February 10, 2011

The Honorable Edwin M. Lee
Mayor, City and County of San Francisco
City Hall, Room 200
1 Dr. Carlton B. Goodlet Place
San Francisco, CA 94102

The Honorable David Chiu
President, San Francisco Board of Supervisors
City Hall, Room 244
1 Dr. Carlton B. Goodlet Place
San Francisco, CA 94102

Dear Mayor Lee and President Chiu:

Over the last 18 months, an independent team of scientists and engineers with expertise in coastal restoration has worked to prepare the attached report on Sharp Park, *Conceptual Ecosystem Restoration Plan and Feasibility Assessment: Laguna Salada, Pacifica, California*.

This restoration alternative, the most in-depth and only peer-reviewed study of Sharp Park to date, was prepared to help San Francisco create a better public park at Sharp Park. Unlike the November 2009 restoration alternative put forth by the San Francisco Recreation and Parks Department, this report is responsive to the 2009 Board of Supervisors Sharp Park restoration planning ordinance and gives San Francisco a true range of alternatives and a science-based assessment for the future of the park.

The report is authored by ESA/PWA, a renowned coastal engineering firm, with the aid of preeminent coastal ecologists and biologists. The authors have unparalleled expertise in coastal restoration and ecology and the peer-reviewers are experts in local historical ecology and coastal ecology. The report contains the best available science regarding restoration options at Sharp Park and makes several key findings:

1) The least costly restoration alternative that would most benefit endangered species at Sharp Park would remove the golf course and restore the natural ecosystem, saving taxpayers tens of millions of dollars in a time of budget crisis;

2) Restoring the natural processes of Laguna Salada will preserve the Sharp Park beach, while the Park Department's proposal will result in the beach eroding away;

3) Sharp Park historically provided more extensive habitat for the California red-legged frog and the San Francisco garter snake, and only through reviving a natural functioning coastal lagoon system can a sustainable and resilient habitat for these endangered species be maintained at Sharp Park in the face of future climate change;

4) The proposed restoration will provide improved flood and erosion protection for surrounding properties.

Sharp Park is beset by many problems, but these findings should inform San Francisco in its planning and future development of Sharp Park for a new era of recreational users. Park users in San Francisco have overwhelmingly indicated in polls, city questionnaires and public meetings that a top priority is increasing sustainability of park resources while reducing expenditures on golf. This report will help the Recreation and Parks Department match modern recreation supply to modern recreation demand in the City.

The report findings run counter to many of the controversial and unsupported conclusions of the 2009 Recreation and Parks Department report on Sharp Park. The new report addresses and dispels several misconceptions about the ecology of Sharp Park and the constraints on restoration. It unearths new data to help understand the historic and modern conditions at the site and separate myths from fact. It puts forward a restoration design concept that is based on accepted scientific understanding of coastal lagoon processes and experience gained in other nearby coastal restoration projects, rather than predetermined conclusions to support the status quo.

Again, the restoration plan attached is estimated to be far less costly than and environmentally superior to the alternative favored by the Park Department, while addressing longer-term sustainability to both natural lagoon functions and endangered species populations. We hope that this vision of restoration is helpful to decision makers as long-term plans for Sharp Park are developed.

Sincerely,

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CONCEPTUAL ECOSYSTEM RESTORATION PLAN AND FEASIBILITY ASSESSMENT: LAGUNA SALADA, PACIFICA, CALIFORNIA

Prepared for:

Wild Equity Institute
Center for Biological Diversity

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with

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February 9, 2011

ESA PWA

CONCEPTUAL ECOSYSTEM RESTORATION PLAN AND FEASIBILITY ASSESSMENT

LAGUNA SALADA, PACIFICA, CALIFORNIA

Prepared for

Wild Equity Institute
Center for Biological Diversity

February 9, 2011

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EXECUTIVE SUMMARY

Laguna Salada represents one of the best opportunities in the Central Coast region to improve and restore impaired lagoon wetland habitats for endangered species. Restoration opportunities for wetlands and endangered species are compatible with restoration of Salada Beach and broader recreational land uses in a coastal park setting. Other public benefits of restoring Laguna Salada and Salada Beach include improved flood protection to adjacent residential areas, with lower long-term costs and maintenance requirements. The restoration opportunities at Laguna Salada depend on a broad vision for long-term park land use with adaptations to sea-level rise, and without restriction to existing recreational land uses.

The Laguna Salada restoration concept presented in this report is aimed at restoring beneficial dynamics, resilience and adaptability to the Laguna Salada wetland ecosystem in a regime of changing climate, coastal processes, and sea level rise. The design concepts are based on historical and modern natural coastal lagoon reference systems that support California red-legged frog populations and garter snakes in specific sub-habitats. Key elements of the restoration design include: reduction in pumping freshwater out of the system, resulting in significantly higher and seasonally fluctuating lagoon water levels and expansion of fresh-brackish marsh landward; expansion of seasonal wetland and upland transition zones; creation of more freshwater pond refuge habitat landward of the lagoon; expansion of wildlife corridors within and beyond Sharp Park; set-back flood control levees located near the landward edge of Sharp Park and adjacent residential areas; restoration of a natural sand outlet of the lagoon; and phased replacement of the armored shoreline levee road with a boardwalk that allows the beach to retreat and adjust to rising sea level.

The existing Laguna Salada wetlands are impaired by past and ongoing impacts. Principal impacts include artificially low water levels with limited seasonal fluctuation, wetland loss due to historical fill of marsh and floodplain areas for conversion to turfgrass; eutrophication (nutrient loading from turfgrass fertilizer, at times at levels known to have toxic effects on frog larvae); excessive spread by dense, solid stands of cattails and tules across the shallow, drained lagoon; mowing of marsh and uplands, eliminating essential wildlife cover; and loss of connection to suitable upland and seasonal wetland habitats around the lagoon. Some impacts, like salinity seepage through the beach to the artificially lowered lagoon water surface, will increase as sea level rises. The existing degraded wetlands will not be sustainable in the long term as sea level rises, and will likely require increasing costs and maintenance with higher impacts to the wetlands and the beach.

The historical Laguna Salada, prior to Sharp Park construction, supported fringing marshes with cattails and bulrushes that were intolerant of high salinity. Laguna Salada was not a salt pond with salinity near seawater salt concentrations, but merely a brackish to fresh-brackish wetland like other seasonal or non-tidal coastal lagoons in the region. California red-legged frogs, and San Francisco garter snakes that prey on them, occupy seasonal fresh-brackish lagoons with cattail and bulrush vegetation south of Laguna Salada today. In the following report, we used both the historical conditions of Laguna Salada as well as reference conditions from neighboring natural lagoons to provide scientific guidance for designing the restoration of a dynamic, adaptable coastal lagoon ecosystem, including recovery measures for the endangered frogs and snakes at Sharp Park.

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1. SUMMARY

The San Francisco Parks and Recreation Department (SFPRD) is currently considering enhanced management alternatives at Laguna Salada, a lagoon within Sharp Park, located in Pacifica, CA. While the Sharp Park Conceptual Restoration Alternatives Report (SPCRAR) by Tetra Tech et al. (2009) formulated and evaluated a range of alternatives, the report focused primarily on maintaining existing land uses. The SPCRAR plans have a range of concerns including: endangered species protections, the cost and quality of the restoration alternatives, management of an ecological area in an unnatural configuration, including a levee / seawall structure extending more than 3,000 feet. In contrast, this conceptual restoration plan and feasibility analysis considers what is possible for interim and long-term wetland restoration aimed at sustainable habitat for multiple endangered species without the constraint of maintaining specific recreational land uses in the future.

This report provides additional ecological assessments of historical and modern conditions at Laguna Salada. This report also develops a conceptual plan to restore the ecologic processes, structures, and functions of Laguna Salada and Sanchez Creek, while maintaining the beach. This report more fully evaluates an alternative not previously considered that would restore more natural lagoon hydrology and expand freshwater and fresh-brackish marsh habitat and transition zones back to the eastern (landward) floodplain of Laguna Salada, at higher elevations above tides and farther from ocean influence. The natural lagoon wetland ecosystem structure and function would significantly expand endangered species habitat at more stable and sustainable positions in the landscape. Restoration goals of this alternative include long-term sustainability, restoration of endangered species habitat, flood and erosion hazard management for the surrounding community, beach restoration, public access, and low cost.

Our findings show that the Laguna Salada prior to golf conversion was a fresh-brackish, non-tidal coastal lagoon that supported populations of San Francisco Garter Snake and California red-legged frog. Available data are also consistent with the hypothesis that Laguna Salada was a dynamic fresh-brackish lagoon with a landward freshwater gradient prior to agricultural conversion. We find that only through full rehabilitation of the physical and ecological processes at Laguna Salada can a natural, sustainable, and resilient habitat for these species be maintained in the face of future climate change. In addition, the genetic health of the local populations of both frogs and snakes are dependent on a restoration plan which provides gene flow via connective corridors to outside populations. Moreover, such a restoration can, with the use of setback levees and smaller relocated pump stations, provide improved flood and erosion protection for the surrounding areas. The plan described here is estimated to be less costly than and environmentally superior to the SPCAR, while addressing longer term sustainability to both natural lagoon functions and endangered species populations. We hope that this “vision” of restoration is helpful to decision makers as long-term plans for Sharp Park are developed.

1.1 KEY CONSIDERATIONS

This and prior studies have identified topics that require further evaluation. The following "Key Considerations" are addressed by this study at a conceptual level and should be evaluated further.

1. *Coastal flooding:* our analysis indicates the coastal flood risk to the Fairway Park neighborhood is limited to about a 1' inundation around the homes on the far northwestern corner of the neighborhood, for an extreme event (approximately once in 100-year recurrence). A low earth berm or levee along the west and north side of the development is one approach that appears less costly and more reliable than the existing coastal levee. This is because a levee "set back" to the neighborhood is buffered by the seaward land and would not be exposed to significant wave action. We recommend a more detailed analysis to better assess the flood risk and flood management.

2. *Ecological Enhancement Feasibility and Cost:* Enhancement of the Laguna Salada area for ecological function (aka "restoration") is found to be feasible and have a low cost relative to other published alternatives. We recommend that these prior evaluations be updated to better represent the enhancement / restoration alternative and point out that prior decisions based on more costly plans may be revisited. While additional analysis and engineering are needed, we do not anticipate major increased costs that would reduce feasibility. The largest possible additional cost would be additional earthwork to expand the lagoon eastward or otherwise provide greater habitat resilience (see Habitat Resilience, below), and would not increase the project cost by more than 10% to 30%.

3. Historical Morphology: We conclude that Laguna Salada in its pre-disturbance state was a back-beach lagoon that was predominantly non-tidal and primarily formed by rainfall runoff pooling behind the beach ridge. The coarse-grained beach was built and maintained by strong wave action and adequate sediment supply. Our analysis indicates that the lagoon was not big enough to maintain a tidal opening against the large waves that would close it off. However, waves were (and are) large enough to overwash the beach and bring in salt water. Therefore, we conclude that salinity was controlled by fresh runoff but was variable fresh-brackish (low salinity) due to wave overwash and brief tidal incursions following breaching We anticipate a more detailed analysis of salinity under restored conditions would be required to ensure that CRLF and SFGS habitat would be sustained during wave overwash.

4. Historical Ecology: We conclude that fresh-brackish CRLF and SFGS wetland habitat existed at Laguna Salada before the golf course was constructed, when the site was modified for agriculture. We also conclude that pre-agricultural conditions could have, and likely did, include CRLF and SFGS habitat. Further research and review of historical ecology would be needed to confirm the pre-agricultural ecology of Laguna Salada. Such analysis has been instructive for other lagoon systems (Striplen et al. 2004).

