estimate, geotechnical conditions are based on limited available data and the assumption that conditions are consistent with other diked, subsided former freshwater marsh sites in the Delta. No formal assessment of the suitability of on-site soils for use as engineered levee fill has been made to date. For the purpose of the cost estimate, it is assumed fill for levee construction will need to be imported. Geotechnical exploration will be required to evaluate whether on-site soils are suitable for levee construction.

Refined topographic data (ground surveys) will also be required in subsequent design phases. Photogrammetry and limited ground surveys were used to estimate site topography in this study. Photogrammetry uses assumed vegetation heights to estimate elevations in vegetated areas and is less accurate than ground surveys. A limited ground survey consisting of one transect through the Emerson parcel was performed for this study to ground truth the photogrammetry (Appendix B). If more detailed topographic surveys in subsequent design phases indicate substantial differences from the topography used here, the costs of construction may differ significantly from this estimate.

Planting costs can vary substantially and estimated costs and assumptions are preliminary and subject to refinement with additional site investigation and information.

8.4.2 Assumptions

Planning-level quantities and costs estimates for Alternative 2 are presented in Table 6. Appendix I provides a summary of assumptions for volume calculations and breakdowns of volumes and costs by parcel. The cost estimate is intended to provide an approximation of total project costs based on the conceptual level of design. The cost estimate has an approximate accuracy of -30% to +50%. The estimated costs should be refined and updated as the design is developed in current and future stages of the project.

Table 6 provides estimated costs for permitting, design, and construction. Ongoing costs for site maintenance and project performance monitoring (for environmental compliance) are also included. The following items are not included in the estimated costs for the reasons discussed in the cited report sections:

- Obtaining and transporting imported fill material to the site (see Section 8.4.3);

- The option of excavating additional onsite fill material (onsite borrow) to construct the new east levee, rather than importing fill material (see Section 8.4.4);
- Small-scale adaptive management experiments (see Section 6.2.2);
- Marsh Creek delta restoration (see Section 8.2.1);
- Open water management options (see Section 8.2.2),
- Dredging the wider downstream reach of Little Dutch Slough (see Section 8.3.1);
- Flood control and groundwater seepage control measures that may be needed for low-lying areas to the south of the project site (see Sections 8.3.2.2 and 8.3.3.2);
- Removal and/or relocation of PG&E power and gas distribution infrastructure (see Section 8.3.4.2);
- Maintenance of public access features, such as trails on the habitat levees, the footbridge over the Emerson parcel breach, and the Marsh Creek levee road (see Section 8.5);
- Monitoring for conducting adaptive management experiments (see Section 8.5).

The above-mentioned items would increase project costs. It is assumed that the cost of monitoring large-scale adaptive management experiments and implementing and conducting small-scale experiments will be funded through individual scientific research initiatives. Further study, coordination, and/or design refinement is needed to assess other costs not included. For the management of open water, all options other than deep subtidal would require additional costs. The preferred open water management options and experiments will be defined in future design phases with input from the AMWG. Costs are presented in 2005 dollars, and will need to be adjusted to account for price escalation for implementation in future years.

The majority of implementation costs for the project are for earthwork activities, such as mass grading to create marsh areas and drainage divides, excavating new channels, and constructing the new east flood control levee. As a result, total project costs are sensitive to assumed earthwork volumes and unit prices for earthmoving costs. It is difficult at this stage to accurately estimate earthwork prices; however, the cost estimate includes reasonable assumptions based on construction experience, consultation with local contractors, and costs for similar projects.

Project costs will vary depending on the source of fill material needed to create marsh areas in the Gilbert and Burroughs parcels. Fill material may be either imported or borrowed onsite, as discussed in Sections 8.4.3 and 8.4.4, respectively. Given the level of uncertainty regarding the source(s) of material and other factors discussed below, we have prepared cost estimates assuming different fill availability scenarios. Given the large volume of fill needed, imported fill material may be cost prohibitive unless it can be obtained and transported to the site at a relatively low cost compared to borrowing soils onsite.

Preliminary earthwork volumes were estimated using available topography and generally assuming no losses between cut and fill volumes. In reality, the volume of excavated material is expected to increase (by bulking) and decrease (due to compaction, transport losses, etc.) during fill placement, but the net change is not expected to be significant. As an exception, more significant volume losses are anticipated for peat soils due to compression, wind erosion and transport losses. In general, peat soils are located in the northern portions of the site. For this reason, we have accounted for 20% losses for subtidal excavation in the northern areas of the Burroughs and Gilbert parcels (see Section 8.4.4 Onsite Borrow).

For cost estimating purposes, "minimum" project costs are estimated based on the scenario that suitable fill material could be obtained and transported to the site at no cost to the Dutch Slough project. (This scenario could occur if a nearby earthwork project were generating a significant amount of excess material, such as the Marsh Creek Delta Restoration project discussed in Appendix J. However, it is more likely that the potential fill source project would expect some degree of cost sharing for the material transport.) For comparison, we also estimated the project costs assuming that additional fill for creating marsh areas is obtained by over-excavating northern portions of the Gilbert and Burroughs parcels (onsite borrow). The cost of additional onsite to obtain fill for construction of the new east levee is not included.

8.4.3 Imported Material

In the Gilbert and Burroughs parcels, imported fill material is needed to create marsh areas (approximately 360,000 cubic yards) and levee construction (approximately 190,000 cubic yards). Imported fill may be obtained from other projects that generate excess material, either by dredging tidal areas or excavating from upland areas.

Table 6. Preliminary Volume and Construction Cost Estimate for Alternative 2

	Description	Quantity	Units	Unit Cost	Total
1.	**Site Preparation**				**$2,326,000**
A.	Mobilization (5%)	1	lump sum	$858,000	$858,000
B.	Vegetation Clearing	760	acres	$800	$608,000
C.	Demolition	28	each	$20,000	$560,000
D.	Construction Survey	1	lump sum	$300,000	$300,000
2.	**Utilities Relocation**				**$312,000**
A.	Ironhouse Pipeline Relocation	4,800	linear feet	$50	$240,000
B.	Marsh Creek Levee Road Resurfacing	3,000	tons	$24	$72,000
3.	**New East Levee**	**7,700**	**linear feet**		**$4,905,500**
A.	Foundation Excavation	48,000	cubic yards	$3.00	$144,000
B.	Credit for Reduced Import (Burroughs Parcel)	48,000	cubic yards	($2.00)	($96,000)
C.	Levee Fill Placement (Imported)	186,000	cubic yards	$10.00	$1,860,000
D.	Outboard Levee Armoring	7,700	linear feet	$165	$1,270,500
E.	Groundwater Cut-Off Wall	1	lump sum	$1,727,000	$1,727,000
4.	**Footbridge on Emerson Parcel**	1,600	square feet	$100	**$160,000**
5.	**Breaches**	11	each	$50,000	**$550,000**
6.	**Little Dutch Slough Dredging**	3,200	cubic yards	$37	**$118,000**
7.	**Marshplain Grading**	**1,680,000**	**cubic yards**		**$6,811,000**
A.	Fill Placement (Onsite Borrow)	1,321,000	cubic yards	$3.00	$3,963,000
B.	Fill Placement (Imported)	359,000	cubic yards	$2.00	$718,000
C.	Low Elevation Fill Placement (premium)	505,000	cubic yards	$3.00	$1,515,000
D.	Main Channel Excavation (premium)	45,000	cubic yards	$4.00	$180,000
E.	Tributary Channel Excavation (premium)	87,000	cubic yards	$5.00	$435,000
8.	**Habitat Levee**	**33,300**	**feet**		**$923,500**
A.	Levee Slope Fill (premium)	5,000	cubic yards	$1.50	$7,500
B.	Riparian Planting	31	acres	$25,000	$775,000
C.	Levee Lowering (premium)	47,000	cubic yards	$3.00	$141,000
9.	**Revegetation**	**732**	**acres**		**$1,920,000**
A.	Marsh Revegetation (Tule Pre-establishment)	662	acres	$1,000	$662,000
B.	Riparian Planting (including Dunes)	30	acres	$12,000	$360,000
C.	Native Grassland Planting	40	acres	$1,200	$48,000
D.	Water Control Structures	11	each	$50,000	$550,000
E.	Water Level Management (for Marsh Revegetation)	3	years	$100,000	$300,000
	Sub-total - IMPORT FILL AT NO COST				**$18,026,000**
	Construction Contingencies (30%)				$5,408,000
	Planning and Design (10%)				$1,803,000
	TOTAL - IMPORT FILL AT NO COST				**$25,237,000**

Additional Costs for On-Site Borrow from Subtidal Areas					
10.	**Additional Vegetation Clearing**	**180**	**acres**	**$800**	**$144,000**
11.	**Additional On-Site Excavation for Marshplain Fill**	**431,000**	**cubic yards**	**$6.50**	**$2,802,000**
	Sub-total - ADDITIONAL COSTS FOR ON-SITE BORROW FROM SUBTIDAL AREAS				**$2,946,000**
	Construction Contingencies (30%)				$884,000
	Planning and Design (10%)				$295,000
	TOTAL - ON-SITE BORROW FROM SUBTIDAL AREAS				**$29,362,000**

Annual Maintenance and Monitoring Costs					
12.	Maintenance of Adaptive Management Design Features	1	lump sum	$3,000	$3,000
13.	New East Levee Maintenance	1.5	miles	$15,000	$22,500
14.	Project Performance Monitoring	1	lump sum	$60,000	$60,000

Items not included in the cost estimate are listed in Section 8.4.2

Item	Footnote
1.B., 9.	Assumes existing vegetation will be mowed and disked into surface soils.
3.A.	Assumes peat material over-excavated for the levee foundation can be used as marsh fill on Burroughs parcel.
3.B.	Credit due to reduced import fill volume needed on Burroughs parcel due to levee foundation excavation (Item 6B).
3.C.	Includes placement and compaction of importing mineral soil. Assumes imported material has been delivered to site at no cost.
4.	Assumes bridge is built on piers.
5.	Includes breaches for restored marsh and open water areas; open water inlets may be breaches or water control structures, depending on the open water management option.
6.	Includes cost to remove existing road crossing and culvert.
7.A.	Base cost for onsite excavation from high elevation (upland) southern areas and fill placement (for creating marsh areas, marsh drainage divides, habitat levee bench, etc.). Premium costs are applied to select earthmoving activities which require more effort and/or different equipment (see below).
7.B.	Base cost for placing imported material. Assumes imported material has been delivered to site at no cost.
7.C.	Additional cost for placing fill on low-lying areas due to wet conditions (added to Item 6.A. base cost.)
7.D, 7.E.	Additional cost for excavating channels (added to Item 6.A. base cost.)
8.A.	Additional cost for placing fill on existing levee slope to construct habitat levee bench (added to Item 6.A. base cost.)
8.C.	Additional cost for excavating the existing levees (added to Item 6.A. base cost.)
9.D.	Water control structures at future breach locations to allow interim water management for revegetation.
9.E.	Labor for water management to pre-establish tules in restored marsh areas and interim management of open water areas (periodic adjustments for vegetation, vector control, drainage, etc.)
11.	Assumes additional marshplain fill (6.B.) will be generated by over-excavating onsite from low elevation (subtidal) northern areas, rather than importing fill. Additional cost for excavating and transporting wet material (added to Item 6.B. base cost.); accounts for 20% losses for peat soils Does not include additional cost for on-site excavation of fill for New East Levee (3.C.)
13.	Average cost over 20 years; assumes maintenance is required 4 times over 20 years and costs $15,000 each time
14.	Average cost over 10 years; monitoring is assumed to occur at 0, 1, 3, 5, and 10 years after construction; Average estimated cost of each monitoring event is $120,000; total estimated cost of monitoring over 10 years is $600,000.

Actual costs to the Dutch Slough project for importing fill material could vary significantly and will depend on several factors that are unknown at this time. These factors include:

- The source of imported material, including geographic location, excavation and transportation methods (hydraulic dredging, land-based excavation, and trucking, etc.), and timing.
- The degree of cost sharing by the source site, and availability of other funding options.
- For hydraulic dredging, site preparation costs for receiving imported fill material (*e.g.*, containment berms, decanting structures, off-loading facility, etc.).
- The cost of planning, permitting, and environmental compliance specifically for reuse of imported material.

Hydraulic placement of dredged material is generally considered to be a cost effective source and method for importing large volumes. Given the level of uncertainty regarding dredged material source(s) and other factors listed above, we have not developed cost estimates for dredged material placement at this time. If dredged material were used, methods for site grading and channel excavation after decanting would need to be considered.