5. Habitat Resilience: Salt inflow during wave overwash events poses a threat to CRLF and SFGS habitat. This risk exists and will increase with sea level rise, and the existing CRLF habitat is particularly vulnerable to ocean salt water via groundwater intrusion if managed water levels in the lagoon fall farther below rising sea level. The conceptual restoration plan mitigates this risk by expanding habitat to the east at higher freshwater flooding elevations, where overwash has less potential effect. The proposed lateral expansion of freshwater marsh landward is driven by vertical rise in lagoon freshwater levels due to a reduction in pumping which we estimate would substantially increase the width of the lagoon and extend habitat 200 to 500 feet eastward (See Figures 6 and 8, restoration plan and sections). Also, additional riparian and freshwater marsh habitat would be created along the restored Sanchez Creek Corridor, which would extend an additional 1000 feet inland. Populations in these landward areas would not likely be impacted by wave overtopping even with very high sea level rise and storm surges, providing freshwater refuges for populations that could recolonize the lagoon wetlands following a severe overwash event. Raising lagoon water levels also limits salt intrusion into groundwater, dilutes salt concentrations, and impedes salt water overwash and trapping. We recommend further evaluation of habitat resiliency and consideration of lagoon expansion to the east, including topography and vegetation that could impede wave overwash. The evaluation should include water and salt balance calculations (see below).

6. Water and Salt Balance: The hydrology and salinity of the restored lagoon should be analyzed to support further design and environmental review of the proposed alternative. The analysis conducted by Kammen Hydrology (2008) is an example of the type of analysis that should be applied, and has been applied for other projects (PWA, 2005).

2. INTRODUCTION

2.1 PROJECT BACKGROUND

Sharp Park is a 417-acre multiple use park facility owned and maintained by the City of San Francisco Recreation and Parks Department (SFRPD) in Pacifica, CA (Figure 1, Figure 2). The Park occupies a historical lowland coastal lagoon wetland complex and adjacent stream valley floodplain landward of the Sharp Park State Beach. The modern Laguna Salada is the remnant of a natural back-barrier coastal lagoon (wave-sheltered waterbody or wetland formed behind a barrier beach) within the floodplain of the historical Sanchez Creek watershed (Figure 3). The Laguna Salada lagoon lacked a persistent tidal inlet, and formed a predominantly non-tidal aquatic habitat. Its wetlands and floodplain were drained and converted to crop agriculture, and later filled to construct the Sharp Park Golf Course in the 1930s. From the 1930s to 1970s, various modifications to the beach and lagoon altered the natural hydrology of the system (Appendix A describes this process in detail). An artificial coastal embankment (levee) was constructed in the 1980s, eliminating the natural barrier beach processes that regulate lagoon outlet formation and natural lagoon drainage. The artificial coastal embankment (levee) requires pumping and artificial water management which has lowered the lagoons' natural water levels and resulted in an engineered, managed coastal lagoon wetland complex of reduced extent relative to historical conditions. Surrounding development, including HWY 1, acts as a barrier to wildlife migration and genetic exchange with wildlife populations outside the park.

Despite these significant alterations to the natural hydrology, the remnants of the Laguna Salada wetland complex continue to provide some habitat for isolated populations of the federally listed threatened California red-legged frog (CRLF; *Rana draytonii*) and endangered San Francisco garter snake (SFGS; *Thamnophis sirtalis tetratenia*). The GGNRA has worked hard to restore and provide suitable habitat for these species and enhance public access to the south of the park at Mori Point. The long-term viability of their populations and habitats at Sharp Park is a key issue for wetland management, particularly in view of 21st century climate change and accelerated sea level rise.

The U.S. Fish and Wildlife Service (USFWS) has identified the wetland complex at Sharp Park as important habitat for the SFGS (USFWS 1985, 2002). Most of the historical habitat for SFGS and CRLF at Sharp Park has been displaced by human development (e.g., fill, channelization and draining of the lagoon for agricultural practices, and construction of the golf course; Appendix A). Further, habitat quality for these species at Sharp Park has declined over the past few decades due to altered hydrology, sedimentation, vegetation, reduction of open water habitat, and lack of adjacent upland habitat (Appendix A, D; Tetra Tech et al. 2009). Concrete barriers on both sides of HWY 1 act as movement barriers and development has reduced and perhaps eliminated the connectivity of existing populations of SFGS and CRLF from other inland populations such as Arrowhead Lake, San Andreas Lake, and Crystal Springs Reservoir.

Freshwater inflows into Laguna Salada would naturally cause water levels to rise and fall seasonally, but peak and average lagoon levels are drained to artificially low levels by year-round operation of electric pumps to prevent flooding of low-lying portions of the golf course. Artificial stabilization of lagoon levels to maintain existing land uses minimizes the natural breadth and diversity of seasonal freshwater and fresh-brackish wetlands bordering Laguna Salada marshes. Maintenance of permanent low water levels in the lagoon, mowing of the floodplain, and degradation of water quality have significantly altered wetland habitat quality for wildlife. Management of drained uplands in the floodplain, including mowing, fertilizer applications, and elimination of native vegetation and burrowing mammals, have degraded and eliminated upland habitat for SFGS and CRLF, which need sheltered upland areas such as mammal burrows to survive. Pumping also harms CRLF in winter and spring by stranding adhesive egg masses on vegetation as the water surface is abruptly lowered (Tetra Tech et al. 2009). State and Federal wildlife agencies have recommended that SFRPD enhance habitat conditions in and around the wetland complex to ensure the viability of these populations and to obtain permits from them (USFWS 2005).

SFRPD retained a team of consultants to prepare a conceptual alternatives report to "develop and analyze various alternatives for restoring SFGS and CRLF habitat" within the wetland complex and surrounding areas (Tetra Tech et al. 2009). The SFRPD analyzed three habitat enhancement alternatives, presented in the Sharp Park Conceptual Restoration Alternatives Report (SPCRAR) (Tetra Tech et al. 2009), which vary with respect to configuration and extent of enhanced areas. In November 2009, the SFRPD recommended that the City pursue the alternative that maintains existing land uses at the park, while providing some enhancement of existing habitat areas in and around the lagoon (Alternative A18, Tetra Tech et al. 2009). In response to concerns about coastal erosion and sea level rise, and specifically that the managed system is not sustainable, the SFRPD is pursuing construction of a seawall along the 3,200 ft length of shore (ARUP, 2009). These combined projects are estimated to cost approximately $13 to 20M of public money as an interim measure along with operations and maintenance costs on the order of $100,000s per year (not including existing land use costs such as golf course maintenance, etc., ARUP, 2009; Tetra Tech et al., 2009).

The previous habitat enhancement plans developed by the SFRPD (PWA 1992; Tetra Tech et al. 2009) have been constrained by existing land uses and infrastructure. These constraints include the Sharp Park Golf Course and the levee constructed along the barrier beach. These plans did not compare habitat alternatives based on long-term dynamics of wetlands and coastal processes as they affect endangered species or consider long-term sustainability of existing infrastructure and hydrology in response to future sea level rise. The past filling of the Laguna Salada wetlands, land use, coastal erosion, sea level rise, and managed hydrology and maintenance (i.e., pumping, lagoon drainage, mowing), have displaced endangered species habitats out of the landward floodplain areas and confined these habitats into a vulnerable, narrow zone immediately behind the coastal levee. These changes have "squeezed" the CRLF and SFGS into the artificially drained lagoon, with uncertain long-term viability.

Even with the habitat enhancements proposed by the SPCRAR, this habitat will become increasingly vulnerable and difficult to maintain in the coming decades. Sea level rise will induce erosion and recession of the shoreline. The beach will narrow and the risk of levee overtopping and failure will increase. Eventually, the beach will become so narrow that larger and larger waves will impact the levee and the beach could be lost. This scenario is a fragile, brittle (not resilient) system prone to catastrophic failure which depends on maintenance of the levee and pumping infrastructure.

In response to the SPCRAR, the Wild Equity Institute (WEI), with support from the Center for Biological Diversity, has requested the current study to provide a long-term vision for Laguna Salada that considers coastal processes and is not constrained by existing uses on the site. This is a new restoration alternative not previously considered. This proposal expands on the previous work by proposing additional corridors to areas outside of Sharp Park so that the existing CRLF and SFGS populations have the potential to maintain long-term viability via genetic flow to outside areas. A related purpose of this report, from a scientific perspective, is to critically examine assumptions and gaps in previous studies, and introduce additional relevant scientific literature, data, analyses, and conceptual models to better understand the historical and modern ecosystem functions at Laguna Salada. Our hope is that our findings will be a platform upon which informed discussions of future restoration alternatives can be based. The team was also scoped to describe near-term actions to transition from present land use and identify aspects of the SPCRAR that conflict, if any.

The study approach was to integrate geomorphology, coastal engineering, hydrology, and ecological sciences to formulate a robust conceptual model of Laguna Salada (i.e., an integrated multi-disciplinary working hypothesis of back-barrier beach and wetland dynamics in response to sea level rise). Prior work was used to the extent appropriate. Prior work was considered well-developed in some areas such as rainfall-runoff modeling, existing species use, and the need to create suitable upland habitat for SFGS. Other areas were not adequately addressed in prior studies to inform long-term planning: these included physical processes of coastal lagoons and beaches, sea level rise, and historical ecology.

2.2 PURPOSE, GOALS, AND OBJECTIVES

The intent of this study was to evaluate the feasibility of rehabilitating or restoring the full ecosystem supporting Laguna Salada, including the beach and watershed, not just the remnant wetlands and ponds below the golf course We consider long-term restoration opportunities unconstrained by existing land uses and compare those opportunities with alternatives previously developed in other studies.

Key elements of this report include a conceptual model of coastal and lagoon physical processes and expected changes in the lagoon function with sea level rise. This conceptual model was used to develop an ecosystem “restoration” plan that provides long-term support for local endangered species populations and also accounts for adjacent suburban land use, infrastructure, recreational opportunities, and management requirements. The plan is not to be constrained by existing recreational land uses or ownership, and emphasizes natural ecology and adaptation to sea level rise. The plan considers and evaluates potential future habitat linkage for California red-legged Frog (CRLF) and San Francisco Garter Snake (SFGS) to adjacent inland areas.

In keeping with the overall biological and ecological goals of the 2009 Sharp Park Conceptual Restoration Alternatives Report (SPCRAR), we retain or adapt the following site-specific management goals adopted by the SFRPD:

- Maintain and restore aquatic habitat for listed species, particularly the SFGS and CRLF.
- Maintain and restore upland habitat for listed species, particularly the SFGS and CRLF.
- Meet the recommendations of the SFGS Recovery Plan (USFWS 1985).

- Restore high-quality, dynamic, complex non-tidal coastal lagoon wetland and terrestrial ecotone habitats that are sustainable with low maintenance.
- Comply with the requirements of state and federal regulations, including the Endangered Species Act and the Clean Water Act.
- Preserve and enhance recreational opportunities consistent with the goals for the listed species.

We modify or add the following goals to embrace a more comprehensive concern for large-scale processes and long-term population viability and resilience, and realistic long-term assumptions about external physical processes (e.g., sea level rise, coastal erosion, etc.) that drive fundamental ecosystem dynamics and trends:

- Enhance and restore ecosystem processes, structure, and functions that support listed species, particularly SFGS and CRLF.
- Adapt habitats of target species to long-term climate change and sea level rise to promote long-term sustainability of wetland dynamics and habitat quality.
- Adopt an adaptive management program promoting the need and priority to develop a long term CRLF and SFGS monitoring plan with clear feedback communications so that specific future management actions can be implemented for both species. Adaptive management must address water and sediment quality, all amphibian species populations, non-native aquatic species, and lagoon hydrology.
- Meet the recommendations of the CRLF recovery plan (USFWS 2002) and SFGS recovery plan (USFWS 1985) by creating a suite of habitats and increasing on-site viability and connectivity with neighboring populations.
- Minimize direct, indirect, and cumulative adverse impacts due to flooding and erosion to adjacent private residential properties and beaches.
- Enhance and promote sustainable long-term recreational uses, coastal access, and scenic coastal views while minimizing long-term maintenance costs.
- Adapt coastal wetland design to minimize or reduce coastal and fluvial flooding risks to adjacent residential property and roads.
- Rehabilitate native plant communities within a landscape structure adapted to long-term coastal and watershed processes.

This is a preliminary assessment subject to revision based on further analysis. This plan is intended to be the first phase of a conceptual vision for rehabilitating sustainable, resilient, improved wetland and terrestrial habitats at Laguna Salada. It does **not** intend to include the specific permitting requirements required for the concept to be implemented. If the concept is chosen to be implemented, specific documents for planning, environmental review, and permitting will need to be made under a different scope.

Given the multiple objectives of the full range of stakeholders, we anticipate that a range of alternatives will be developed, evaluated, and compared. The alternative described here emphasizes the objectives of natural ecology, flood protection for surrounding areas, public access, sustainability, and low public cost. It is the authors' desire that this report conveys an environmental vision, and fosters informed planning toward an effective plan supported by stakeholders.

3. HISTORICAL ECOLOGY AND CONCEPTUAL MODELS

The restoration or rehabilitation of a damaged ecosystem requires some basic understanding of its natural structure, dynamic processes, and composition. Historical ecology and paleoecology (study of ancient ecological conditions and trends over geologic time) can help establish reasonable ecological goals and natural models for effective ecological and geomorphic restoration designs. At Laguna Salada, careful examination of historical ecology is also important to understanding how the pre-agricultural and pre-urban wetland complex supported endangered species habitats and how those habitats were structured.

This section provides an overview and synthesis of a more detailed assessment of historical ecology evidence and analysis presented in Appendix A: Historical Ecology and Conceptual Models. The analysis and interpretation of historical ecology at Laguna Salada is informed by a physical conceptual model of seasonal and non-tidal coastal lagoons, based on detailed review of the scientific literature in coastal geomorphology. The reader should refer to Appendix A for additional discussion and references.

3.1 BACKGROUND

Laguna Salada is a type of coastal lagoon. Coastal lagoons are widespread features in stream valleys and coastal lowlands of the Central California coast. They are formed by gradual inundation of stream valleys or other lowlands as sea level slowly stabilized over the last several thousand years, following a long period of rapid sea level rise during glacial melt. Lagoons are formed by barrier beaches that enclose and shelter wetlands behind them. There are various types of coastal lagoons prevalent along the California coast ranging from tidal, to seasonal tidal, to non-tidal lagoons. Tidal lagoons, like Bolinas Lagoon, Bodega Harbor, and Drakes Estero, form where relatively large-volume back-barrier lagoons support permanent tidal inlets that are sheltered by headlands from full ocean wave exposure (Figure 4a). Tidal lagoons are regularly flooded by marine waters and generally support salt marshes dominated by highly salt-tolerant plants like pickleweed.

In contrast, small coastal lagoons and small streams fronted by beaches with direct ocean wave exposure are generally either seasonally or intermittently tidal when high winter streamflows cut through the beach at the stream's mouths. These lagoons are typically non-tidal during the low-flow dry season. When their mouths are closed and the lagoons are non-tidal, the barrier beach acts like a permeable dam and impounds freshwater inflows. These inflows fill the lagoon level above adjacent sea level during the spring-summer growing season and cause dilution of salinity in the lagoon. Heavier salt or brackish water normally forms a bottom layer in deeper parts of the lagoon, while lighter freshwater or dilute brackish water remains near the top of the lagoon, where marsh vegetation grows. This layering, or segregation, of water masses by density is referred to as "stratification" of the water column. The "perched", or higher, lagoon water level (relative to sea level) causes seaward seepage through the permeable sandy beach.

Examples of seasonal lagoons (seasonal estuaries) occur at nearly all coastal stream mouths of the Central Coast and North Coast (Figure 4b). Well-known contemporary examples include Gualala River, Russian River, Salmon Creek Lagoons (Sonoma), Redwood Creek (Big Lagoon; Marin), Pescadero Creek Lagoon, San Gregorio Creek Lagoon (San Mateo County), Laguna Creek Lagoon (Santa Cruz), Salinas and Carmel River lagoons (Monterey) – all of which support fresh-brackish water marsh (tule, cattail, bulrush, silverweed, spikerush marsh assemblages. See Appendix A for scientific names.).

Lagoons with a small size and small tributary streams are often non-tidal drainage lagoons. In this case, the wave-driven sand transport is stronger than the discharge from the lagoon, and waves build the beach berm above tidal levels. These non-tidal lagoons have a surface water connection with the ocean during the wet season, when water drains over and down the beach. These drainage lagoons are non-tidal with fresh to brackish salinities. Examples of non-tidal or intermittent seepage lagoons with fresh to fresh-brackish water marsh include Rodeo Lagoon, Abbott's Lagoon, historical Lake Merced, and historical San Pedro (Linda Mar, Pacifica) Lagoon (Figure 4c).

Salinity gradients within seasonal and non-tidal coastal lagoons generally occur with brackish marsh closest to the barrier beach and fresh-brackish to freshwater marsh upstream (landward).

Nontidal and intermittently tidal lagoons breach from back to front when they rapidly overfill with stream inflows or wave overwash and spill over and cut a channel through the beach. This generally occurs in winter storms with high rainfall and stream flow. Wave action rapidly re-closes their outlets when the lagoon levels drop. While their outlets are open, overwash or tides briefly flood the drained lagoon with seawater, but only to the level of tidal inundation (e.g. ocean tide levels). Perennial and seasonal freshwater marsh habitat above the limit of tides persists largely unaffected. After the lagoon outlet is closed by wave action and sand deposition, freshwater inflows start to fill the lagoon with freshwater, which mixes and dilutes seawater to brackish concentrations, and later stratifies fresher water over the brackish bottom water.

3.2 HISTORICAL ECOLOGY OF LAGUNA SALADA

A detailed preliminary investigation of Laguna Salada's historical ecology, and a supporting conceptual model based on the scientific literature on coastal lagoons, is presented in Appendix A. An investigation of Laguna Salada's historical ecology was important for habitat restoration planning because different scientific assumptions about Laguna Salada historical ecology support contrasting approaches to restoration. Incorrect or insufficiently tested assumptions may lead to infeasible or counter-productive habitat restoration and management plans, or important lost opportunities for recovery of endangered species in changing environments.

One widespread popular assumption about Laguna Salada's ecological history was that it was a kind of salt pond, as a literal and uncritical interpretation of its place-name suggests. This perception was reinforced by the experience of wildlife biologists who witnessed the effects of extreme marine overwash events at Laguna Salada in the 1983 El Nino storm, which resulted in flooding of the low lagoon with seawater and reported subsequent decline in red-legged frog and San Francisco garter snake populations. The assumption that Laguna Salada was historically and naturally a salt pond implied that Sharp Park construction and maintenance artificially converted it to a freshwater or fresh-brackish wetland that became colonized by snakes and frogs that could not tolerate saline lagoon wetland habitats. Recently, this assumption was adopted in the SFPCAR report's habitat enhancement design approach, but without additional scientific investigation of the historical or ecological accuracy of the "saline pond" assumption.

To investigate historical ecological and land-use conditions of Laguna Salada, with a focus on its evolution prior to Sharp Park, we compiled historical herbarium collection data, reviewed published floras, carefully analyzed and interpreted historical maps and ground photos, and compared our findings with other reference lagoons in old maps and in modern studies. Our historical ecology investigations were guided by conceptual model of coastal lagoon processes, dynamics, structure, and composition, based on careful review of applicable scientific literature and regional studies of coastal lagoons. The methods and results of this investigation are presented in Appendix A.

The results of the preliminary historical ecology investigation of Laguna Salada reveal that it was not a salt pond/saline lagoon prior to Sharp Park golf course construction. Botanical records and photographic documentation of Laguna Salada vegetation and landforms from the early 20th century indicate that the wetlands of the lagoon supported extensive marsh typical of fresh-brackish emergent marsh in decades prior to the early Sharp Park Golf period. There is strong photographic evidence that tall emergent grass-like marsh vegetation with structure like bulrush or cattail was prevalent around the lagoon prior to Sharp Park. This vegetation type is associated with California red-legged frog habitat in comparable coastal lagoons in the Central Coast region.

Despite evidence of earlier artificial breaching of the barrier beach to drain the lagoon when Laguna Salada valley flats were farmed, there are no associated records of salt marsh plants or visible (photographic evidence) indicators of historical salt marsh dominance in the marsh. This evidence is consistent with the hypothesis of relatively little change in fresh-brackish salinity range of wetland types between the agricultural (farming) and golf periods of 20th century Laguna Salada.

Laguna Salada was one of only two historical coastal lagoons in Pacifica present in the mid-19th century. San Pedro Creek lagoon (now Linda Mar) was influenced by a larger watershed and more freshwater discharge. The only other potential pond frog habitats in the Pacific watershed south of Lake Merced indicated in detailed historical topographic maps were the Skyline sag ponds. If red-legged frogs and San Francisco Garter Snakes were not indigenous to a fresh-brackish Laguna Salada, they would have had to have colonized Sharp Park jointly or in sequence before the 1950s from considerable distances to suitable remnant habitats.

Our findings support a conceptual model of Laguna Salada in its dynamic, natural condition that is based on similar coastal lagoon reference systems in the Central Coast region. Like similar lagoons, Laguna Salada maintained environmental gradients between fresh-brackish marsh at its landward end, and more brackish marsh closer to the beach. Salinity and water levels likely fluctuated strongly among seasons, filling with varying proportions of freshwater from the watershed, diluting ocean water from winter storm overwash. Most marsh occurred at the landward fringes, where it was influenced by freshwater discharge from the creek, surface flows, and groundwater from the valley. The landward edge of the marsh likely graded into broad seasonal wetland meadows and coastal grassland and scrub. Frog breeding habitat was probably concentrated along the fresh-brackish landward fringing marshes, where winter runoff and streamflow established fresh-brackish habitat in wet years. Fringing marsh elevation range in the lagoon was higher than normal tidal marsh elevation range, associated with higher lagoon levels dammed by the beach, as in most seasonal or non-tidal coastal lagoons in the region today that support California red-legged frog and garter snake populations.

These historical ecology and conceptual model findings provide important guidance for restoration design and rehabilitation of Laguna Salada habitats. They indicate the value of impounding freshwater runoff and establishing high, fluctuating lagoon levels that establish wide fresh-brackish marshes above tidal elevation range. They also indicate the importance of marsh location at the landward fringes of the lagoon, where freshwater influence is greatest (brackish dilution), and where seawater flooding potential is most attenuated. These features are reflected in the proposed restoration design, in addition to natural gradients (transition zones) between uplands, seasonal wetlands and marsh.

3.3 MODERN OPERATIONS AND ECOLOGY

The prior Enhancement Plan (PWA 1992) recommended habitat enhancement to the south and east, but at the time much of the property was privately held. Recent efforts by the National Park Service (NPS) Golden Gate National Recreation Area (GGNRA) have expanded CRLF and SFGS habitat by creating ponds at higher elevation in more sustainable areas farther east and south on Mori Ridge.

In addition to the new ponds, changes to the maintenance of the remnant Laguna Salada and surrounding golf course operations have been proposed. These changes include limitations on pumping in Laguna Salada during frog breeding season, in order to protect the frog eggs, limitations on chemical and mechanical lawn treatments, monitoring, and development of an enhancement plan (Tetra Tech et al., 2009). However, these plans rely on the levee/seawall and pump station to maintain habitat where it would not have existed historically (i.e., immediately behind the beach berm). These efforts do not address the key issue of future sustainability of critical habitat within Laguna Salada-Sharp Park.

4. COASTAL PROCESSES AND FLOODING

Coastal processes and flooding relevant to the restoration planning are summarized below and discussed in detail in Appendix B: Coastal Processes and Flooding. Coastal processes and their interaction with the Laguna Salada ecosystem were not directly considered in prior enhancement plans. An understanding of the coastal processes at Sharp Park is important to inform our expectations of future site evolution under various management alternatives.

4.1 COASTAL HYDROLOGY

The central California coast experiences mixed semidiurnal tides (i.e., two high and two low tides of unequal height each day). The tides exhibit a strong spring-neap[1] variability over a two week cycle; spring tides exhibit a large difference between high and low tides while neap tides show a smaller than average range. The highest monthly tides occur during summer and winter months. The mean diurnal range (Mean Lower Low Water to Mean Higher High Water) is 5.8 ft.

The climate in this region is primarily influenced by the Pacific High, a persistent zone of high pressure located over the eastern North Pacific Ocean. During the winter months, north Pacific storm systems affect the central portion of the state. Longer term climate variations are linked to the El Niño-Southern Oscillation (ENSO), which has a cycle of 3-8 years. During El Niño years, Central California's climate is characterized by above average rainfall and increased frequency and intensity of Pacific storms.