Imported material may be available from the Marsh Creek Delta Restoration project proposed for the Ironhouse Sanitary District's land immediately west of the Emerson parcel and Marsh Creek (Appendix J). The Marsh Creek Delta Restoration project would be integrated with the Dutch Slough restoration to coordinate restoration efforts, including the excavation of fill material from the Ironhouse Sanitary District's land to create marsh areas at Dutch Slough. Material could be excavated from the Ironhouse parcel using self-loading scrapers and transported over Marsh Creek and onto the Emerson parcel via a temporary bridge. Excess material from either the Ironhouse parcel or the Emerson parcel could be transported onto the Gilbert and Burroughs parcels. The cost of importing material from the Ironhouse parcel has not been estimated, however this approach is expected to be cost-effective. Transporting material from the Ironhouse or Emerson parcel to the Burroughs parcel is expected to be incrementally more costly than transporting material to the Gilbert parcel because it would require trucking over a greater distance and is expected to be more costly. The suitability of using soils from the Ironhouse parcel as wetland cover would need to be assessed before the feasibility of the approach can be determined. Only sediments that meet the Regional Water Quality Control Board's criteria for wetland cover will be used for fill.

8.4.4 Onsite Borrow From Subtidal Areas

If imported material is not available or cost effective for the Gilbert and Burroughs parcels, it is assumed that fill material for creating marsh areas will be generated from onsite excavation of the low (subtidal) northern areas of these parcels. Earthwork costs depend on several factors including type of equipment used, ease of site access, total volume of earthwork (*e.g.*, economy of scale), construction phasing and anticipated groundwater levels. As discussed above, the cost of excavating fill material to construct the new east levee is not included because further geotechnical investigation is required to evaluate the suitability of onsite soils for engineered levee fill.

Self-loading scrapers are usually the most cost effective type of land-based earthmoving equipment; however, their utility is limited to relatively stable, well-drained soils. At the Dutch Slough site, it is assumed for now that scrapers can be used for cut and fill above elevation -2.0 ft NGVD. For more subsided areas and/or deeper excavations, it is assume that earthmoving would be accomplished using track-mounted excavators, off-road trucks, and bulldozers. These assumptions are based on the limited groundwater data available and are only to assist with preliminary cost estimating. In future design phases, the actual groundwater conditions throughout the site should be investigated further (using test pits, monitoring wells, etc.) to better understand appropriate construction equipment and the feasibility of dewatering excavated areas to facilitate earthmoving and reduce costs.

8.4.5 Phasing

Project implementation may be phased over several years. These phases may include levee grading and construction, utilities relocation, management of low elevation open water areas prior to full implementation, marshplain grading, and re-vegetation. The Gilbert and Burroughs parcels may be restored in one phase and the Emerson parcel in a separate phase. It is assumed that all construction would be performed in the dry season (generally April 15th to October 15th). Appendix I contains a table summarizing project phasing.

The first phases of project implementation will most likely include constructing the habitat levee bench, the new east flood control levee, and relocating the Ironhouse pipeline and on-site power and gas utilities. Site preparation will be needed for each of these phases. Constructing the habitat levee bench and relocating the utilities will be necessary prior to managing water levels (*i.e.*, allowing controlled flooding) in low elevation open water areas. Constructing the new east levee could occur prior to or concurrently with marshplain grading in the Burroughs parcel.

Water may be allowed to collect or pumped onto the low elevation northern areas of each parcel during an interim management phase prior to full project implementation. Interim management of open water areas may have several benefits. Pumping requirements during the winter season will be reduced. Tules are expected to establish in the low elevation areas, which would be a precursor to managing these areas for subsidence reversal or pre-establishing tules on the habitat levee bench prior to tidal breaching. Techniques for native SAV revegetation could also be tested. If fill material is borrowed from these low elevation areas, establishing tules is not expected to significantly effect the feasibility of excavating fill. Vector control measures would need to be considered in the interim management of open water areas. During marshplain grading, the site will be drained and tules established in the interim phase may die back; however, tules are expected to re-establish more rapidly in the subsequent revegatation phase than the initial phase of tule establishment.

Marshplain grading will be a major phase of project implementation and will require site preparation and mobilization. Since each parcel is accessible by land, it is assumed that standard costs can be used for equipment mobilization. Construction is simpler if earth fill does not need to be transported between the different parcels. Given the relatively large earthwork volumes, construction would likely be phased over at least two years. Accomplishing earthwork in phases may increase project costs because of additional mobilizations, winterizing, etc. During marshplain grading, onsite water should be managed so that soils are as dry as possible to increase earthmoving efficiency (and reduce costs).

The revegatation phase is expected to follow marshplain grading. Water control structures will be used to flood graded marsh areas and manage water levels to encourage tule establishment. Water management will also be used to establish tules on the habitat levee bench in open water areas that are to be breached to tidal action (if any). Riparian woodland, native grassland, and dune scrub vegetation will be planted in upland areas and on habitat levees. Upland plant species may be field grown on-site prior to revegetation. In upland areas that will not be graded, revegetation may begin in an earlier phase; however, this is not expected to be a large area. The grading of habitat levees will to create lower elevation riparian and high marsh habitats will likely occur as part of or immediately prior to the revegetation phase.

Once tules are established in the restored marsh areas, the site will be breached to tidal action. It is recommended that the construction schedule allow for at least one growing season (winter-spring) following completion of site grading to allow vegetation to establish prior to tidal breaching. Therefore, it is likely that the site may not be breached until three years after marshplain grading commences.

The Gilbert and Burroughs parcels may be restored prior to the Emerson parcel. This approach to phasing has the advantage of allowing the flexibility of phasing project funding. As the large-scale adaptive management experiments will be located on the Gilbert and Burroughs parcels, this approach will allow for experimental comparison of restored marsh areas. Phasing the restoration of the parcels may increase mobilization costs. If funding is available for full project implementation, then restoring all three parcels in a single phase is preferred.

8.5 SITE MAINTENANCE AND MONITORING

The primary components of the Dutch Slough restoration project – marsh areas, uplands, and habitat levees – are designed to be self-maintaining within the project planning horizon. Initial maintenance will be required to control for weeds in upland areas and is included in the revegetation costs above. Vector control measures and costs are not expected to be significant for restored tidal marsh areas. The costs of managing open water areas will depend on the preferred management option and are not included in the cost estimate. Certain options are expected to require ongoing maintenance and active vector control measures, while others are not (see Table 5).

An allowance is included in the cost estimate for maintaining design features that are important for conducting adaptive management experiments. This may potentially include removing obstructions from tidal channels (*e.g.*, debris), filling unintentional channels that cut through marsh drainage divides and connect marsh areas, or repairing unintentional breaches in the habitat levees surrounding tidal marsh or managed open water areas. The cost estimate assumes that maintenance of adaptive management design features will be required for 20 years after project construction.

The new east flood control levee will require regular maintenance. The estimated levee maintenance costs include items such as levee inspections and patrolling, grading, engineering, vegetation and rodent control, debris removal, drainage cleaning, seepage control, underwater surveys, and slope protection (erosion, slipouts, subsidence) (T. Hall, DWR, pers. comm.).

The costs of maintaining public access facilities, such as trails on the habitat levees and the footbridge over the Emerson parcel breach, are not included. It is assumed that the City of Oakley will be responsible for these maintenance costs. It is assumed that the cost of maintaining the Marsh Creek levee road for access to the Ironhouse Sanitary District's pipeline will be part of the cost for maintaining the public access trail.

Monitoring will be required to fulfill several objectives: establish baseline conditions, monitor project performance, and perform adaptive management experiments. The cost estimate includes project performance monitoring, which is expected to be required for permit compliance. Project performance monitoring costs assume physical and biological monitoring at 0, 1, 3, 5, and 10 years after construction. Appendix C-2 contains a plan and costs for water quality monitoring to address the data gaps and potential impacts discussed in Section 8.3.5. The Natural Heritage Institute is leading the development of the Dutch Slough Adaptive Management and Monitoring Plan with input from the AMWG. Monitoring costs for adaptive management experiments are not included, as it is expected that experimental monitoring with be funded through research initiatives.

9. NEXT STEPS

The following items are recommended for future phases of the Dutch Slough restoration planning and design:

Flood protection and groundwater seepage control measures for low-lying areas to the south. Further study of flooding and seepage to the south and coordination with CCWD, Bureau of Reclamation, Contra Costa County, and potential developers is recommended to develop a detailed plan. Site-specific assessments of groundwater seepage will be needed for residential projects constructed below the flood level in the adjacent sloughs.

Groundwater seepage control measures for the Hotchkiss tract. Further coordination with Contra Costa County and/or Hotchkiss tract developers is recommended to assess the possibility of integrating groundwater seepage control systems for the Dutch Slough restoration project and the Hotchkiss tract development. Lowering the groundwater in any remaining peat areas in the Hotchkiss tract may cause consolidation of the peat and may accelerate peat deflation. Both consolidation and deflation can lead to additional or accelerated ground surface subsidence. A more detailed evaluation of this area will be needed for preliminary design.

Groundwater monitoring program. Groundwater data are limited around the project site. A well planned groundwater level investigation and monitoring program will be needed for project design and implementation. Continuous monitoring of groundwater elevations using automated data loggers will be needed for at least one full year prior to project implementation. The monitoring wells will need to be located such that monitoring can continue after the site becomes tidal. The preferred monitoring locations will be on adjacent properties to verify that seepage is not affecting the property or to indicate that expanded measures are needed to control seepage. In future design phases, the actual groundwater conditions throughout the site should be investigated further (using test pits, monitoring wells, etc.) to better understand appropriate construction equipment and the feasibility of dewatering excavated areas to facilitate earthmoving and reduce costs. Future design phases will also require groundwater monitoring and soil borings to accurately characterize aquifer conditions for the design of groundwater seepage control measures.

Flood protection for the Dutch Slough Community Park. Further coordination with the City of Oakley is recommended to determine the level of flood protection required for the Dutch Slough Community Park.

Northeast corner of the Burroughs parcel. The northeast corner of the Burroughs parcel will not be restored to tidal marsh and will remain diked behind the new east levee to protect PG&E's on-site infrastructure. It may be possible to restore upland or other habitat in this area (approximately 25 acres) or incorporate the area with the adjacent Delta Access Park being planned by the City of Oakley. Further coordination with PG&E and the City is recommended to develop a plan for this area.

Open water management. Further input from the AMWG is necessary to determine the preferred option of open water management. This decision process should consider maintenance, sustainability, cost, and vector control.

Water and sediment quality monitoring. The Dutch Slough Water and Sediment Quality Monitoring Plan (Appendix C-2) identifies monitoring station locations, sampling frequency, and sampling methods to develop more robust baseline water and sediment quality conditions, assess project implementation, and provide data necessary to adaptively manage the Dutch Slough site. The proposed sampling design includes recommendations for additional water sampling to better define the water quality of Marsh Creek and inform the selection of the preferred Marsh Creek delta restoration option.

Marsh Creek delta restoration. Restoring a large marsh floodplain delta has the potential to improve flood protection, however it will be necessary to perform hydraulic modeling to confirm this. Further study of the sediment yield from Marsh Creek is recommended in future design phases to estimate the potential deposition rate in the restored creek delta. The project will need to coordinate will the Contra Costa Flood Control District and will need to consider overall flood performance (including sedimentation) to maintain or improve existing level of flood protection.

Marsh Creek levee. The plan to relocate the Ironhouse Sanitary District's pipeline assumes that the Contra Costa County Flood Control District (CCCFCD) will allow the pipeline to be relocated into their levee. Further coordination with the CCCFCD is recommended to confirm this plan. Further coordination with (CCCFCD) is also recommended to determine if it is possible to protect their levee slope using biotechnical approaches, such as planting riparian woodland or native grasses on the slope.

Habitat levees. Soil tests are recommended to determine exact levee treatments. The design of the habitat levees and slope protection will be detailed and refined in future design phases through the assessment of potential wind-wave action and erosion.

Survival of existing riparian woodland. Detailed elevation surveys and further assessment of inundation tolerance are recommended in future phases of the project to evaluate the potential for the existing riparian woodland to survive, such as the well developed riparian woodland in the southern part of the Burroughs parcel.

Tidal circulation. Further assessment of the rate of channel scour and the resilience of low marsh vegetation to partial drainage will be needed in future design phases to assess whether it is necessary to dredge the wider northern reach of Little Dutch Slough in addition to the narrow reach or not. Also, if the open water area on the Emerson parcel is breached to Emerson Slough, further study of the potential for tidal damping and channel scour is recommended to assess the potential to impede drainage through the culverts at the upstream end of Emerson Slough.