Storm surges during these events can act to elevate the water level above predicted astronomical tides by as much as 2-3 ft. These estimates do not include wave action and wave setup, which can significantly increase water levels at the coast temporarily during storms. The wave climate exhibits significant spatial and temporal variability due to seasonal and annual weather patterns, offshore topography, and coastline orientation. Wave heights generally range from 5-30 ft with periods from 10-25 seconds. The shoreline at Sharp Park is very exposed to large waves during coastal storm events. The 100-yr deepwater[2] wave height offshore of Sharp Park is estimated to be 32-38 ft.

Sea level rise over the past century at the Presidio tide gage has been about 8 inches (0.7 ft). For long-term planning purposes, current California State guidance recommends incorporating future rates of sea level rise of 16 inches by 2050 and 55 inches by 2100.

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[1] Spring-neap refers to a twice-monthly cycle in tide range, with spring tides having higher high tides and lower low tides due to alignment of the moon and sun with the earth: Neap tides have lower ranges.

[2] Deepwater, or offshore, wave heights are not affected by wave transformations such as shoaling, breaking and refraction and are used as an indicator of local wave climate. In contrast, shallow water, or nearshore, wave heights can vary substantially along the shore.

4.2 COASTAL EROSION

4.2.1 Historical and future rates of shoreline change

A review of prior studies indicates that the shore has eroded substantially. PWA (1992) estimated historical long-term erosion rates of approximately 3-5 ft/yr since the golf course was constructed in 1932. The U.S. Geological Survey (Hapke et al. 2006) estimated long-term shoreline erosion at Sharp Park to be 1.5-2.5 ft/yr. Recent short-term rates at Sharp Park indicate even more rapid rates of shoreline recession on the order of 2-6 ft/yr. A large fraction of this erosion likely occurred during the 1983 El Niño storms. Based on our understanding of coastal erosion processes and future projections of climate change, it is expected that future erosion rates will meet or exceed historical rates. Pending further study, long-term erosion rates on the order of 1-2 ft/yr can be expected as a minimum. The coastal erosion rates and associated maintenance costs at Sharp Park are expected to increase and may accelerate in the future.

4.2.2 Beach response to seawalls

Seawall effects on beaches are typically categorized as either “passive” or “active.” Passive erosion refers to the narrowing of a beach in front of a seawall due to the continuation of erosion processes that occurred before the seawall was built. The presence of the seawall prevents natural landward recession of the shoreline, thereby “squeezing” the fronting beach and reducing beach width over time.

Active erosion refers to an acceleration of beach erosion due to the presence of the seawall, resulting from its interaction with the surf zone. In Pacifica, the negative impacts of seawall construction can be seen directly north of Laguna Salada along Beach Boulevard (Figure 5). The photographs show the reduction of beach width over time.

The loss of beach seaward of the structure also increases the extent, duration and persistence of wave loading[3] on coastal structures, making the armoring increasingly expensive and difficult to maintain. The City of Pacifica has regularly instituted repairs to the seawall at Beach Boulevard, and now places hazardous conditions signs due to wave overtopping, and occasionally closes the road due to unsafe conditions.

In addition to passive and active effects, the footprint of the structure on the beach narrows the accessible beach width (this is called “placement loss”) (see Appendix B, Figure 4).

[3] Wave loadings refers to forces imparted by waves on the structure, and overtopping of the structure. These increased “loads” lead to increased potential for failure of the structure (e.g. collapse) and failure of its intended function (to limit flooding and prevent erosion).

4.3 MORPHOLOGY OF SHARP PARK BEACH

The beach fronting Laguna Salada is coarse grained and steep. The beach narrows northward towards the developed areas and seawalls at Clarendon Road. The sediment at Sharp Park beach is dark and coarse, contrasting with the predominant sediment farther north in the Manor District of Pacifica. Anecdotal evidence indicates that there are several sand sources in the area:

- The eroding bluffs of Mori and Mussel Rocks, possibly augmented by historical deposits of offshore sediments. These are typically coarse (pebble/gravel size to sand size) and dark; and

- The eroding bluffs of Manor (district of north Pacifica) and Daly City comprised of unconsolidated dune sands and weekly lithified sandstone. These are typically fine to medium sands, tan to brown in color.

A comprehensive study of coastal processes along the Pacifica and Daly City shoreline has not yet been completed. It appears that the Sharp Park beach is comprised primarily of sediment derived from erosion of Mori Point, accumulated over the last 20,000 years as sea level rose and stabilized. The coarser sediment can move onshore and northward under westerly and southwesterly swells. The finer, brown sands from the Manor area most likely move southward and offshore at Mori Point, unable to remain on the high energy steep beach at Sharp Park. The armoring near and north of the pier inhibits northward movement of sediment from southern Sharp Park. Therefore, except for offshore exchange[4], a natural beach at Laguna Salada should be relatively stable, neither accreting nor eroding significantly in the long term. However, historical shoreline positions show that the beach was eroded and the shore receded, as described below.

4.3.1 Historical conditions

Historical maps and photographs show that the Sharp Park beach was wide and low, with a morphology that allowed relatively infrequent wave overwash (as opposed to coastal dunes which are eroded by overwash) south of the present day Clarendon Road. The entire area was a sandy deposit that formed as sea level rose over the last 20,000 years. Wave power and sediment supply were sufficient to build a ridge of sand that typically blocked drainage from the lagoon, resulting in the formation of Laguna Salada.

A regional comparison with unaltered barrier beach reference sites indicates that the berm would equilibrate to around +18 ft NAVD (range of 15 to 20 ft NAVD). (NAVD refers to the elevation data set used and stands for North American Vertical Datum.) This condition is approximately represented by Rodeo Lagoon Beach in Marin County (Figure 4). Appendix A provides the supporting data. This elevation is close to the typical annual runup elevation[5] based on calculations conducted by PWA (2009).

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[4] Offshore exchange refers to the movement of sand between shallower and deeper depths, often also referred to as "cross-shore transport." Offshore exchange is typically forced by a change of wave conditions, which are typically observed as seasonal changes to beach width and storm-induced changes.

[5] Annual runup elevation is total water level elevation that is exceeded about once per year.

4.3.2 Existing conditions

The Sharp Park beach exists in front of an armored coastal structure. The back beach appears to be artificially elevated against the earth levee, which directs wave runup upward, and creates a narrower but locally higher and steeper beach than would occur naturally. Narrow steep beaches tend to increase wave reflection and the size and intensity of shorebreak waves, and enhance the potential erosion during extreme events. Additionally, the steep beach conditions enhance wave runup, and the potential to overtop the levee crest. Conceptually, wave runup is a process of dissipating wave momentum, which is dissipated by frictional effects and gravity: For a given amount of momentum, runup can be dissipated by being forced high into the air (against gravitational acceleration) or by horizontal travel. A levee forces wave runpup upward while a natural shore allows greater lateral travel.

While dune building and stabilization in the 1920s to 1940s altered the natural beach berm morphology, a significant coastal structure did not exist until decades later. A review of historical photographs and documents indicates that the existing levee was not constructed until the 1980s. The majority of the coastal levee/seawall was constructed in 1989-1990. Approval for this (and future) construction appears to be partly based on the assumption that a contiguous levee or seawall existed prior to the 1983 storms, based on a declaration of categorical exemption from CEQA from the City of Pacifica (see Appendix B of Geomatrix 1987). A review of available photos prior to 1983 shows an earth embankment at the north and south ends of the shore, with no embankment in the middle third. The embankments are not as large as the existing levee and proposed seawall structures, and do not extend the full length of the shore. Therefore, the implication by Pacifica's categorical exemption that the existing levee and proposed upgrades are a replacement and/or maintenance of a similar prior structure is not supported by available information.

To our knowledge, a review of the potential adverse effects of the berm (or levee, seawall) on the coastal and lagoon habitat has not yet been completed. This is astonishing, given its dimensions of about 3,200 linear feet, a crest elevation of +30 ft NAVD, and its construction more than a decade after the California Coastal Act (1976).

We recommend that future modification of the levee (as proposed by SFRPD) should be subject to a full environmental review of potential impacts to the beach, lagoon hydrology, and habitat over the long term and relative to historical conditions.

4.3.3 Future conditions

4.3.3.1 Managed conditions with seawall

Relative sea level rise will induce erosion and recession of the shore. If the hard edge of the levee/seawall is maintained, the beach will narrow and the levee will be overtopped more frequently (or raised to prevent overtopping). If the levee is maintained, the beach will become so narrow that larger waves will frequently impact the levee/seawall and the beach will be largely lost. This condition has already occurred north of the pier at Beach Boulevard (Figure 5), which is overtopped multiple times each winter, and requires frequent, intensive maintenance. Therefore, over time, progressively increasing risk of failure can be expected. While levee/seawall failure at Laguna Salada may not harm CRLF and SFGS populations on the inland/east side of the lagoon, failure of the levee or wave overwash could devastate the existing CRLF population and SFGS habitat at artificially low marsh elevations where they currently exist.

The proposed SFPRD enhancement plan of Laguna Salada relies on a seawall and highly managed pumping system to maintain the habitat closer to the ocean than would exist naturally. As sea level rises and beach erosion continues, the risk to the habitat will increase and make its maintenance difficult and likely not feasible.

4.3.3.2 Natural conditions without seawall

If the levee is not maintained, it will erode and a wide sand barrier beach will re-form. The elevation of the berm will be close to the existing beach elevation (approximately 18-20 ft NAVD), with relatively gentle shallow wave overtopping occurring annually. The wave action will transport sand inland and build up the beach-barrier, conceptually rising and migrating landward with sea level rise. A phased shift of habitat from its existing location at Horse Stable Pond to the eastern fringe of Laguna Salada would occur over time (discussed later in Section 6.4). CRLF and SFGS habitat along the eastern side of Laguna Salada, away from high salinity ocean water, would expand and likely occur naturally in most years.

4.4 RAINFALL/RUNOFF FLOODING

Rainfall runoff enters Laguna Salada from Sanchez Creek and storm drains serving adjacent neighborhoods. Discharge entering Laguna Salada is impounded behind the seawall, which prevents natural drainage to the ocean, where it collects and is later pumped out onto the beach. Assessments of rainfall/runoff flooding in Laguna Salada were completed by PWA (1992) and Kamman Hydrology & Engineering (KHE 2009). KHE (2009) estimated 2, 5, 10, 25, 50, and 100-yr flood levels in Laguna Salada for a 24-hr rainfall event. The modeling assumed operational pumps at Horse Stable Pond (southwest portion of lagoon, Figure 2) and an initial lagoon water level of 6.8 ft NAVD. Peak flow rates were found to be approximately 5 to 25 times greater than the pumping capacity, and added an additional 2 to 8 feet of water to the lagoon for a 2 and 100-yr storm, respectively. Flood levels ranged from 9 to 15 ft NAVD. Failure of the pumps during a storm, or an initially elevated lagoon water level (e.g., due to adjustment to keep CRLF egg masses from stranding or a prior rainfall event), would result in even higher flood levels. Detailed results are discussed in KHE (2009) and summarized in Appendix B.

4.5 COASTAL FLOODING

The Sharp Park site is very exposed to large waves. The long period waves result in strong wave setup, which can elevate water levels at the shoreline and allow much larger waves to impact the beach and levee. As waves break and runup on the beach, waves can overtop the crest of the levee. The following sections describe previous coastal flood studies for Pacifica and evaluate the present day coastal flood hazards at Laguna Salada.

4.5.1 Summary of previous coastal flood studies

The effective flood study is the 1987 FEMA Flood Insurance Study (FIS) for the City of Pacifica, CA, San Mateo County (FEMA 1987), which estimated the Base Flood Elevation (BFE), or 100-yr wave runup elevation, to be 27 ft NGVD (29.8 ft NAVD). FEMA is currently in the process of updating the Pacifica Flood Insurance Rate Map (FIRM). The BFE for the revised preliminary map is 30 ft NAVD.