Power and gas distribution facilities. Further coordination with PG&E is recommended to develop a plan and costs for moving or decommissioning PG&E's gas distribution lines and power distribution lines, equipment, and transformers.

Delta salinity. Modeling of tidal flows and salinities in the Delta are necessary to assess potential project impacts in future phases of the project.

Geotechnical and topographic data collection. Formal investigation of geotechnical conditions will be required to inform subsequent design phases. Geotechnical data collection allow for the evaluation of whether on-site soils are suitable for constructing the new east levee and other design features. Refined topographic data (ground surveys) will also be required in subsequent design phases.

Tidal channel morphology data. The collection of additional data on tidal channel dimensions and plan form relationships to marsh area in Delta marshes is recommended in future phases of the project to reduce the uncertainty in designing and predicting fish response to tidal channel morphology.

Hydrodynamic modeling. The sizing of hydraulic features such as breaches, tidal channels, slough dredging, water control structures, and culverts will require hydrodynamic modeling in subsequent phases of the design.

Construction costs. The estimated costs should be refined and updated as the design is developed in current and future stages of the project. Further study, coordination, and design refinement are needed to assess several potential cost elements not included in the cost estimate, such as restoration of a Marsh Creek delta, open water management options, and small-scale adaptive management experiments. Further study, coordination, and design refinement are also needed to determine whether the additional fill material needed to create marsh areas will be imported or borrowed from on-site. Planting costs should be refined in future stages with additional site investigation and information.

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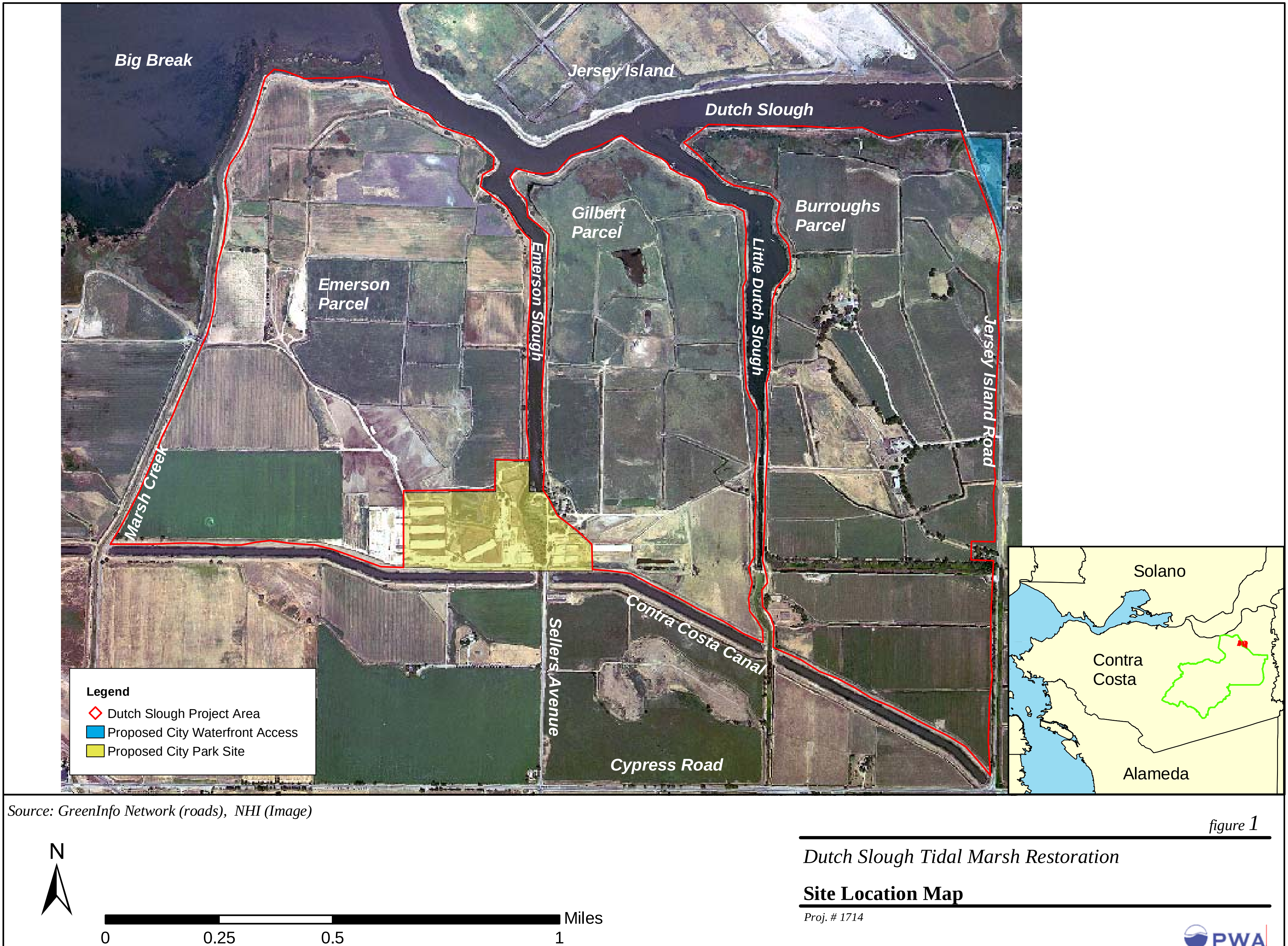
12. FIGURES



Source: GreenInfo Network (roads), NHI (Image)

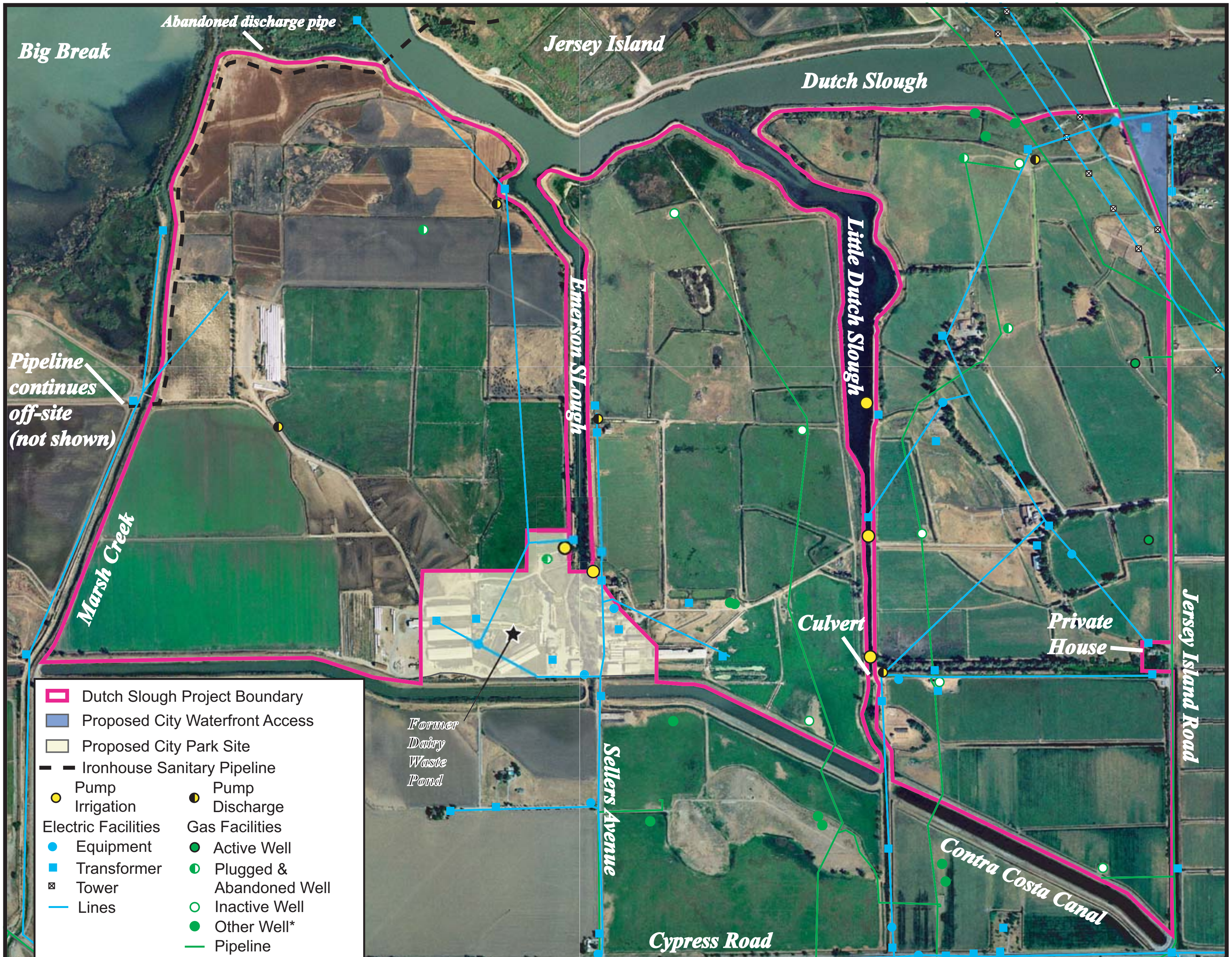
figure 1

Dutch Slough Tidal Marsh Restoration

Site Location Map

Proj. # 1714

PWA



Note: Other wells were identified on a map provided by PG&E; however, the location and status of these wells have not been verified.

Source: PGE (Electric and Gas Facilities, Image), DWR & ENGEO (Well Location and Status), USGS (Dairy Waste Pond), NHI (Ironhouse Pipeline)

figure 2

Dutch Slough Tidal Marsh Restoration

Existing Infrastructure

Proj. #1714

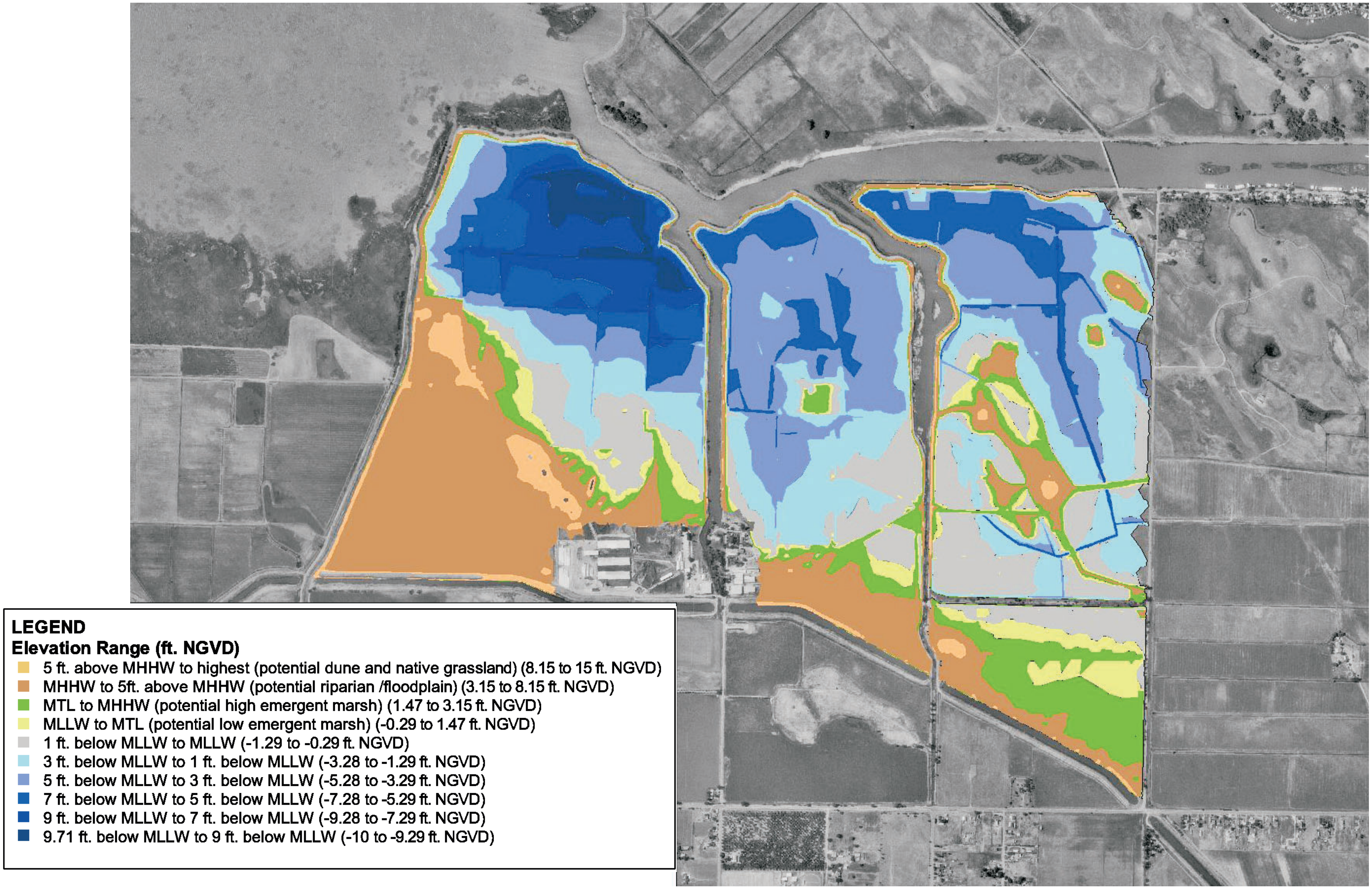


figure 3

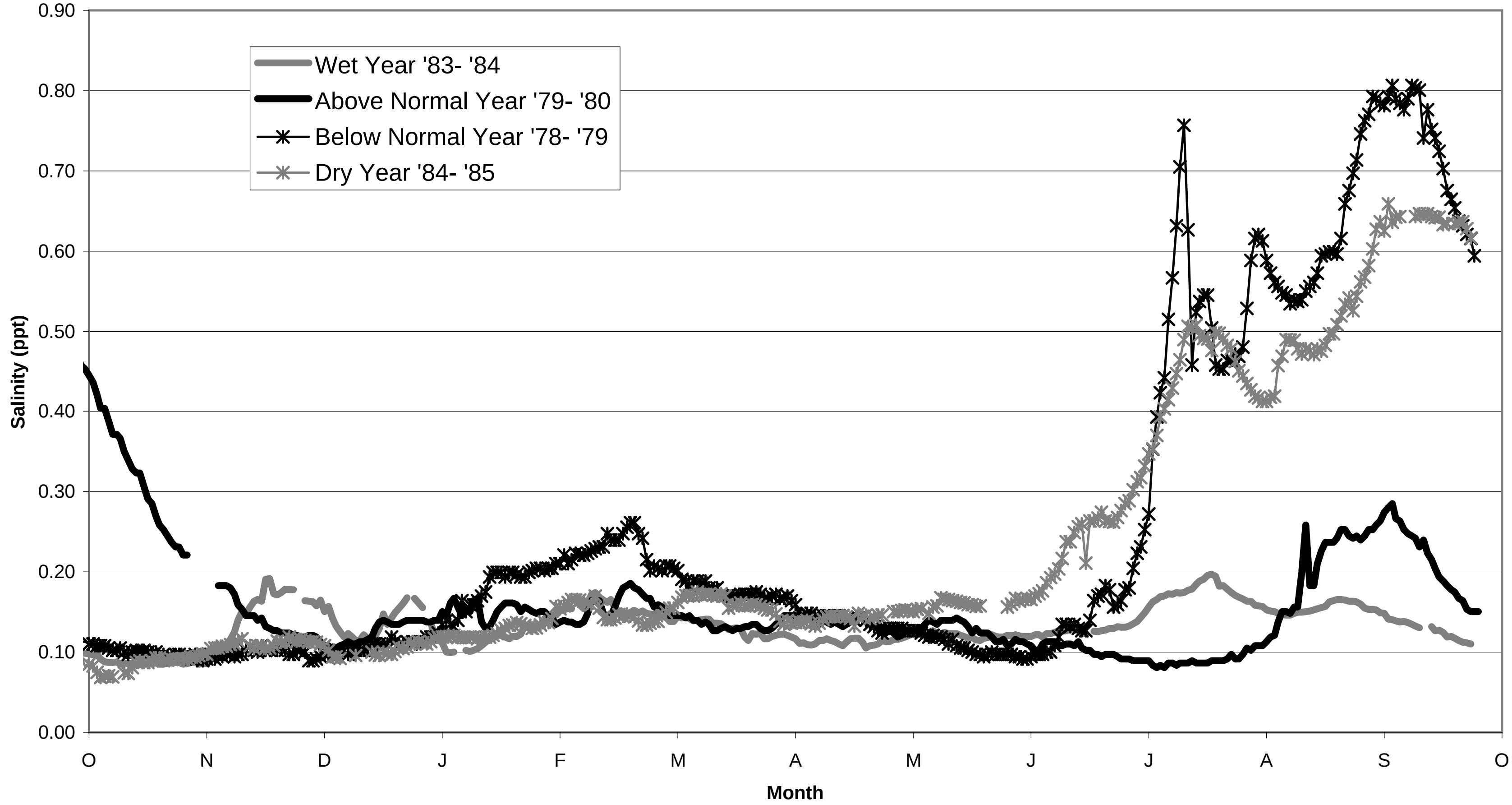
Source: Carlson, Beebee, & Gibson (topography), WWR (tidal datums), USGS (Image)
Notes: Site elevations shown relative to lower Marsh Creek tidal datums.
MHHW = mean higher high water
MTL = mean tide level
MLLW = mean lower low water

Dutch Slough Tidal Marsh Restoration

Site Elevations Relative to Tidal Datums

PWA#: 1714 ExTopo.cdr

PWA



Source: United States Bureau of Reclamation, Central Valley Operations Office (IEP 2005).

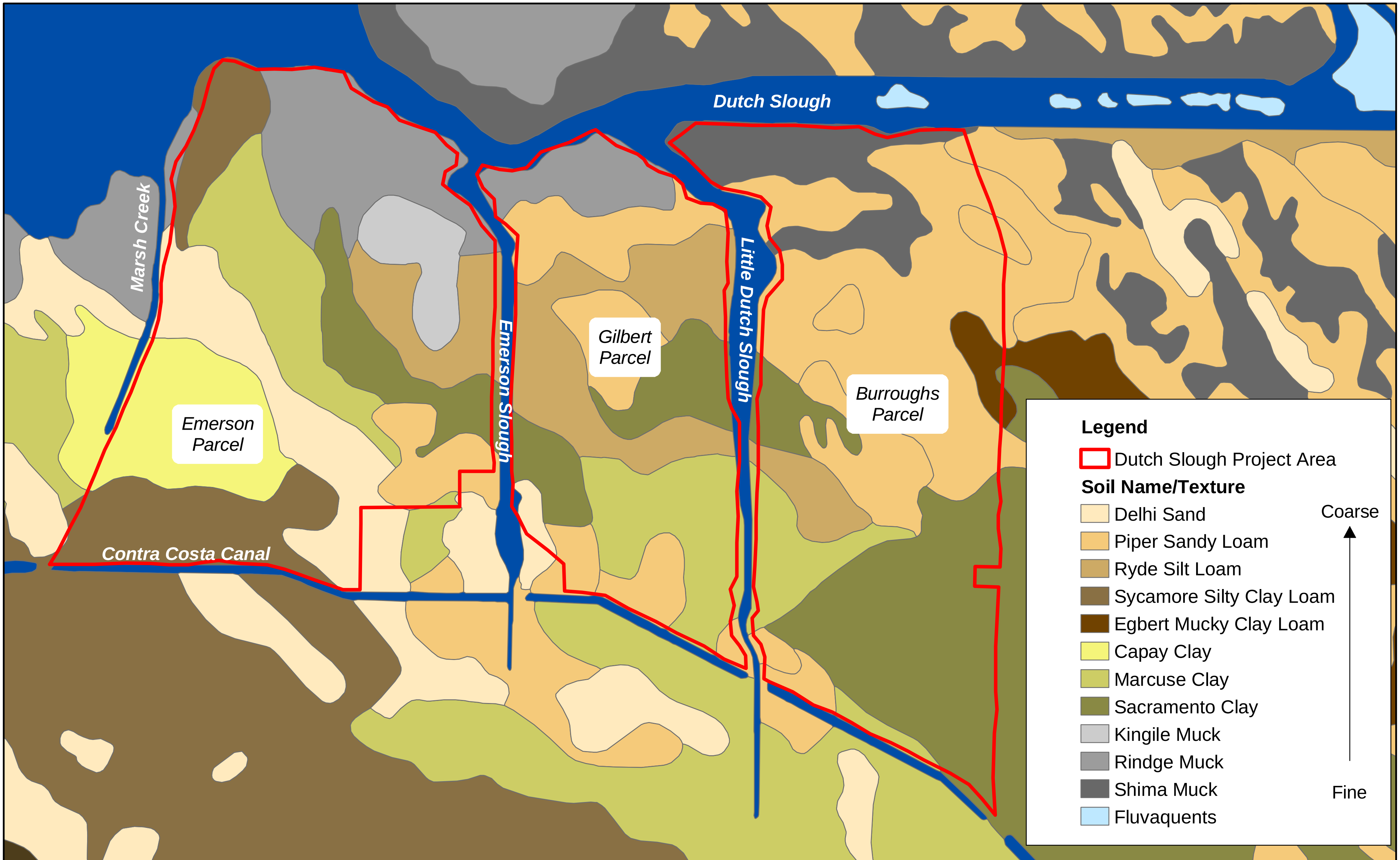
Note: ppt = parts per thousand

figure 4

Dutch Slough Tidal Marsh Restoration

Salinity at Dutch Slough

PWA



Source: NRCD (soils)
Note: Texture is defined by codes for the USDA texture for the surface layer or horizon (SSURGO).