The BFE estimate indicates the highest **potential** runup elevation attained by waves breaking and running up the beach and levee surface. This potential elevation is the elevation that the structure or other barrier would need to achieve to prevent water from overtopping it, and this potential runup elevation is used in FEMA flood maps in the vicinity of barriers. This is the 30 ft NAVD elevation identified in the previous paragraph. In reality, water rushing up the face of the levee or other barrier typically has forward momentum and it takes a trajectory that reaches a lower height but overtops the structure. When the runpup is calculated to exceed the barrier crest, a process called “wave overtopping” occurs. The rate and volume of overtopping is used to estimate the potential for flooding inland of the levee or other barrier. Once the wave overtops the levee and carries water over the crest of the levee, the water propagates in shallow but rapid flow and then collects and ponds on the landward side. Thus, the wave runup elevation is not the same as the resulting flood inundation level on the landward side of the levee (or other barrier such as a beach and dune or seawall). Therefore, the flood inundation level on the landward side of the levee is different than the FEMA BFE. Geomatrix (1987) estimated the volume of wave overtopping of the 1980s unprotected coastal embankment; however, modifications to the beach over the past 20 years and construction of the levee have rendered this assessment out of date.

4.5.2 Landward coastal inundation by wave overtopping

Coastal flood hazards for the 100-yr coastal storm event were evaluated for three cases at Laguna Salada:

1) **Existing levee** – wave overtopping of existing levee
2) **Degraded levee** – wave overtopping of existing levee with levee crest degraded by 2 ft during coastal storm event
3) **Natural barrier beach –** wave overtopping of natural wave-built barrier for restored lagoon conditions

Details of the landward inundation calculations are described in Appendix B. A 4-hour overtopping duration was selected, which conceptually allows for overtopping to occur before and after peak high tide. Inundation calculations assume that wave overtopping occurs over 800 ft of levee, which is the existing length with average crest elevation of 29 ft NAVD. For the degraded levee case, we assume that erosion of the levee during a coastal storm event would lower the levee crest by approximately 2 ft to an elevation of 27 ft NAVD. The implication is greater wave overtopping and inland flooding.

Overtopping rates and volumes for the existing and degraded levee cases were estimated to determine the extent of landward inundation assuming an initial lagoon water level of 6.8 ft NAVD. Wave overtopping of the levee was found to raise lagoon water levels by approximately 3 and 10 ft to an elevation of 10 ft NAVD and 17 ft NAVD, respectively, for the existing and degraded levee cases. The methods used for these calculations are simple and conservative (provide high overtopping estimates). Lagoon inundation is likely overestimated. The calculated elevations are close to the elevations for rainfall-runoff flooding (see Section 4.4 Rainfall/Runoff Flooding).

Overtopping rates of the natural barrier beach (restored lagoon) case for a 100-yr coastal flood event were not estimated, although substantial overtopping would occur. However, the presence of an unarmored natural barrier beach would allow both overtopping and free outflow from the lagoon to the ocean during a storm. As a result, the maximum lagoon flood elevation would be controlled by the elevation of the barrier beach berm. As discussed in Section 4.3.1, we estimate a maximum restored natural beach berm elevation of approximately 20 ft NAVD, and therefore estimate a high water level of about the same elevation: That is wave overtopping would be balanced by a backflow of water to the ocean. Under this scenario, wave action would scour the beach, create one or more drainage channels and limit lagoon water levels. Once one or more channels form, the lagoon level can rapidly drop and end up lower than pre-event levels.

This analysis indicates that the flood elevations published for the beach at levees, seawalls, and cliffs (+30’ NAVD) is much higher (at least 10’) than can be expected farther inland at Fairway Park even without a levee present (maximum flood elevation estimated to be +20’ NAVD). Accounts of overtopping into Laguna Salada in 1983 are not precise but are consistent with lagoon levels lower than +20’. More detailed analysis methods are recommended for future studies.

4.6 COMBINED FLUVIAL AND COASTAL FLOODING

Flood levels within Laguna Salada are due to the combined effects of rainfall runoff, discharge from Sanchez Creek, and wave overtopping of the outboard levee. As previously discussed, the landward coastal inundation flood level has not previously been determined for a combined event under existing (or future) conditions at Laguna Salada. Using the fluvial flood results from Section 4.4 and the coastal flood results from Section 4.5, we estimate the lagoon flood level due to a combined coastal and rainfall/runoff event. An initial lagoon water level of 6.8 ft NAVD was selected based on assumptions made in KHE (2009) for the rainfall/runoff modeling.

While the joint probability of coastal flooding and elevated rainfall runoff are not known, a 10-year rainfall event coincident with a 100-yr coastal event is recommended for conceptual planning until more detailed analysis is accomplished. For this storm event, we estimate flood levels of between 13 and 20 feet depending on the condition of the levee. Since some degradation of the levee is likely during a severe overtopping event, the higher elevation may be more likely.

The 1983 coastal flood event was reportedly severe and is considered to be representative of the 100-year coastal flood event. Rainfall runoff reportedly contributed to the flooding. The resulting flood levels did not achieve the elevations described herein (e.g., +20’ NAVD), and hence the combined flood elevations reported are expected to be high, probably due to the overestimate of wave overtopping volumes.

4.7 GROUNDWATER AND PUMPING

Water levels within Laguna Salada are currently maintained by the operation of a pumping station (combined capacity of 11,500 gpm) at the southern end of the historical lagoon at Horse Stable Pond (Figure 2). The pumps are activated when lagoon water levels exceed 6.9 ft NAVD. The pumps convey runoff from the lagoon to an outfall on the beach and prevent flooding of the golf course by continually pumping down the lagoon water level.

The direct ecological implications of pump operations are discussed in Section 1. An indirect effect of artificially lowering the lagoon water level is increased vulnerability to groundwater salinity seepage from the ocean to the lagoon. While the typical direction of groundwater seepage is from the lagoon to the ocean, a lowered lagoon water level reverses the gradient. KHE (2009) noted that under certain conditions, the groundwater gradient may reverse and allow higher salinity groundwater to flow into the lagoon. Field observations by the ESA PWA team in spring 2010 revealed saline seeps emerging in golf turf patches immediately behind the coastal levee at the north end of Sharp Park (see Appendix D. Ecological Assessment and Appendix F. Summary of Salinity Intrusion at Laguna Salada). The saline seeps occurred coincident with high winter tides and storm waves, which act to elevate beach groundwater levels, which in turn cause a reversal in the typical seaward groundwater flow through the beach berm (Isla and Bujalensky 2005; Carter and Orford 1984).

Landward salinity intrusion to Laguna Salada by reversal of groundwater gradients at the barrier beach is already happening, and is likely to increase and accelerate as sea level rises, storm waves increase in magnitude and frequency (Allan and Komar 2000), and as the shoreline retreats (Hapke et al. 2006, Hapke et al. 2007).

5. EXISTING CONDITIONS ECOLOGICAL ASSESSMENT

The ecological functions of the existing Laguna Salada wetland complex are affected by past and ongoing impacts within the wetland complex, and indirect influences of the surrounding landscape and watershed. In this section, we reassess past and present impacts to the back-barrier wetland ecosystem at Laguna Salada, with emphasis on factors that affect current and long-term habitat for special-status wildlife species (San Francisco Garter Snake, California red-legged frog, and western pond turtles). Both long-term cumulative impacts and short-term impacts are considered. Special-status species habitat abundance, distribution, quality, and dynamics depend on larger-scale coastal lagoon ecosystem processes that must be considered in this context. Detailed analysis and interpretation of ecological conditions are presented in Appendix D: Laguna Salada Ecological Assessment. An overview is presented here.

5.1 LONG-TERM ENVIRONMENTAL IMPACTS

5.1.1 Urban Development and Genetic Isolation of SFGS and CRLF at Sharp Park

The existing population of SFGS at Sharp Park is thought to be small and not very robust. SFGS were documented to occur at Laguna Salada in 1951 by W.L Fox, but not in great numbers.
SFGS were detected at Horse Stable Pond as recently as 2008, but have not been detected during the most recent (2009) surveys at this location (Swaim 2009). Although SFGS have not been seen during other species surveys, the status of SFGS at Arrowhead Lake, Sanchez Creek, or the lagoon or should not be assumed as absent as these areas have not been thoroughly assessed. SFGS are known to occur in the North Pond, on the hill-slope a few hundred feet to the east of the Horse Stable Pond by GGNRA Staff Biologist and at the nearby Mori Point Ponds (Swaim 2008). The existing potential SFGS habitats at Sharp Park's Arrowhead Lake, Sanchez Creek, the Lagoon and Horse Stable Pond need well timed and focused SFGS surveys that include sex ratios so that the population and potential for future viability at Sharp Park can be better understood. It is critical to focus the upland as well as aquatic habitat enhancements and creations (see 2.2 goals and objectives) for the SFGS so that the existing population has a chance to become more robust. It is equally important to provide dedicated SFGS movement corridors with a mix of basking and vegetative cover (not shared with recreational use such as walk or bike paths) for SFGS within Sharp Park and to adjacent areas. If such dedicated SFGS corridors are made, populations from the neighboring Mori Point or North Pond have a better chance for successful range expansion attempts.

The Laguna Salada SFGS population is on the northernmost edge of the species range (USFWS 1985), and may be important for genetic interchange between other populations further south. However, surrounding development has become a barrier to SFGS movement into and out of the park, isolating park populations from outside genetic flow. Concrete highway barriers occur on both sides of HWY 1 adjacent to Sharp Park and Mori Point. While these barriers protect SFGS from vehicular traffic they also act as movement barriers. Dense urban development immediately north of Sharp Park and south of Mori Point and the quarry in Pacifica, combined with HWY 1 to the east, have isolated the existing population in what ecologists refer to as a "land locked island habitat". These modifications have isolated Laguna Salada populations from the east side of Sharp Park, Arrowhead Lake and other undeveloped areas.

The east section of Sharp Park is adjacent to undeveloped lands with existing passage for wildlife (snakes, frogs, and their prey and predators) to other known locations of SFGS at San Andreas Lake and Crystal Springs Reservoir. This potential corridor area is critical to the long-term recovery of the snake as it is the only place where such a "land bridge "from Sharp Park to other populations can occur.

5.1.2 Filling of floodplain and permanent lagoon drainage

The filling of the floodplain and permanent drainage of the lagoon to artificially low water levels are the primary controls of ecosystem structure, dynamics, and functions at Laguna Salada. These alterations are the primary constraint on quality and sustainability of endangered species habitats (freshwater marsh, seasonal wetlands, riparian scrub, and terrestrial ecotones). The artificially pumped down water level (maximum of +7.5 ft NAVD) is the primary hydrologic control of marsh elevations within the lagoon relative to (rising) sea levels. The marsh fringing the lagoon is forced to occupy an artificially narrow zone, within a few feet of the lagoon bottom, and close to the elevation of the highest tidal elevations.

The most fundamental consequence of maintaining perpetual "drought" lagoon levels at a narrow elevation zone near high tide elevation is that almost all the fresh-brackish marsh habitat is forced down to a low elevation behind the levee where there is a potential for flooding by seawater from overwash. Fringing marsh elevations at natural non-tidal coastal lagoons support fringing fresh-brackish marsh at elevations mostly above the tidal range, where they occupy a zone in equilibrium with lagoon water levels maintained by beach-impounded stream inflows and groundwater. Examples include managed Laguna Creek Lagoon and Rodeo Lagoon. Elimination of high lagoon flood levels that approach the beach crest elevation (at Laguna Salada, close to 20 ft NAVD), i.e., draining all wet-season freshwater storage of the lagoon, confines the marsh habitat to near the bottom of the lagoon.

When natural lagoons breach, or when waves overwash, seawater flows into the lagoon basin. Overwash and brief tidal inflows have relatively little impact on the marsh habitat that exists above tidal range, and almost no impact on the landward freshwater reaches of lagoon gradients, which function as freshwater refuges. At Laguna Salada, where the marsh zone is mostly at or below the high tide elevation range, almost all the marsh habitat today is subject to seawater flooding. The potential salinity impacts of seawater flooding at Laguna Salada are due primarily to indirect effects of long-term drainage by pumping in low marsh elevations relative to sea level. This impact risk will inevitably increase as sea level rises, while marsh zone elevations and topography remain fixed.

The potential freshwater refuge habitat at Laguna Salada is almost non-existent because the landward end of the salinity gradient – the floodplain at the east end of the lagoon - is filled and converted to well-drained turfgrass, and because Sanchez Creek is channelized and forced to discharge at elevation ranges subject to extreme high tidal flooding. In natural lagoons, the landward freshwater end of the floodplain wetland complex extends beyond the reach of maximum tidal surge or overwash. The 1869 U.S. Coast Survey map of Laguna Salada shows no single-thread Sanchez Creek channel, but it shows three slender distributary channels extending through the eastern floodplain marsh of the lagoon (Figure 3). This structure indicates that freshwater discharge was distributed through floodplain wetlands before crop agriculture and ditching for drainage occurred. Artificial fill for golf links, placed in the late 1920s, steepened the seasonal wetland gradient of the drained floodplain, compressing all freshwater wetlands in a narrower zone closer to Salada Beach – resulting in "coastal squeeze". The freshwater compression towards the coast forced potential freshwater marsh refuge habitat into the seaward fresh-brackish lagoon zone, where it is more vulnerable to episodic overwash flooding. This precarious landscape-level wetland habitat structure is maintained today for recreational land uses. The "coastal squeeze" of the lagoon wetland complex to a narrow zone behind the barrier beach – the zone that is naturally the most brackish and disturbed – forces a conflict between natural beach migration in response to rising sea level (adapting shoreline position and elevation, conserving the beach) and maintenance of the freshwater refuge end of the fresh-brackish lagoon wetland gradient.

Other indirect effects of "perpetual drought" caused by lagoon drainage include the interaction between tule and cattail depth tolerance and the depth gradient of the drained lagoon. The drainage of the lagoon brings most of the lagoon bed shallows within the depth tolerance for tules and cattails, which can grow in standing water depths under 1 m (3.3 ft). Eliminating the natural prolonged high seasonal lagoon stands results in widespread deepwater conditions above the submersion tolerance of tules and cattails and restricts their lateral expansion. Draining the lagoon to a constant shallow depth enables tule-cattail marsh to spread over the shallow gradient (water less than 3 ft deep) of the lagoon, progressively encroaching into open water at variable rates inversely proportional with depth. In contrast, natural lagoons with prolonged periods of widespread deepwater restrict the spread of tules and cattails, due to submersion intolerance. Some open water areas are needed for SFGS to forage on tadpoles. Artificial drainage and elimination of prolonged high lagoon stands, not sedimentation, are primarily responsible for marsh encroachment of Laguna Salada. This is a key component of the conceptual restoration plan presented in Section 1.

Perpetual artificially low lagoon levels relative to saline beach groundwater levels, which are raised by wave runup above still-water tidal elevations, increases the lagoon's risk of salinity intrusion as sea level rises. Lagoon water levels above sea level and beach groundwater levels are needed to maintain positive seaward seepage flows and exclude salt or brackish water inflows from the beach to the lagoon. Salt seeps, indicated by efflorescent salts on turfgrass patches during rainless periods in winter when high waves and tides occur, were observed in 2010 (Appendix C), and brackish groundwater near the western lagoon edge has been confirmed by previous analyses (KHE 2009). Simply put, more freshwater retention (less pumping and artificial drainage) is needed to buffer against salt water intrusion and wave overtopping.

Natural deepwater lagoons behave differently than shallow water lagoons as greater water depths allow for stratification (or separation) of the water column. This allows heavier saltwater to sink to the bottom with fresher water on top (see Appendix A). CRLF have porous skin and require freshwater conditions to survive, with salinity intolerance levels of approximately 9 – 10 ppt for adults (Smith, 2007 and pers. comm. 2010, McGinnis 1986), 5-6.5 ppt for tadpoles (McGinnis 1986; Jennings and Hayes 1990; Reis 1999), and <4 ppt for eggs. The fresh surface layer can be important to adult CRLF movement to refuge areas. Shallow water lagoons subject to wave overtopping do not have the same ability to stratify captured salt water, and the salty surface layer can act as a barrier to adult CRLF movement. SFGS have scales and impermeable skin, and therefore do not have the same salinity intolerances as do frogs. However, SFGS rely on frogs and tadpoles as a food source, and therefore habitat loss occurs with the loss of frog populations.

5.2 SHORT-TERM ENVIRONMENTAL IMPACTS

5.2.1 Pumping for lagoon drainage

Artificially abrupt and recurrent fluctuations of lagoon water levels are caused by pump activation during the breeding season of California red-legged frogs. CRLF will lay eggs from November (with earlier records in more southern locations USFWS) to late May (Reis 2006-2009) depending on the water year and site location. At Laguna Salada, including Horse Stable Pond and the connecting channel, and Arrowhead Lake, CRLF eggs have been observed in January and February (Swaim Biological 2008). The artificially abrupt fluctuations have caused stranding of adhesive egg masses on vegetation at the water surface – an impact that has been documented in previous years (SFRPD 2006). This is a current and ongoing impact, rather than legacy impact of past fill and landscape structure that has been maintained.

5.2.2 Terrestrial ecotone displacement and exclusion

The natural transition between perennial freshwater marsh, seasonal freshwater marsh and willow thickets (swamp), and transitional (ecotone) terrestrial habitats at the landward edges of the lagoon is maintained as an abrupt mowing line that extends into freshwater marsh: golf turf encroaches directly into the marsh. The “turfgrass” bordering the marsh is composed of strong wetland indicator species (brass-buttons, bulrush, silverweed, creeping bentgrass) that dominate the adjacent marsh, mown down to the height of turfgrasses. The ongoing mowing and drainage of the golf turf in wetland habitat zones, and elimination of seasonal high lagoon stands, erases the natural wide transition zone between terrestrial vegetation, seasonal wetland rush and sedge meadows, and emergent marsh. No buffer zones between primary wetland habitats and uplands occur above or even within a seasonal wetland zone.

Adult CRLF forage on rodents (mice) along the water’s edge, insects and treefrogs. CRLF need moist upland areas and will spend as much as 77 days away from water (Appendix D). The SFGS needs a mix of small basking areas with immediate or nearby cover from predatory birds and mammals. Elimination of gophers and other burrowing small mammals to maintain smooth turfgrass eliminates essential burrow habitats to which treefrogs and CRLF retreat for moisture refuges in summer while they forage in upland areas, and where San Francisco Garter Snakes forage for them. Mowing and turf maintenance also eliminates tall vegetation canopy (including rush mats) and large woody debris that provide moist cover for frogs, basking area for SFGS, as well as emergent dispersal corridors inland of the marsh for both snakes and frogs.

Optimal upland basking and refuge habitat for SFGS consists of native grassland and shrubs which provide a combination of small open patches immediately adjacent to vegetation cover. Rodent burrows or large soil crevices that remain unsaturated throughout winter provide upland retreats. SFGS basking and refuge habitat should be located within close distance to the water's edge. Under existing conditions, this type of habitat is limited to an area south of Horse Stable Pond.

5.2.3 Nutrient loading and biogeochemical impairment

Fertilizers applied to turfgrass, regardless of chemical form (organic or soluble salt), load nitrogen in the immediate watershed of Laguna Salada. Nitrogen compounds are the most abundant nutrient in turfgrass fertilizers (Goss 1972). Turfgrass fertilizers are apparently applied adjacent to and even within mown marsh turf at the lower turfgrass edge bordering the marsh at eastern Laguna Salada. Past measurements of nitrate and ammonium (forms of nitrogen) in Laguna Salada have occurred within the range known to have ecotoxic effects on treefrog and CRLF tadpoles (see Appendix D). Swaim Biological (2008) observed unexplained absence of California red-legged frog tadpoles in the main lagoon, despite egg masses and suitable salinity ranges. Previous assessments of Laguna Salada habitat expressly declined to evaluate fertilizer impacts on water quality and habitat of frogs (Tetra Tech et al. 2009, Swaim Biological 2008). Nitrate, nitrite, and ammonium (all inter-convertible forms of nitrogen produced by microbial activity in marshes) even within allowable EPA standards for human drinking water can have ecotoxic effects on treefrog and CRLF, causing developmental problems, disorientation, and death (Marco and Quilchano 1999, Nebeker and Schuytema 2000, Greulich and Pflugmacher 2003).. The use of nitrogen fertilizers on the golf greens at Sharp Park is a potentially negative impact that urgently requires analysis.

Phosphorus loading and warm summer temperatures may interact to facilitate blooms of toxic blue-green bacteria and microalgae that have recently caused acute wildlife toxicity and mortality in California (Appendix D). Fertilizers for golf greens are known to create overloads of phosphorus which can result in both terrestrial and aquatic cyanobacteria blooms (Colbaugh 2002). Trematode outbreaks, which cause deformities in tadpoles during development, are known to occur as a result of excessive nutrient loading to freshwater habitats (Appendix D). Appendix D contains a summary of nitrate, nitrite, and ammonia concentrations found during water quality monitoring at Laguna Salada by PWA (1992) and Curtis & Thompson Laboratories (2009), which are at harmful levels. Nitrogen fertilizers applied regularly to the turfgrass surrounding eastern Laguna Salada is likely causing degradation of water quality and habitat suitability for amphibians and therefore, SFGS. The recovery plan for the San Francisco Garter Snake recommended monitoring of fertilizer use at Sharp Park to ensure no adverse impacts (USFWS 1985 p. 43, recovery task 253).

Riparian scrub and grass-like seasonal wetland vegetation (sedge-rush meadows) are highly efficient at uptake of nitrate in runoff and seepage. Riparian scrub and seasonal wetland areas are also good foraging areas for CRLF. Vegetative biomass, especially decay-resistant fibrous sedge, rush peat, and leaf litter, stabilizes nitrogen and sequesters it. Broad zones of seasonal wetland sedge meadows and riparian scrub naturally intercept potential transport of mobile nitrogen to lagoon surface waters. These zones at Laguna Salada are effectively eliminated or severely truncated by turfgrass encroachment down to the freshwater marsh zone, eliminating nearly all potential nutrient buffer zones, and creating a low-biomass transport pathway for nitrogen runoff to directly enter the lagoon's fringing marsh.

The bottom sediments of the lagoon are naturally anoxic (free of oxygen) and accumulate fine organic matter that fuels microbial activity. Anoxic, slightly brackish organic-rich lagoon and wetland sediments generate hydrogen sulfide and iron sulfides at the lagoon bottom. Concentrated sulfides are toxic to plants and most amphibians that are adapted to marsh surface or edge environments (Appendix D). When sulfides are exposed to oxygen when lagoons are drained and bottom sulfidic sediments emerge, they oxidize and form iron oxides and acid sulfates, causing extremely low pH (Appendix D). The artificial summer drawdown of Laguna Salada exposes bottom sediments to oxidation, and surface films of orange-brown iron oxide form, with jet-black iron sulfide muck immediately below the surface. These effects are widespread at both the north and south ends of the lagoon in summer (Peter Baye, personal observation). These acid sulfate soils at the marsh surface or edge are usually restricted to infrequent extreme drought conditions affecting natural non-tidal lagoons, but they are a regular feature of Laguna Salada due to pumping to low levels through the early dry season.

5.3 CONCLUSIONS

The primary limiting factors for habitat quality (in the lagoon and surrounding terrestrial environment), sustainability, and population persistence of SFGS and CRLF are likely to be consequences of three primary influences: lack of suitable upland habitat paired with ongoing golf course maintenance and operations; stabilization of artificially low lagoon levels and the lack of an available corridor to connect these populations to the eastside of HWY 1. Golf maintenance impacts result from the following: mowing of marsh and upland edges, exclusion of dense native vegetation cover by wetland and riparian vegetation and large woody debris, and chronic nitrogen loading of the lagoon due to fertilizer application to turfgrass. Stabilization of artificially low lagoon levels with minimal seasonal fluctuation has multiple significant short-term and long-term impacts to the habitat quality and sustainability of the lagoon wetland complex. These impacts include elimination of the lagoon floodplain hydrology and habitat connectivity; increase in the proportion of the lagoon area within depth ranges suitable for rapid spread of cattail and tule vegetation. Artificial stabilization of lagoon wetland elevations within tidal elevation ranges makes them increasingly susceptible to increased marine flooding risks as sea level rises. In addition, pumping the lagoon to fixed, low levels relative to wave runup as sea level rises over decades is likely to induce increasing frequency and rates of salinity intrusion due to reversal of beach groundwater gradients. Therefore, salinity intrusion over decades is a potentially significant threat to CRLF and should be a consideration in area management.