N

0 1,250 2,500 5,000 Feet

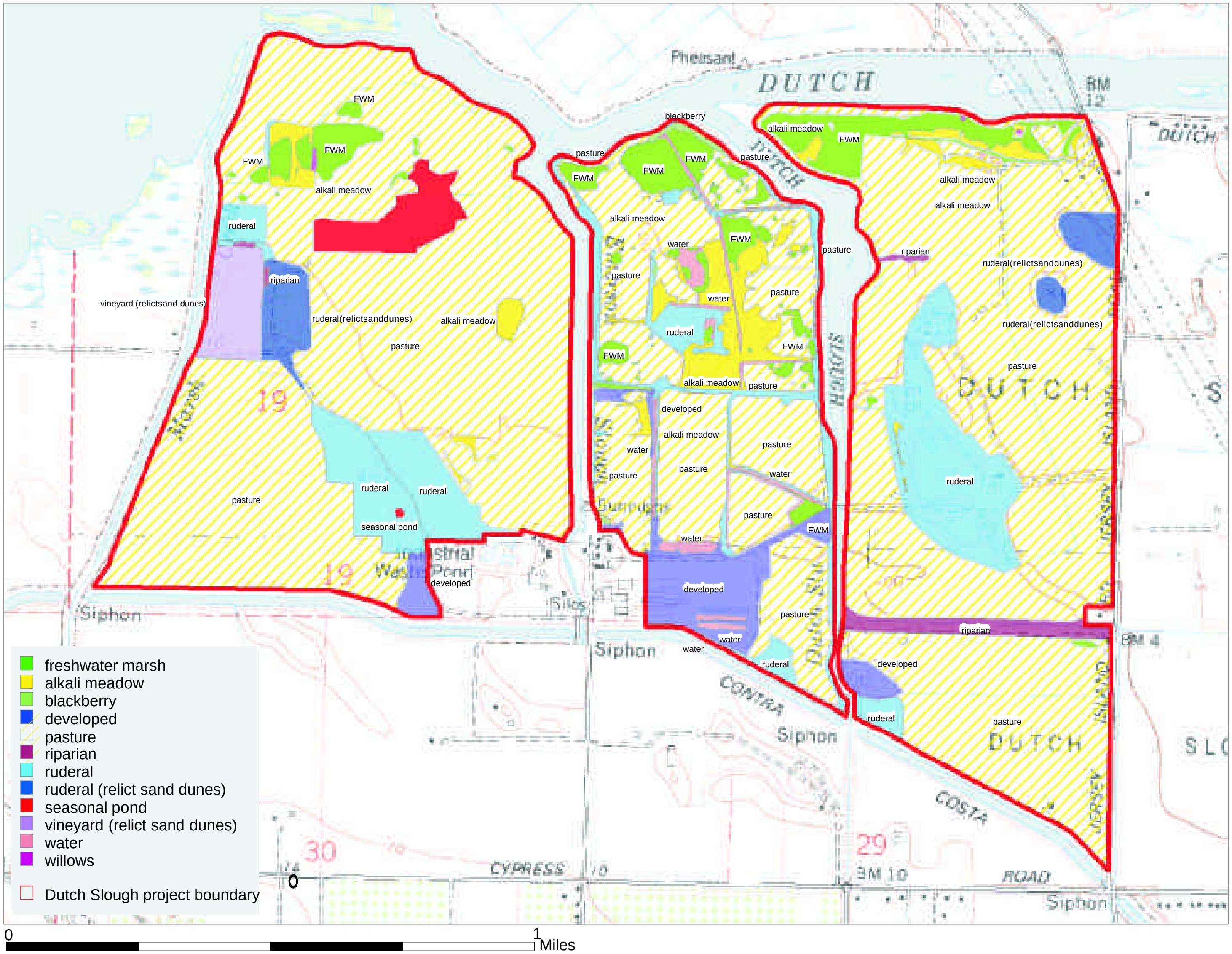
figure 5

Dutch Slough Tidal Marsh Restoration

Soils at Dutch Slough

Proj. # 1714

PWA



Source: DWR, 2005a

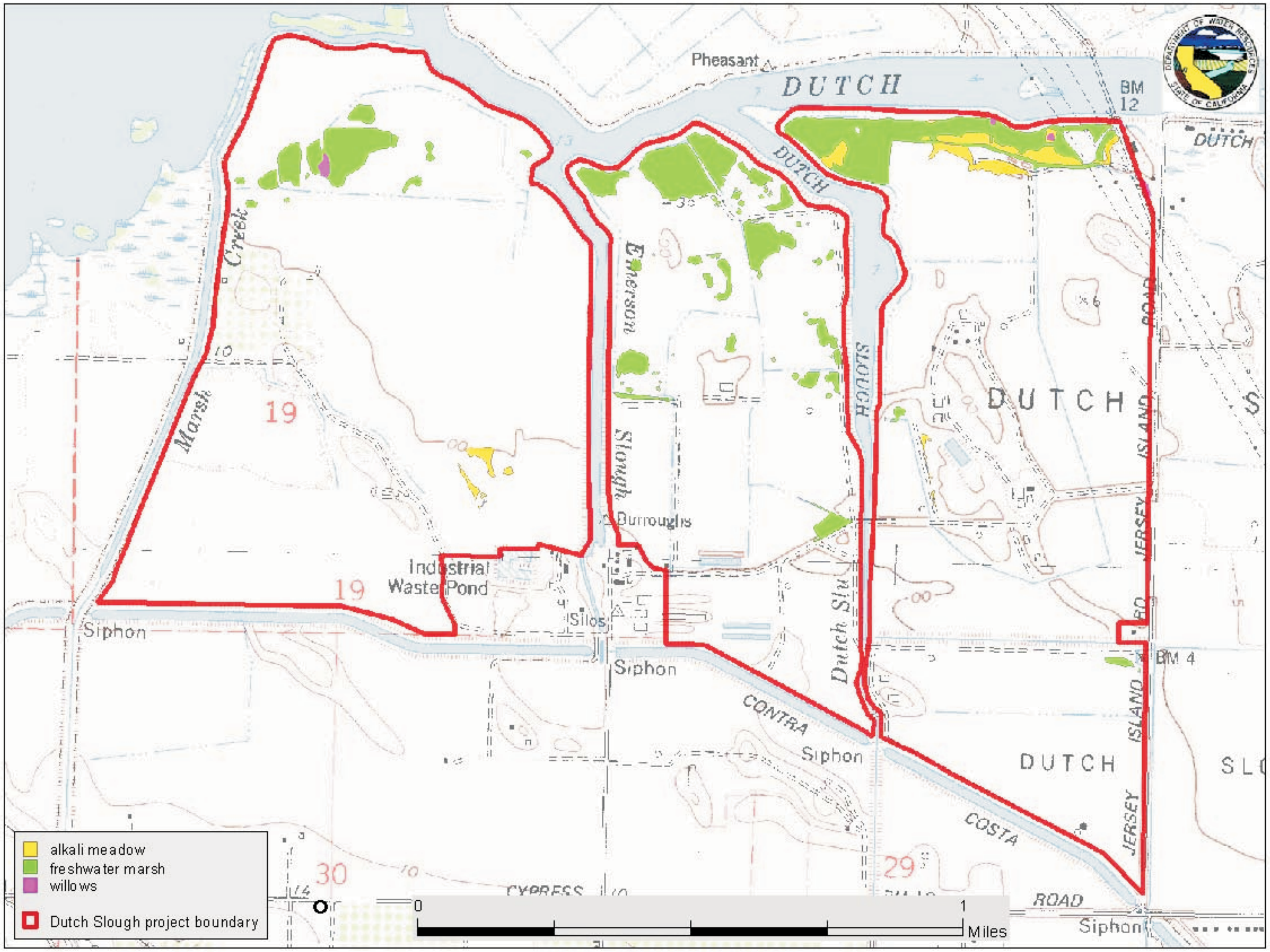
figure 6

Dutch Slough Tidal Marsh Restoration

Existing Vegetation

PWA#: 1614 ExVeg&Hab.cdr

PWA



Source: DWR, 2005b

figure 7

Dutch Slough Tidal Marsh Restoration

Preliminary Determination of Jurisdictional Wetlands

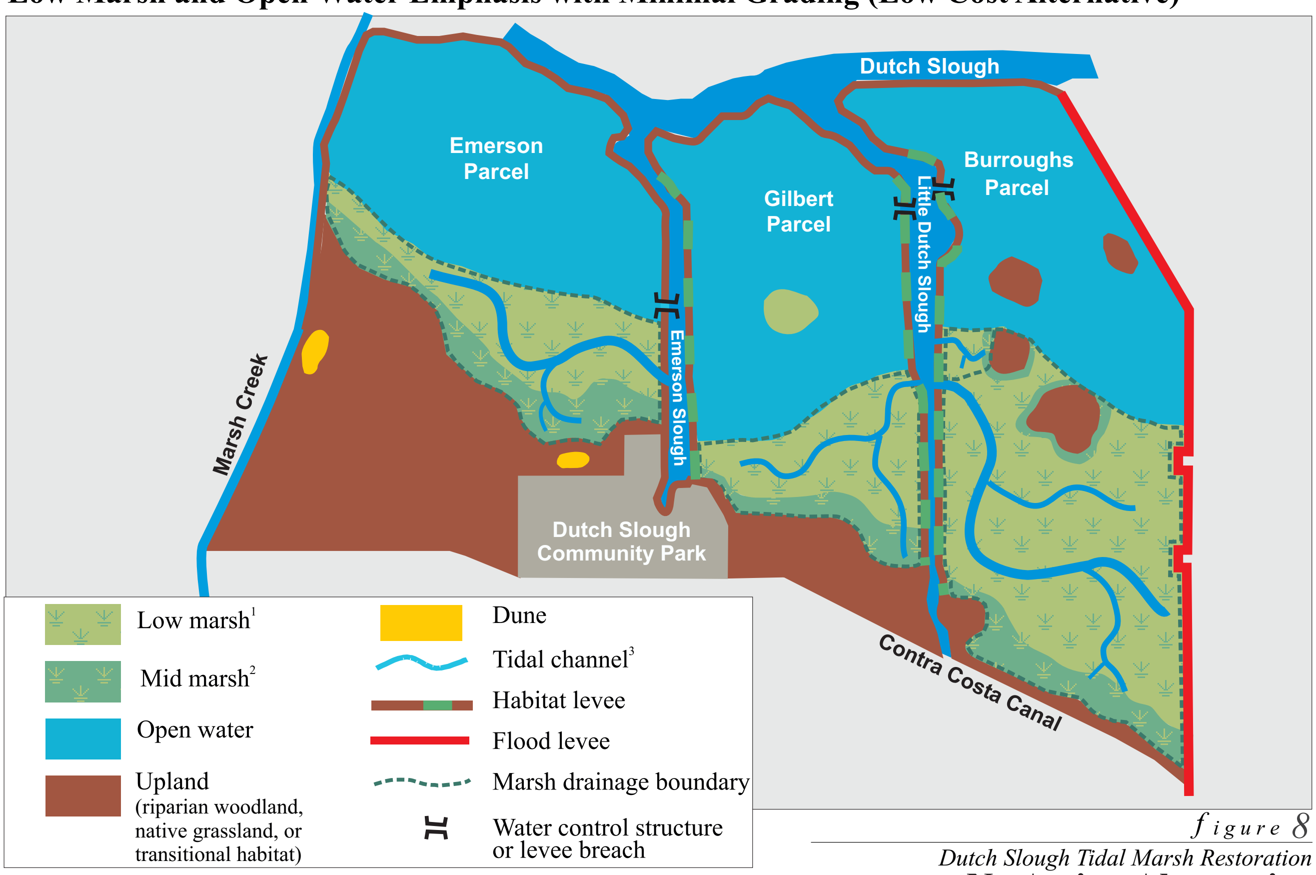
PWA#: 1714 /Task6/PrelimDetrmnJusrisWetland.cdr

PWA

No Action Alternative (Existing Conditions)

Alternative 1

Low Marsh and Open Water Emphasis with Minimal Grading (Low Cost Alternative)



[1]Low marsh elevation ranges from - 0.8 to + 0.2 ft NGVD (- 0.5 to +0.5 ft MLLW)
[2]Mid marsh elevation ranges from +1.0 to + 2.0 ft NGVD (- 0.5 to +0.5 ft MTL)
[3]Conceptual channel networks not shown to scale; actual channel density will be much greater