6. CONCEPTUAL RESTORATION PLAN

6.1 GOALS, OBJECTIVES, AND APPROACH

The ecological goals and objectives for Laguna Salada were outlined in Section **2.2**. These goals are synthesized here with our understanding of existing ecosystem conditions at Laguna Salada (Section 1), natural lagoon analogs, and local historical ecology (Section 1) to develop a sustainable, long-term plan to rehabilitate the damaged wetlands, reunite them with related habitat and wildlife in the watershed, and enable them to adapt to future climate change and sea level rise. The restoration vision presented here breaks with past habitat management approaches of increasing or intensifying management activities to address habitat degradation. Instead, it aims to restructure the ecosystem so it requires less frequent and intensive management (i.e., cost-effective) while delivering increased ecosystem services including endangered species habitat.

This ecosystem-level approach is essential given the coastal setting of the wetlands and their inherent exposure to coastal geomorphic processes. The same coastal processes that originally created and maintained the wetlands of Laguna Salada are now, ironically, considered “threats” to the survival of the existing artificially stabilized wetland ecosystem. The core of our restoration vision is to correct these basic structural constraints and restore flexibility, diversity, dynamics, and extent of the lagoon ecosystem. The most fundamental feature of this restoration vision is to reduce artificial drainage of the lagoon and allow water levels to rise to natural levels, expanding freshwater perennial and seasonal wetlands in the floodplain at higher elevations farther inland than they currently exist. It also restores the freshwater-dominated, landward end of the lagoon wetland gradient, and re-establishes essential linkage with terrestrial and transitional habitats. These habitats will be naturally protected from the reach of storm overwash and will naturally migrate landward with sea level rise. The alternative approach, to increase engineering complexity and management intensity in an effort to sustain the inherited degraded and reduced wetland extent, is likely to be infeasible in the long-term (decades) and very costly in the short-term.

The restoration vision developed herein includes the goal of maintaining an uninterrupted (undeveloped) corridor along Sanchez Creek so that future SFGS restoration opportunities and funds can be identified to provide a viable HWY 1 underpass or overpass specific to SFGS needs. This identified future corridor also includes room to create additional ponds and upland refuge habitat for the snake as “stepping stones” to expand and connect populations to Sharp Park’s Lake Arrowhead and ultimately to undeveloped areas outside and east of the park. This potential corridor area is potentially critical to the long-term recovery for the snake. This corridor will allow the populations of SFGS and CRLF to move in and out of Sharp Park so that the existing population can have the opportunity or chance for genetic flow. This is an essential concept to strive for, otherwise the existing populations at Sharp Park and Mori Point will remain isolated.

The Laguna Salada restoration vision is outlined below as a set of interim or near-term actions and long-term actions that will be implemented by project phasing. Phasing is essential for a number of reasons, most important of which is the need for step-wise ecological actions to be taken to enable local resident special-status wildlife species habitats and populations (primarily CRLF, SFGS, and western pond turtles) and their prey base species to adapt and expand to changing conditions.

6.2 OPPORTUNITIES AND CONSTRAINTS

The existing conditions described here, and elsewhere (PWA 1992; Tetra Tech et al. 2009), represent a number of physical and ecological opportunities and constraints that influenced the development of the conceptual restoration plan. Opportunities for restoration previously identified include (PWA 1992; Tetra Tech et al. 2009):

- Existing freshwater inflow is capable of sustaining a viable natural lagoon and wetland system
- Multiple special status species exist in or near Sharp Park, including San Francisco garter snake, California red-legged frog, San Francisco forktail damselfly, and salt marsh yellowthroat
- Sharp Park clubhouse is a historical feature that can be incorporated into public access plans for the restored site
- Sharp Park is publically held and not threatened by further development

We add the following additional opportunities for restoration:

- Laguna Salada represents a unique opportunity to restore a natural coastal lagoon system of regional significance
- Sharp Park beach seaward of Laguna Salada is wider than the beaches to the north, which have narrowed due to erosion and armoring. The wider beach is consistent with its location against the Mori Point headland which results in a curvature to the planform (the shore faces a slightly more northward direction). This wider beach is an opportunity (asset), while the erosion potential is a constraint.
- Southern Sharp Park, in front of the golf course, is one of the few sections of shore in Pacifica where there is room to maintain a beach without removing private development. It is the only section of shore north of Mori Point which has enough space to allow shore migration without substantial loss of development. With sea level rise, this is the most likely location in Pacifica north of Mori Point to maintain a beach through 2100.
- The existing coastal levee can be removed and a new levee can be constructed in a more landward location. This will restore the natural beach and place coastal flood protection in a less exposed, sustainable location. The more landward location is considered more sustainable because it is less exposed to wave action and overtopping.
- The east section of Sharp Park is adjacent to undeveloped lands with existing passage for wildlife to other known populations of SFGS at San Andreas Lake and Crystal Springs Reservoir. This potential corridor area is critical to the long-term recovery for the snake as it is the only place where such a “land bridge” to other populations can occur.
- Connective corridor for SFGS and CRLF can be demonstrated in the future by seeking restoration opportunities and partners (e.g., Caltrans) to design either a HWY 1 underpasses or overpasses to promote genetic flow among populations.

Previous overriding project constraints included existing and historical land use, reliance on coastal seawall/levee and pumps, impacts to existing wetlands and CRLF breeding areas, and poor runoff water quality. The conceptual restoration plan presented here is not constrained by these factors because it is not based on the underlying assumption that existing land use will continue indefinitely into the future. Restoration of a natural functioning coastal lagoon system renders many of these constraints irrelevant. Constraints relevant to the proposed conceptual restoration plan include:

- Critical habitat is presently concentrated along the western edge of Laguna Salada, where it is especially vulnerable. A mechanism for phased inland migration of snake and frog habitat will have to be developed.
- Existing upland habitat suitable for SFGS is lacking or deficient along most of the lagoon wetland edge. Upland habitat areas for the SFGS will need to be created.
- Flood protection will need to be provided for adjacent neighborhoods at Fairway Park and along Clarendon Road/Lakeside Avenue
- Existing stormwater runoff infrastructure will require retrofit or new elements to allow drainage to the restored lagoon
- HWY 1 east of Laguna Salada is a barrier to wildlife movement. Partnerships with Caltrans will need to be developed to secure a future SFGS corridor underpass or overpass of HWY 1 that provides protection, refuge, and safe passage for wildlife.

6.3 DESCRIPTION OF PLAN ELEMENTS

The proposed conceptual restoration plan includes several new elements that will allow for the rehabilitation of the natural hydrologic and ecologic processes of the Laguna Salada system, including the natural barrier beach, the non-tidal lagoon and associated wetlands, and the Sanchez Creek freshwater/seasonal wetlands and riparian corridor. Restoration actions and plan elements are generally described below and shown in Figure 6 and Figure 7. Project phasing and implementation of the natural lagoon is described in Section 6.4 and shown conceptually in Figure 8. Figure 8 contains a conceptual plan for the lagoon, and does not depict the final/exact elevations to be implemented, especially for the frog ponds adjacent to the lagoon. Figure 9 depicts a conceptual plan for SFGS upland and corridor restoration. The overall strategic elements are:

- **Lagoon hydrology management.** Reduce the current artificial drainage of freshwater inflows for flood protection to allow higher lagoon water levels and increased open water marsh vegetation extent. Flood protection is addressed by different proposed actions.
- **Sanchez Creek riparian corridor restoration.** Culverted sections of Sanchez Creek will be daylighted (culverts will be removed) as distributaries[6] through the restoration site to restore natural fluvial processes, including establishment of a natural riparian corridor and freshwater/seasonal wetlands within Laguna Salada and east of Highway 1. Daylighted creek areas will also enhance habitat for CRLF and SFGS.
- **Habitat enhancements for breeding CRLF and foraging SFGS.** Depressions in the seasonal wetland zone of the eastern floodplain (along the margin of the main lagoon) will be created, similar to the wetland habitats constructed by GGNRA at Mori Point, to provide breeding habitats for CRLF. Large woody debris will be added to wetland-terrestrial transition zones to provide

[6] A distributary channel is a channel that splits off from the main river or creek channel, and is often one of several channels that form over flat slopes, and are often found near the river or creek mouths within the delta formations.

emergent unvegetated basking and roosting sites. Additional basking sites for snakes and frogs will be provided as small gaps in vegetation. Dense vegetation or the underside of logs can provide refuge habitat from predator birds.

- **Expand floodplain and upland transitional habitat.** Excavate artificial fill to expand habitat. Excavated fill will provide source material for other restoration elements (e.g., setback berms, higher elevation mounds for coastal scrub and terrestrial areas for SFGS, etc).
- **Designate the land area for a future SFGS Corridor**. Adopt and identify the areas adjacent to and including Sanchez Creek as a future viable SFGS corridor that provides the potential for safe passage, either under or over road and HWY 1. Work towards finding additional funds and partnering with Caltrans.
- **Upland habitat enhancements for SFGS.** Habitat enhancements for SFGS upland habitat, similar to those proposed by the 2009 SFRPD plan will be included.
- **Existing seawall/levee.** The existing coastal seawall will be allowed to erode and reconfigured, as needed, in phases over time to restore the natural barrier beach berm fronting the lagoon. Existing armor and riprap on the levee and beach will be removed.
- **New setback berms.** New setback berms (small levees) will be constructed along the western and northern edge of the Fairway Park neighborhood (south Laguna Salada) and along Clarendon Rd/Lakeside Ave (north Laguna Salada). The setback berms will provide flood protection against inundation and help accommodate the increased lagoon extent.
- **Existing pump infrastructure.** The existing pump house and drainage culverts at Horse Stable Pond, including the beach outfall, will be removed with the phased levee removal. Artificial water level management will be phased out to allow natural equilibrium water levels to establish in the lagoon.
- **New stormwater runoff detention basins.** New detention basins will be excavated along Lakeside Avenue and Fairway Park to collect stormwater runoff from adjacent neighborhoods.
- **New stormwater runoff drainage infrastructure.** New culverts (Fairway Park) and a new pumping station (Clarendon Road/Lakeside Avenue) will allow drainage of the detention basins to the lagoon.
- **Public access.** Public access elements similar to those proposed by the 2009 SFRPD plan's restoration alternative will be included. Possible enhancements include: pedestrian trails, boardwalks, viewing platforms, modular seasonal bridge, clubhouse enhancements, etc. Public access will be integrated with existing public access at Mori Point.
- **Interim habitat management actions.** As described in Section 6.8.

The long-term conceptual restoration vision proposed here focuses on the new large-scale elements listed above (i.e., those that will drastically alter the functioning of the lagoon system). The small-scale elements and details of the localized lagoon and fluvial habitat enhancements and public access would likely be similar to those described by Tetra Tech et al. (2009).

Taking a broader perspective (i.e., as part of a longer-term master plan or restoration vision), modifications to HWY 1 could greatly enhance restoration by reconnecting the ecotone on either side of the roadway. Highway One forms a barrier to wildlife (and people) which is a stressor to the natural east-to-west orientation of the coastal ridges and valleys. Figure 9 shows a connection across HWY 1 for

SFRPD lands. Mori Ridge provides another connection opportunity. Reconstruction of the highway with an elevated and or depressed alignment would allow reconstruction of the functional landscape and a contiguous coastal valley and ridge (Mori Ridge) habitat. Such realignment could also improve the connection for people, whether going to the beach from neighborhoods or hiking through GGNRA lands. In particular, this is an opportunity for re-establishment of a genetically resilient and dispersed SFGS population. The ongoing planning for improving traffic flow in the area provides an opportunity to consider these ecologic and social objectives. We recommend that these considerations be incorporated in the HWY 1 planning. While modifying a road for human access and environmental enhancements may seem impractical to some, there are recent precedents. One example of a multi-objective roadway renovation project is the Doyle Drive Reconstruction in San Francisco, which includes elevated and depressed sections which will allow ecological and pedestrian connections from uplands to the shore.