figure 8

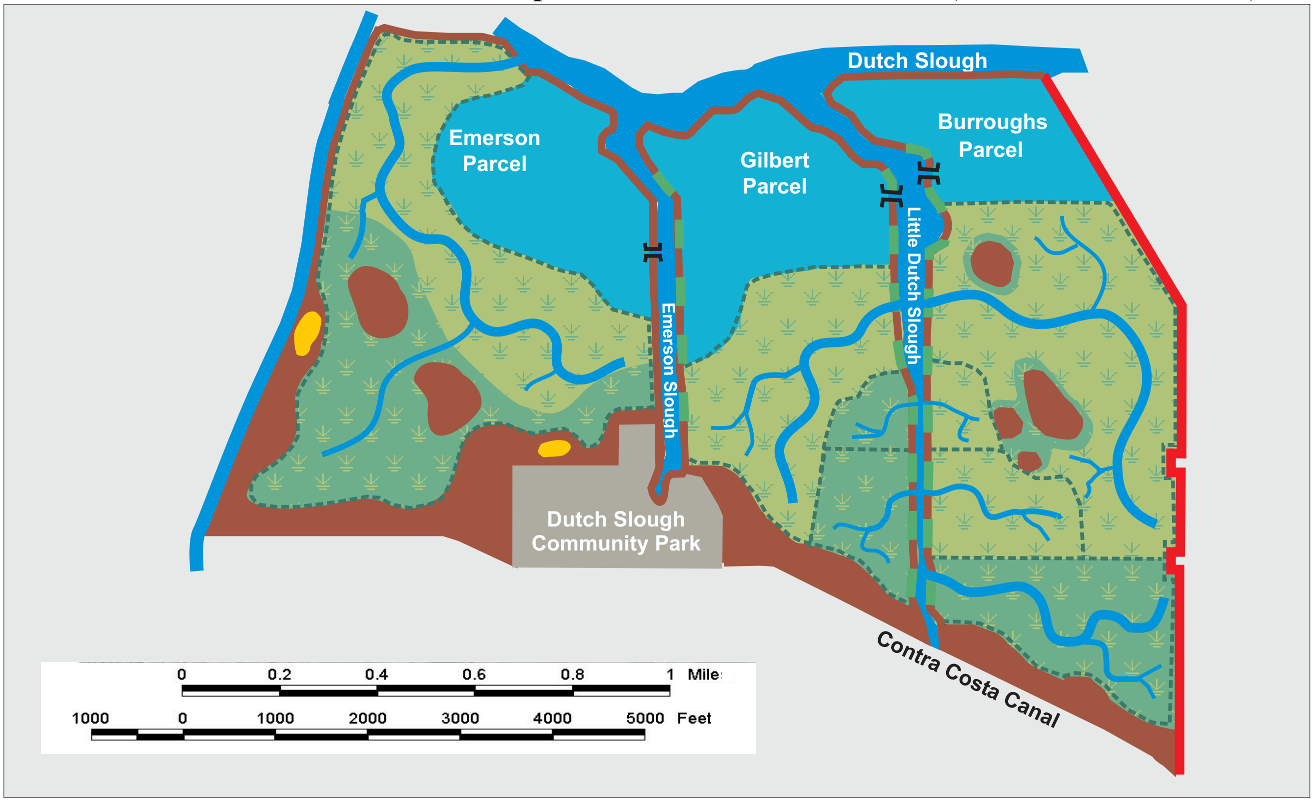
Dutch Slough Tidal Marsh Restoration

No Action Alternative and Alternative 1

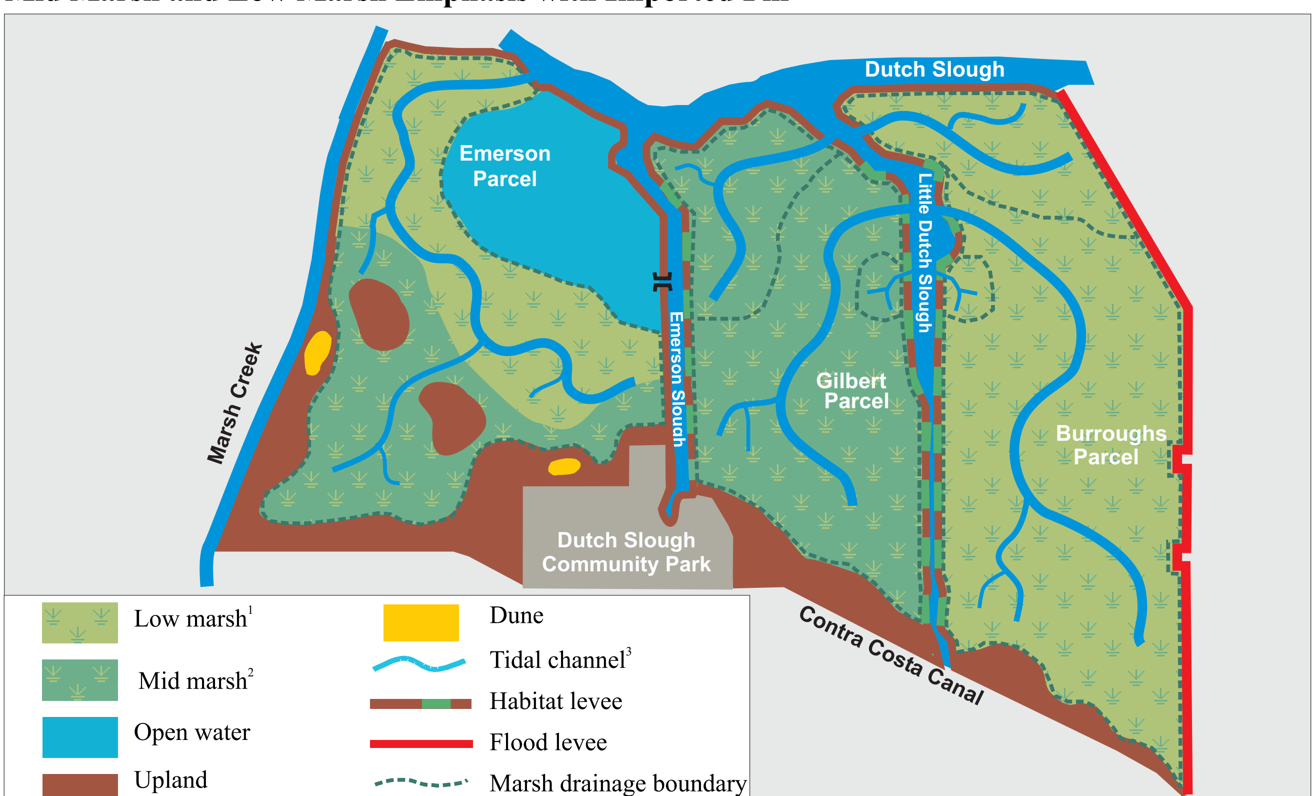
PWA#: 1714 AlternativeNA&1

PWA

Alternative 2
Mix of Mid Marsh, Low Marsh, and Open Water with Moderate Fill (Preferred Alternative)



Alternative 3
Mid Marsh and Low Marsh Emphasis with Imported Fill



Low marsh[1]
Mid marsh[2]
Open water
Upland (riparian woodland, native grassland, or transitional habitat)
Dune
Tidal channel[3]
Habitat levee
Flood levee
Marsh drainage boundary
Water control structure or levee breach

[1]Low marsh elevation ranges from - 0.8 to + 0.2 ft NGVD (- 0.5 to +0.5 ft MLLW)
[2]Mid marsh elevation ranges from +1.0 to + 2.0 ft NGVD (- 0.5 to +0.5 ft MTL)
[3]Conceptual channel networks not shown to scale; actual channel density will be much greater

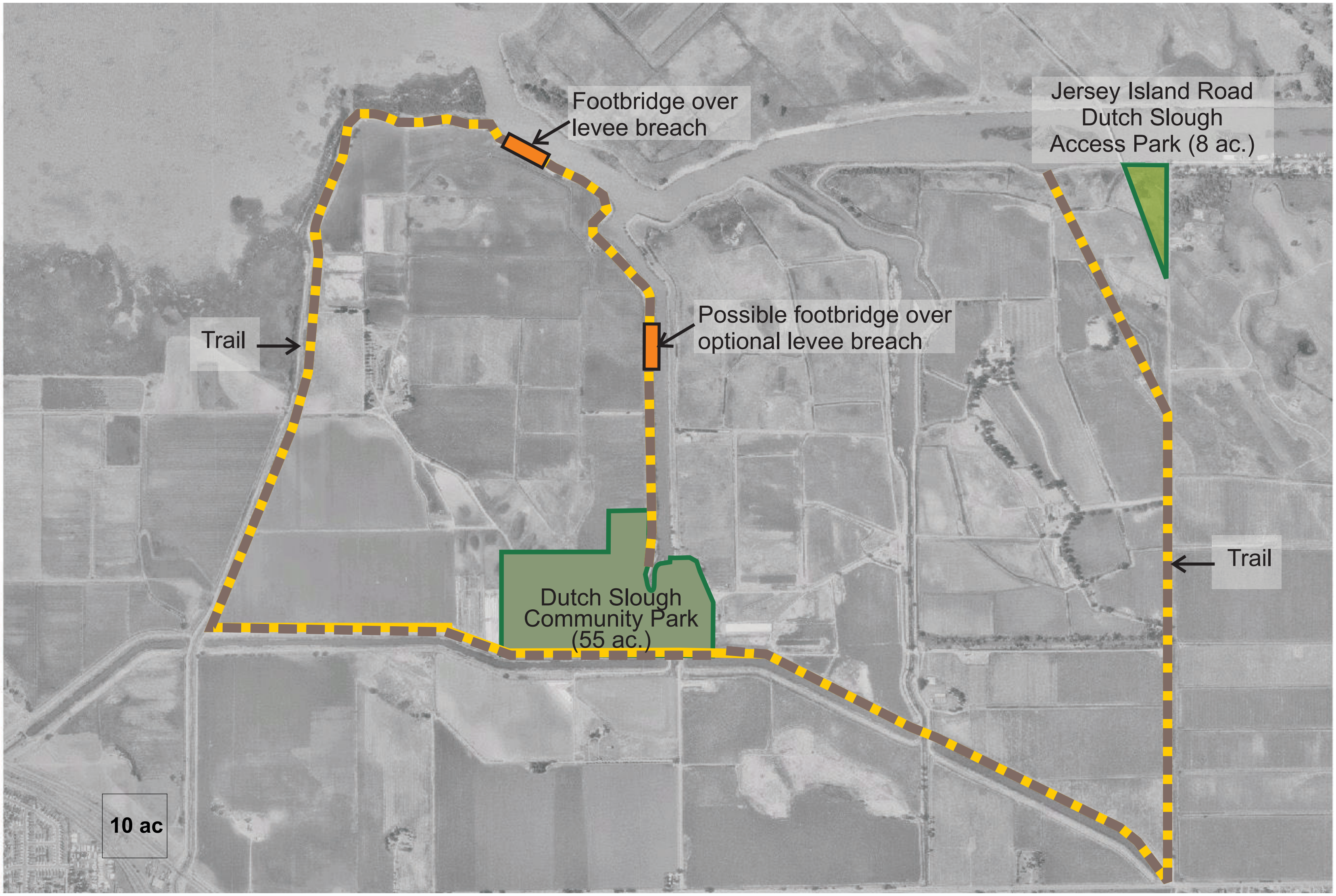
figure 9

Dutch Slough Tidal Marsh Restoration

Alternatives 2 and 3

PWA#: 1714 Alternative2&3_01_06.cdr

PWA



SCALE

0 0.2 0.4 0.6 0.8 1 Miles

1000 0 1000 2000 3000 4000 5000 Feet

figure 10

Dutch Slough Tidal Marsh Restoration

Preliminary Public Access and Recreation Plan

PWA#: 1714 Task 6/ report/figs Jan 2006 publicAccess

PWA

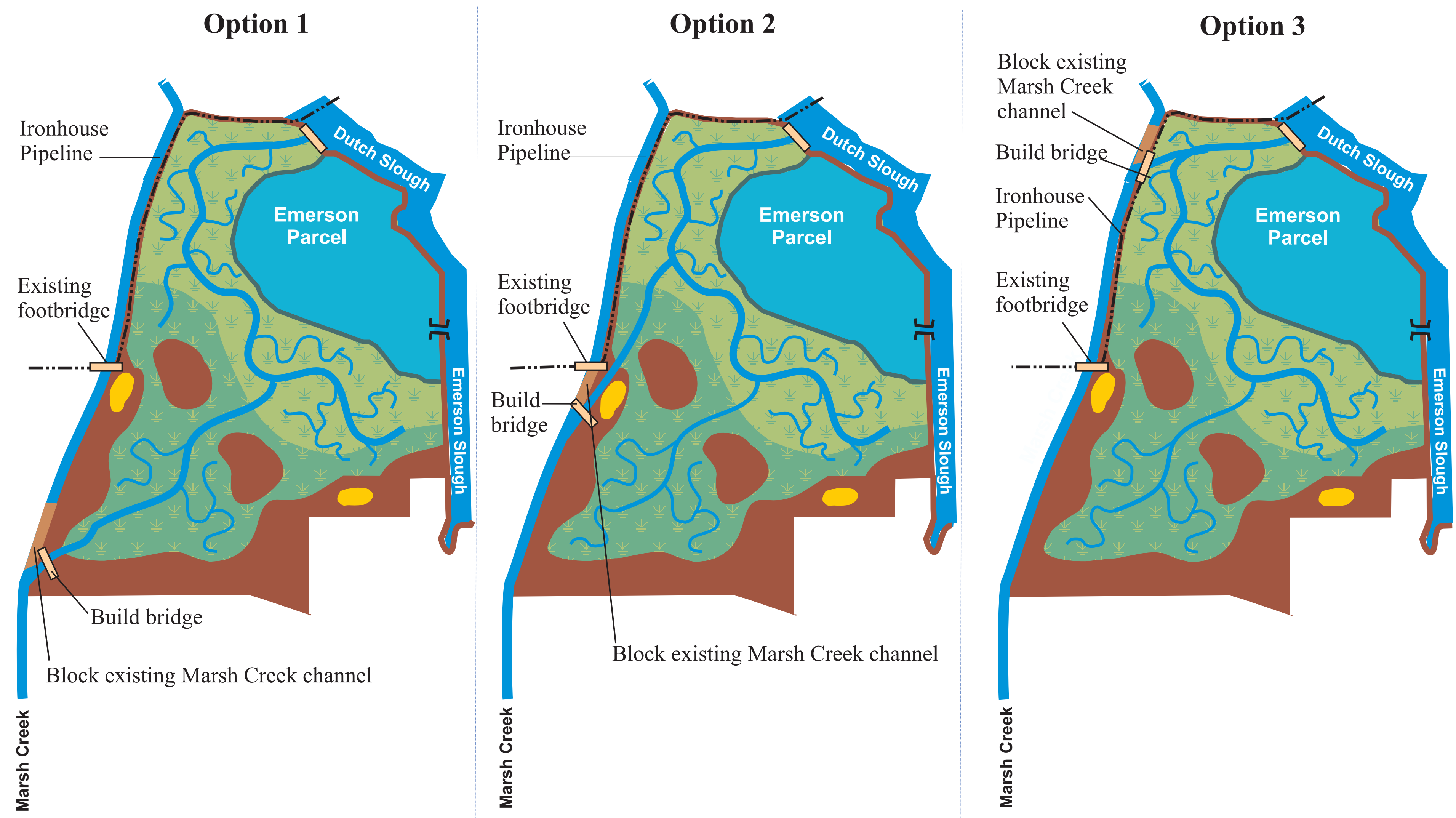
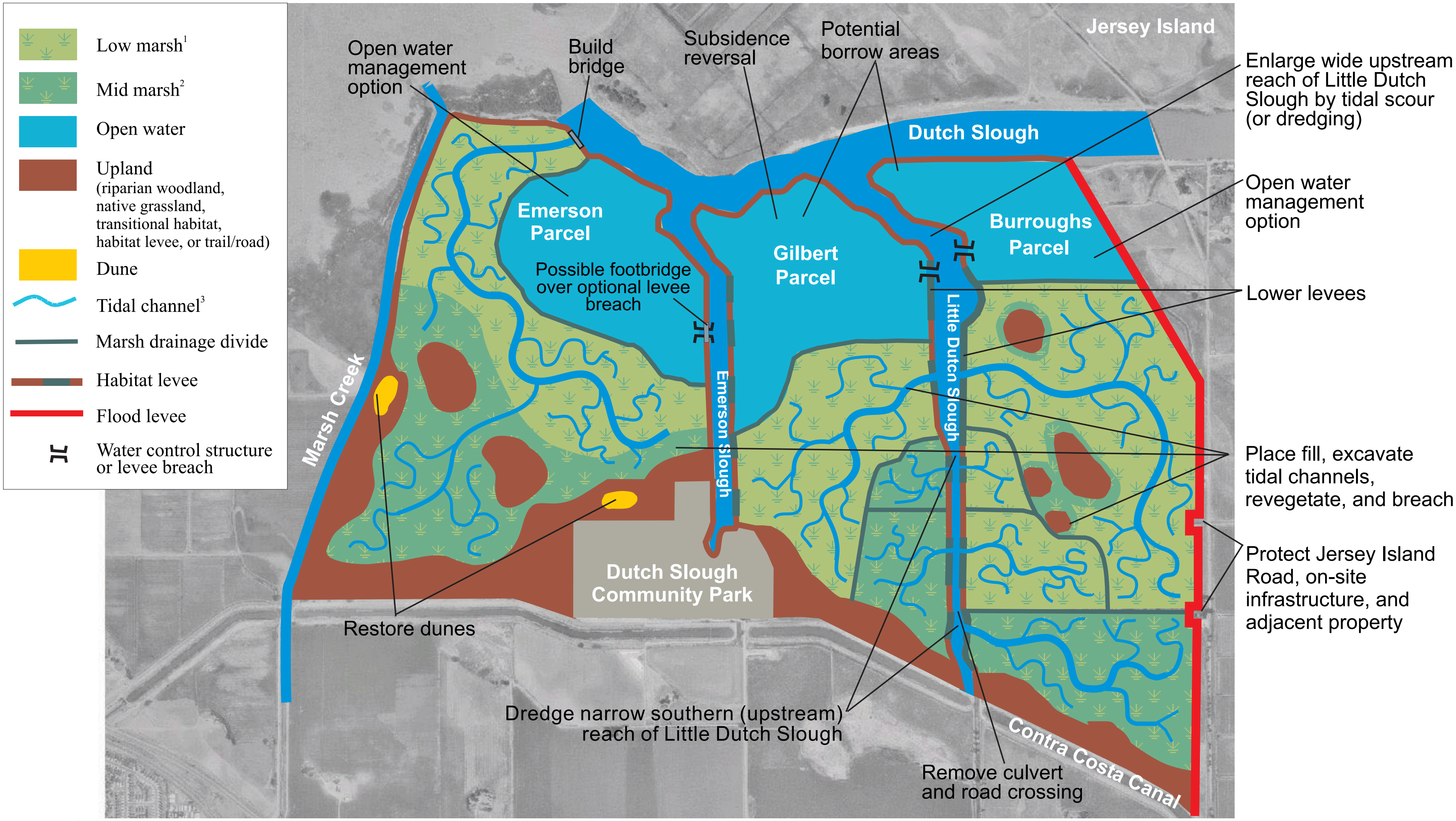


figure 11

Dutch Slough Tidal Marsh Restoration

Marsh Creek Delta Restoration



[1]Low marsh elevation ranges from - 0.8 to + 0.2 ft NGVD (- 0.5 to +0.5 ft MLLW)
[2]Mid marsh elevation ranges from +1.0 to + 2.0 ft NGVD (- 0.5 to +0.5 ft MTL)
[3]Conceptual channel networks not shown to scale

10 ac

SCALE 0 0.2 0.4 0.6 0.8 1 Mile

1000 0 1000 2000 3000 4000 5000 Feet

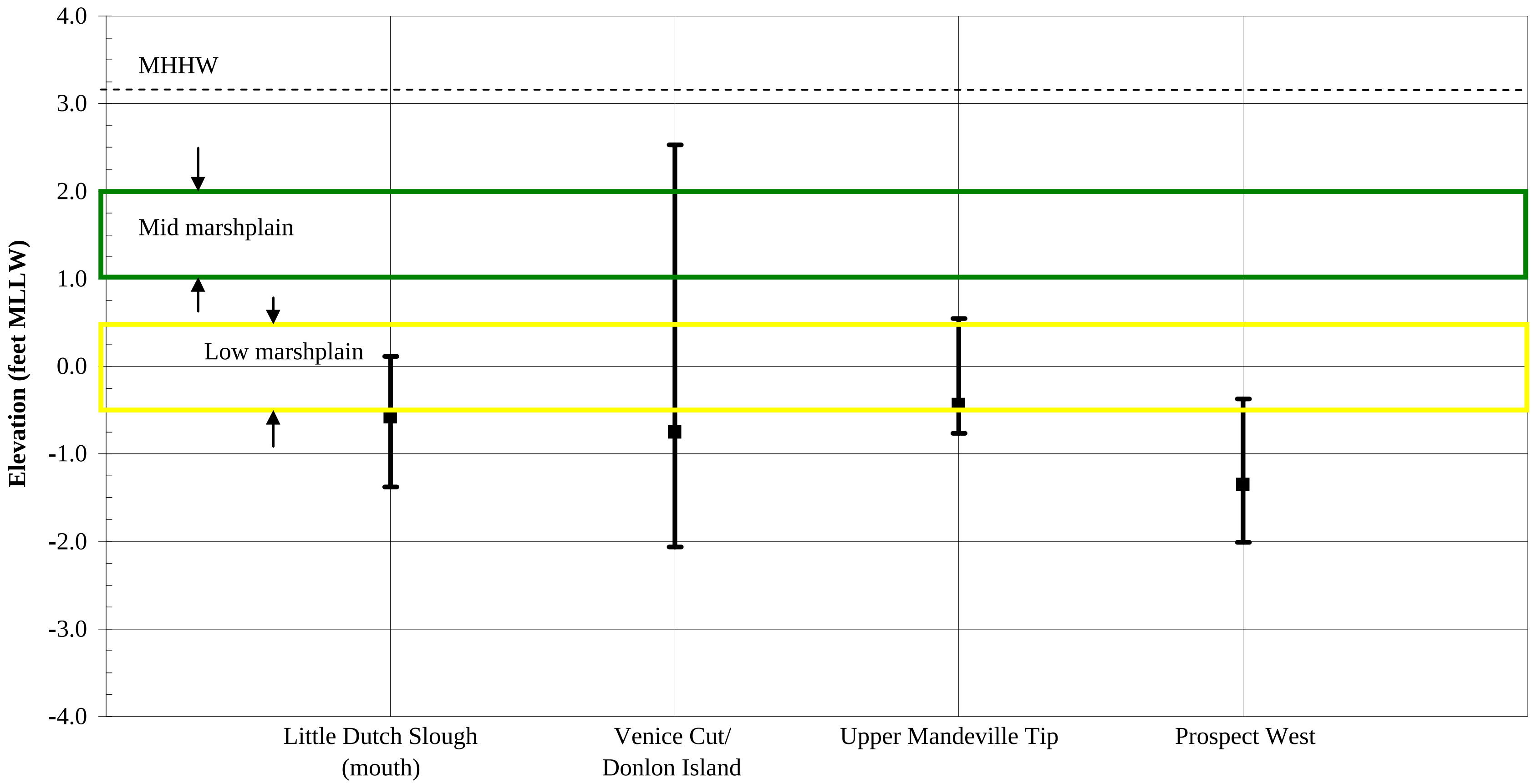
figure 12

Dutch Slough Tidal Marsh Restoration

Alternative 2: Mix of Mid Marsh, Low Marsh, and Open Water with Moderate Fill (Preferred Alternative)

PWA#: 1714 Task 6/figs jan2006Detail_Alt2.cdr

PWA



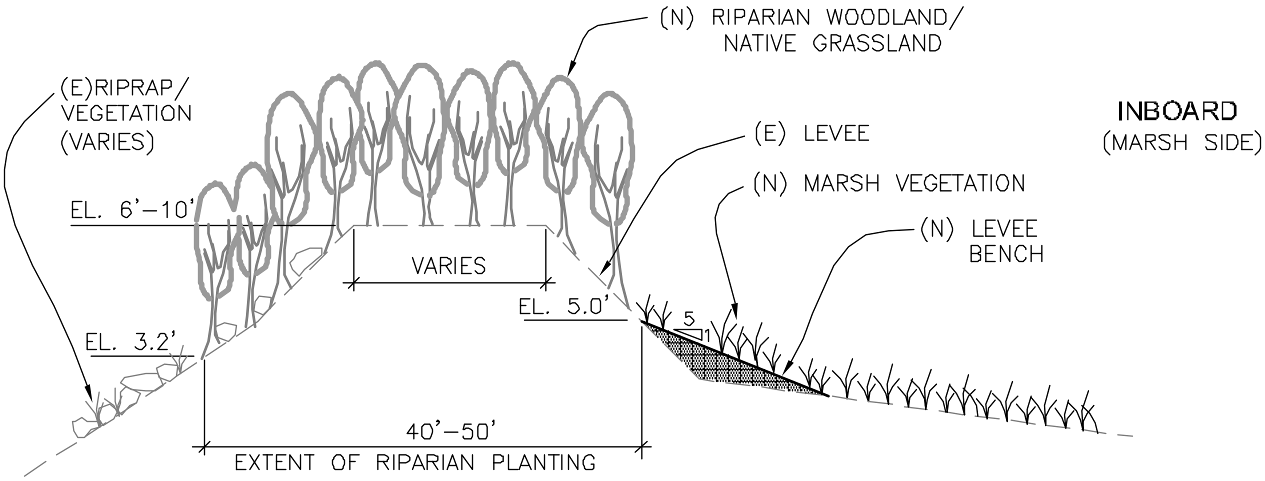
Note: The plot shows the mean and range of tule/mudflat edge elevations. The data are for mature stands of tule (not newly colonized). They represent the lowest elevation range for tule growth, with the exception of the Venice Cut/Donlon Island data, which include points from within the marshplain. Tide elevations for Prospect West may be too low. Sources: PWA surveys in Little Dutch Slough (Appendix B), Simenstad and others, 2000.

figure 13

Dutch Slough Tidal Marsh Restoration

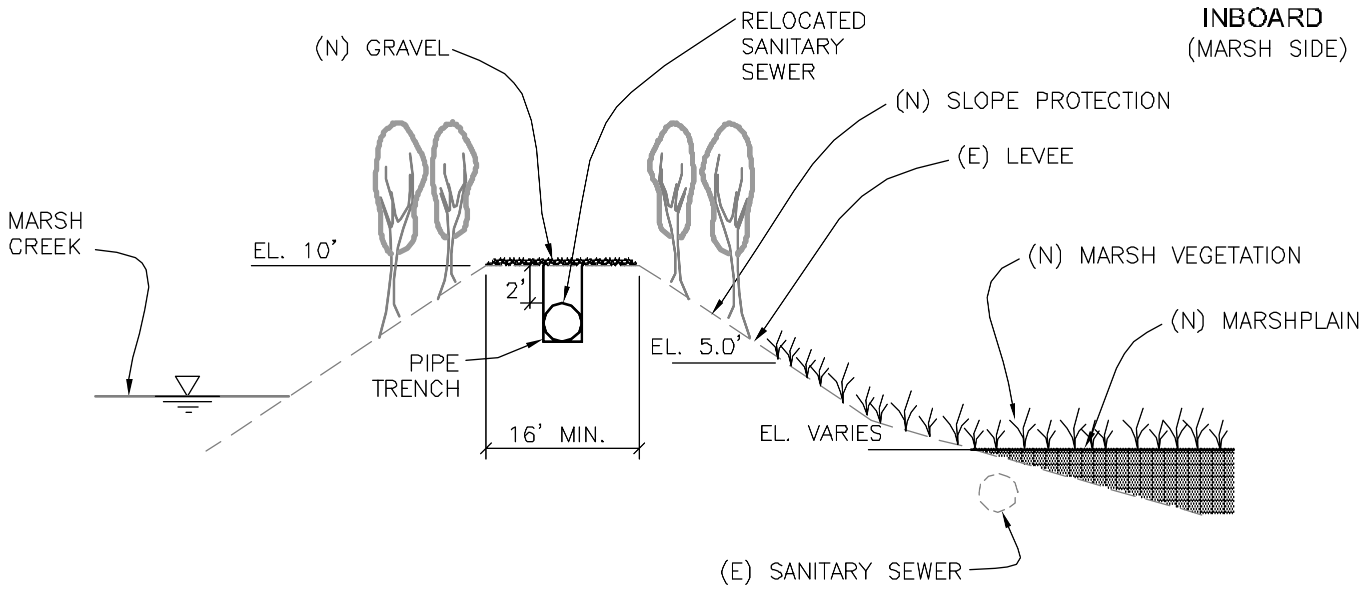
Tule/Mudflat Edge Elevations

PWA



A HABITAT LEVEE

TYPICAL CROSS SECTION N.T.S



B MARSH CREEK LEVEE

TYPICAL CROSS SECTION N.T.S

figure **14**

Dutch Slough Tidal Marsh Restoration

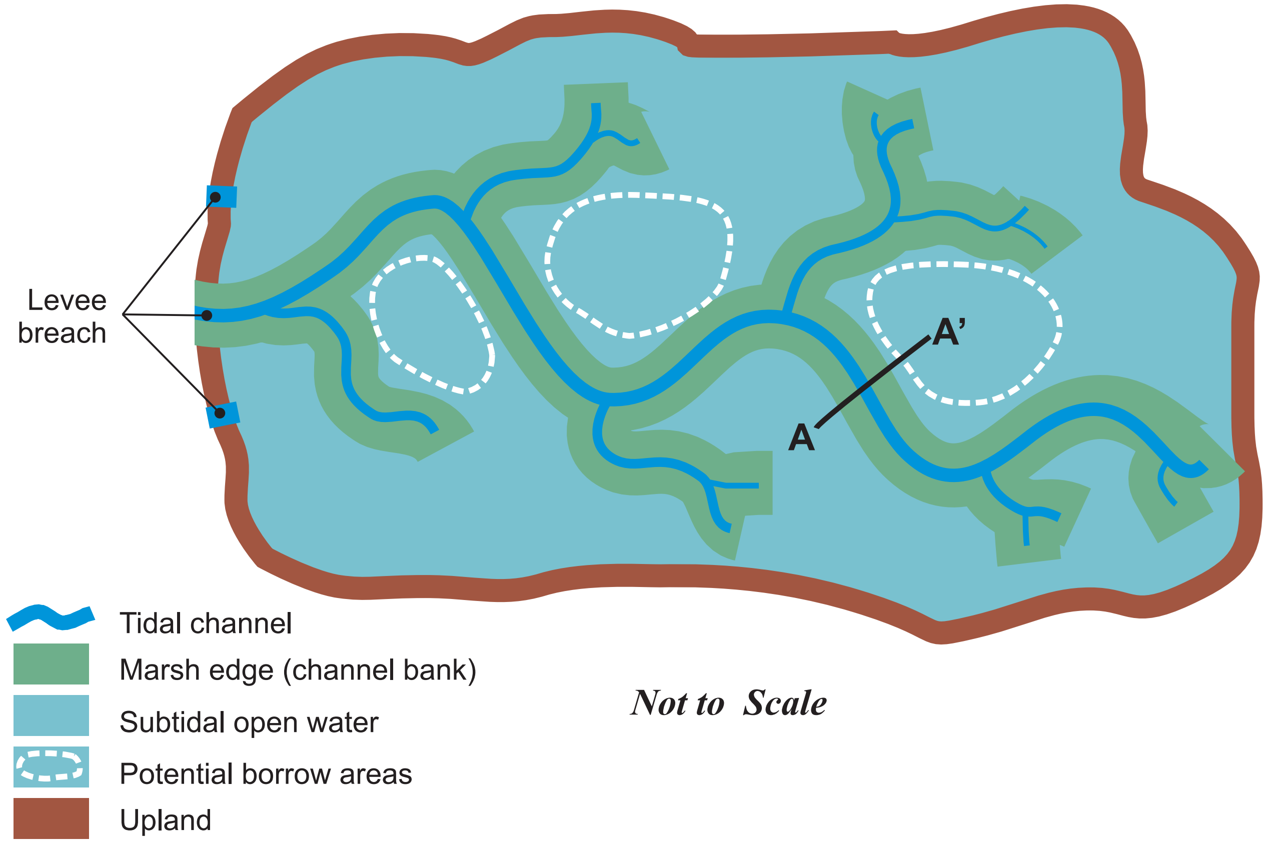
Conceptual Schematic of Marsh Creek and Habitat Levees

NOTE: ALL ELEVATIONS ARE
RELATIVE TO NGVD 29

PWA

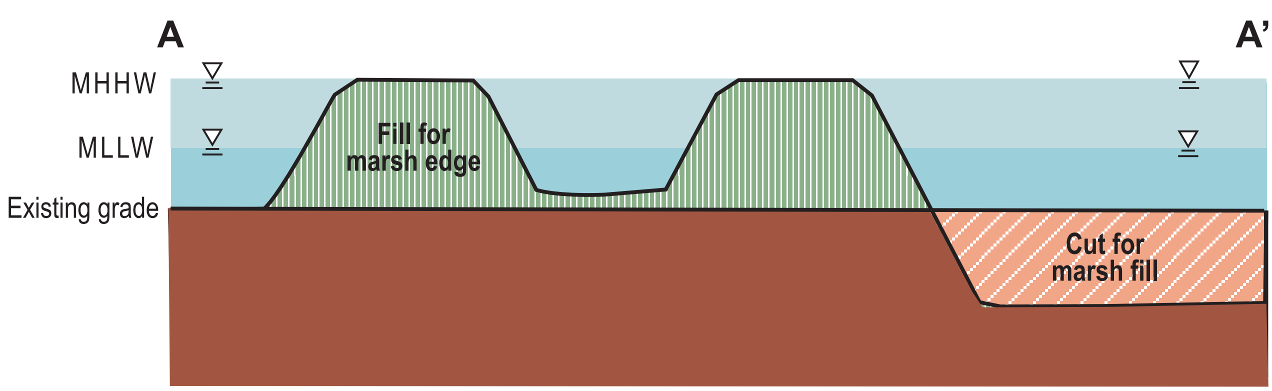
Q:\Projects\1714_DutchSlough\Drawings\1714-C-XS-TYPLEV.dwg 1-31-06 01:42:52 PM r.froio

A. Planview



Not to Scale

B. Cross-Section



Not to Scale

figure 15

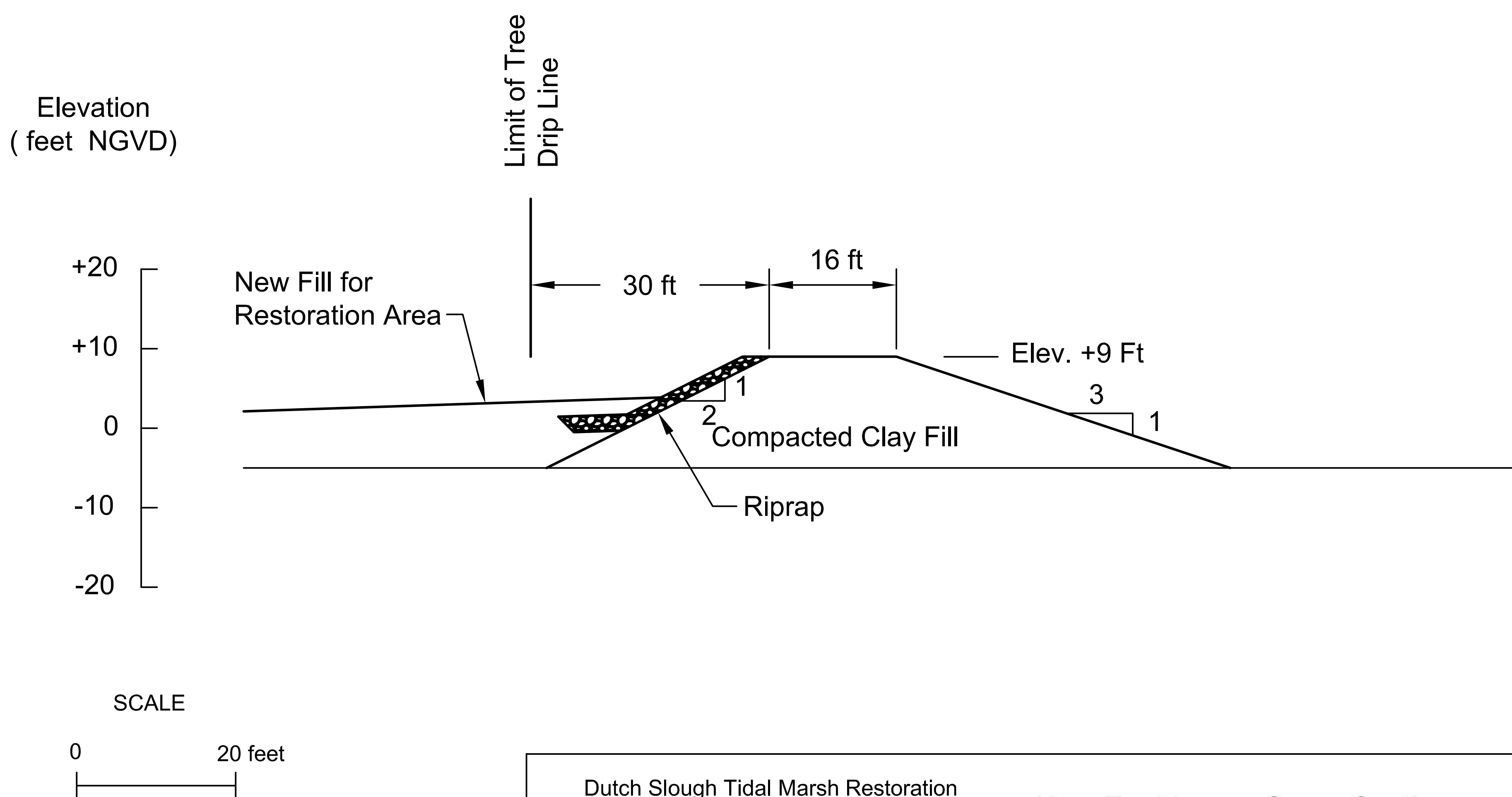
Dutch Slough Tidal Marsh Restoration

Skeletal Channel Network Option for Open Water Management

PWA#: 1714 ChannelNetwork

PWA

In-Kind Replacement Levee Section



Dutch Slough Tidal Marsh Restoration Oakley, California	New East Levee Cross-Section	
Hultgren - Tillis Engineers PWA	Project 608.01	Figure 16

APPENDIX A

Target Species for the Dutch Slough Restoration Project

APPENDIX B

Topographic and Hydrographic Surveys

APPENDIX C

Water Quality

C-1. Final Dutch Slough Conceptual Plan & Feasibility Report Water Quality Assessment

C-2. Dutch Slough Water and Sediment Quality Monitoring Plan

C-3. Reconnaissance-Level Assessment of Pollutant Sources

APPENDIX C-1

Final Dutch Slough Conceptual Plan & Feasibility Report Water Quality Assessment

APPENDIX C-2

Dutch Slough Water and Sediment Quality Monitoring Plan

APPENDIX C-3

Reconnaissance-Level Assessment of Pollutant Sources

APPENDIX D

Existing Conditions

D-1. Mercury

D-2. Special Status Species With Potential to Occur on the Dutch Slough Restoration Area

D-3. Description of Public Use in the Delta Region

APPENDIX D-1

Mercury

APPENDIX D-2

Special Status Species with Potential to Occur at Dutch Slough

APPENDIX D-3

Description of Public Use in the Delta Region

APPENDIX E

Dutch Slough Tidal Marsh Restoration Conceptual Model

APPENDIX F

Geotechnical Assessment

F-1. Geotechnical Assessment of Seepage and Levees

F-2. Peat Settlement Calculations

APPENDIX F-1

Geotechnical Assessment of Seepage and Levees

APPENDIX F-2

Peat Settlement Calculations

APPENDIX G

Planting Methods and Costs

APPENDIX H

Hydrodynamic Modeling of Tidal Drainage

APPENDIX I

Preliminary Volume and Cost Estimates by Parcel

APPENDIX J

Marsh Creek Delta Restoration Project

Prepared by:

Natural Heritage Institute