6.4 DESCRIPTION OF PLAN PHASING

The Laguna Salada Restoration Plan is comprised of the elements described above, implemented in phases. Phases 1-3 extend over an approximately 10-year timeline. Phase 4 is expected to be implemented over a 30 to 60-year timeline.

6.4.1 Phase 1. Expansion and Redistribution of Habitat.

Trigger: Completion of planning, design, environmental review and permitting.

Estimated time frame to start: Five years minimum to accomplish alternatives analysis, environmental review, permitting, funding, and design.

Description: The first Phase will expand and improve wetland habitat on the site, providing the conditions for expanded CRLF and SFGS habitat around the lagoon perimeter, primarily on the east side. To accomplish this, the water management must change. Improved flood protection for the south Sharp Park area of Pacifica is proposed to occur during this stage, to rectify the chronic flooding problems. It is also beneficial, although not essential, to complete earthwork close to the expanded wetland area in their existing highly disturbed state before the wetlands form. Restoration of the Sanchez Creek riparian corridor and associated floodplain wetlands will directly improve habitat on both sides of the highway. Construct depressions in the seasonal wetland zone to form freshwater ponds and marshes and add abundant large woody debris.

- **Expand lagoon by raising water levels.** Pump operations will be modified to allow higher lagoon water levels and increase wetland area and habitat for CRLF and SFGS, among other species. Winter maximum lagoon levels will increase to 12 ft NAVD and summer lagoon levels will increase to near 10 ft NAVD (current upper limit is approximately 7.5 ft NAVD). This will result in a broad shallow wetland fringe and deepen the rest of the lagoon. Raised lagoon water levels will achieve a rapid increase of seasonal and perennial freshwater marsh above the limit of tidal inundation, with significantly lower risk of salt water flooding, even during overwash events. Higher water levels will deepen and freshen the lagoon and initiate drowning of tules and cattails that have encroached upon the lagoon bed in recent decades. Expanding floodplain seasonal wetlands would trap sediment and nutrients, improving water quality of the lagoon and reducing eutrophication.

- **Expand Lagoon by additional excavation and grading.** Additonal earthwork excavation and grading to expand Laguna Salada inland (away from the ocean). This action would increase CRLF habitat farther landward and away from the effects of wave overwash. Topographic barriers could be graded to create overwash barriers and shallow areas where emergent vegetation mats would further impede salt intrusion. This is an option not included in the restoration plan descriptions (graphics, engineer's estimate), but recommended for further consideration in prelimainry design and environmental review.
- **Restore Sanchez Creek and floodplain.** Sanchez Creek will be restored to a natural morphology through the site, on both sides of the highway. On the west side, new creek channel will be graded with a two-stage shallow channel and floodplain. The surrounding area will be planted with riparian vegetation transitioning to riparian scrub or woodland. Multiple distributary channels will be excavated near the lagoon, to facilitate saturated wetland conditions. Depressions in the seasonal wetland zone of the floodplain will be excavated to provide breeding habitat for CRLF.
- **Restore SFGS Upland Habitat.** Upland basking and refuge habitat for SFGS consisting of small open patches of native grassland and shrubs adjacent to vegetation cover will be created. SFGS basking and refuge habitat will be located within close distance to the water's edge along the eastern section of the lagoon.
- **South Sharp Park surface drainage management facility.** This facility will consist of an excavated water storage basin, a setback levee, and a pump station. The facility will prevent ocean and lagoon water from flooding the surrounding neighborhood. The setback levee (a compacted earth berm) will be constructed along the north and northeast boundary of Laguna Salada. The levee will be approximately 5 to 10 feet high with a crest at elevation +22' NAVD. The elevation is approximately set at two feet above the estimated 100-year recurrence flood level (one percent annual chance of occurrence), which is the standard FEMA uses. The levees would transition and end at existing high ground. The water storage basin will provide a reservoir for storm water from the tributary area. Behind the new setback levee, a depression will be excavated to form a storage basin for rainfall runoff from adjacent developed areas. A pump station will be installed to pump water from the detention basin to the lagoon.

6.4.2 Phase 2. Complete Set-back Flood Management Facilities.

Trigger: Expanded Endangered Species Habitat.

Estimated time frame: 2 to 5 years after start of Phase 1. Phase 2 starts after CRLF and SFGS habitat is expanded and populations have increased and redistributed to the new wetland areas along the lagoon perimeter. A key consideration is the establishment of habitat farther east and upland so that CRLF populations can survive extreme wave overtopping events.

Description: Phase 2 consists of flood management for Fairway Park and adaptively phased restoration of the beach.

- **Fairway Park surface drainage and flood protection facility.** A set back levee will be constructed to protect Fairway Park from coastal and lagoon flooding. The design elevation of +22' NAVD is about 3 to 5 feet above existing grades. The elevation is approximately set at two feet above the estimated 100-year recurrence flood level (one percent annual chance of occurrence), which is the standard FEMA uses. The levees would transition and end at existing high ground. The new levee will be aligned to provide a detention basin for rainfall runoff from the Fairway Park area. A culvert with a tide gate will allow drainage by gravity during most lagoon water levels, and prevent backflow.
- **Remove armor from coastal levee, allow natural erosion.** The coastal levee will erode over time as waves attack it. Armor will be removed to facilitate this process, cleaning up the beach and restoring a more natural shoreline.
- **Restore back beach overwash zone at eroded sections.** As needed, as erosion of levee progresses. As sections of the levee degrade, beach sediments will be placed to restore the beach berm to an elevation of approximately +20' NAVD and extending eastward toward the lagoon.
- **Install boardwalks or other public access.** As part of the gradual levee degradation and beach restoration, the levee trail will be lost and a new boardwalk or other trail will be installed to maintain the access amenity.

6.4.3 Phase 3: Remove Existing Levee and Pump

Trigger: Expanded Endangered Species Habitat.

Estimated time frame: 5 to 10 years after start of Phase 1. Once habitat expansion and species redistribution objectives have been attained, the existing pump station and levee can be removed, fully restoring the natural structure and function of the beach and west side of the lagoon.

Description: Phase 3 completes the restoration of natural coastal and lagoon processes with the following elements.

- **Remove remaining levee.** The remaining levee will be removed and the back beach restored. Alternatively, the levee can be allowed to erode and the Phase 2 method of adaptive restoration continued.
- **Install boardwalks or other public access.** This is continuation of Phase 2, where the levee trail is replaced by a boardwalk or other coastal trail.
- **Remove existing pump station at Horse Stable Pond.** With the levee mostly or completely removed, and setback levees installed, there is no need for the existing pump station.

6.4.4 Phase 4: Adapt to Sea Level Rise

Trigger: Sea level rise of two feet or more.

Estimated time frame: 30 to 60 years.

Description: Sea level rise will cause the beach berm to rise and migrate landward. This will raise lagoon water levels, and wetlands will spread upward and inland. Large runoff and wave overtopping events will result in rapid drainage of the lagoon and drawdown that will scour the lagoon bottom farther eastward. Hence, the entire wetland system will migrate up and inland with sea level rise. In response, setback levees will be raised. Also, a pump will be needed to discharge storm water from the Fairway Park area.

- **Install pump at Fairway Park detention basin.** A pump station will be installed at Fairway Park to provide storm drainage with higher sea levels.
- **Raise setback levees to account for sea level rise.** Setback levee crests will be elevated by placement of additional fill to prevent overtopping and provide flood protection.

6.5 ENGINEER'S ESTIMATES OF LIKELY CONTRUCTION COSTS

Table 1 presents the estimate of construction costs for the conceptual restoration described above. For planning purposes we have provided order of magnitude estimates to allow cost comparison of alternatives or previous plans (e.g., Tetra Tech et al. 2009). This cost estimate is intended to provide an approximation of total project costs appropriate for the conceptual level of design. These cost estimates are considered to be approximately -30% to +50% accurate, and include a 35% contingency to account for project uncertainties. These estimates are subject to refinement and revisions as the design is developed in future stages of the project. This table does not include estimated project costs for permitting, design, monitoring and maintenance. Estimated costs are presented in 2010 dollars, present value, and would need to be adjusted to account for price escalation for implementation in future years. This opinion of probable construction costs is based on: ESA PWA's previous experience, bid prices from similar projects, consultation with contractors/suppliers, and R.S Means 2007 edition. Please note that in providing opinions of probable construction costs, ESA PWA has no control over the actual costs at the time of construction. The actual cost of construction may be impacted by the availability of construction equipment and crews and fluctuation of supply prices at the time the work is bid. ESA PWA makes no warranty, expressed or implied, as to the accuracy of such opinions as compared to bids or actual costs.

Table 1. Likely Construction Costs for Restoration

Project Action	Estimated Cost in 2010 Dollars, Present Value				
	Phase 1	Phase 2 (2-5 years)	Phase 3 (5-10 years)	Phase 4 (30-60 years)	All Phases
South Sharp Park Drainage[1]	$1,000,000			$130,000	$1,130,000
Fairway Park Drainage[2]		$210,000		$350,000	$560,000
Sanchez Creek Restoration[3]	$420,000	$100,000			$520,000
Coastal Levee/Berm/Trail[4]		$680,000	$980,000		$1,660,000
Subtotal	$1,420,000	$990,000	$980,000	$480,000	$3,870,000
Mobilization & Contingency (35%)	$500,000	$350,000	$350,000	$170,000	$1,370,000
Total	**$1,920,000**	**$1,340,000**	**$1,330,000**	**$650,000**	**$5,240,000**

Notes:

[1] Includes setback levee, storm water detention basin, pump station, and future levee maintenance.

[2] Includes setback levee, drainage culvert, future levee maintenance, and future pump station.

[3] Includes channel and floodplain excavation, planting, and large woody debris placement

[4] Includes riprap removal, beach berm grading, trail with boardwalk, levee excavation, and Horse Stable Pond pump station removal.

The estimated cost for the Coastal Levee / Berm assumes that all of the existing levee will be mechanically excavated and all of the sand berm enhancement will be accomplished with imported material. However, the proposed phasing includes the allowed erosion of the levee, which would reduce the amount of levee excavation and estimated costs.

6.6 DISCUSSION

The restoration plan presented above represents a hydrologic regime change for the present-day Laguna Salada. The existing lagoon is a managed system in which water levels are artificially pumped down to levels below that which they would naturally occur. The proposed plan would:

- Raise lagoon water levels to restore landward floodplain wetlands above sea level, naturally reducing exposure to seawater flooding and overwash
- Significantly expand acreage and complexity of freshwater wetland and terrestrial habitat gradients, especially at the landward end of the lagoon and its floodplain
- Allow freshwater wetland habitats of special-status wildlife species to expand significantly and shift landward ahead of coastal retreat
- Allow the natural barrier beach and intermittent outlet channel to be maintained by waves and stormwater runoff and serve as a natural line of coastal flood defense
- Significantly increase lagoon open water extent and buffering against salinity intrusion and wave overwash
- Increase lagoon depths without dredging, avoiding water quality impacts of mobilizing sulfidic (toxic, anoxic) bottom sediments

- Restore submerged aquatic vegetation beds providing favorable habitat for waterbirds, SFGS, and CRLF
- Improve coastal and fluvial flood protection through inland perimeter floodwall locations instead of along the high energy wave-dominated shoreline. This would allow for smaller-scale less expensive flood protection infrastructure and preserve the natural beauty and ecologic benefit of the beach.
- Reduce nutrient loading of the lagoon and increase natural biogeochemical water quality functions of lagoon wetlands, including denitrification and nutrient sequestration
- Increase ecological resilience to climate change and sea level rise, and increase ecosystem tolerance of natural perturbations (extreme flood events, seasonal flooding, etc.)
- Promote compatibility between beach protection, shoreline access, and increased public recreational access of Sharp Park

The proposed plan is a long-term restoration vision that makes sense for the sustainability of critical habitat while minimizing initial and ongoing maintenance costs. This plan also restores and maintains the natural shore. This element cannot be over-emphasized given that most of shore north of Mori Point is armored and narrowing. This section of shore, approximately 3,200 linear feet from Mori Point to Clarendon Road, is perhaps the only section of Pacifica where a beach can be maintained for the next 100 years of projected sea level rise without loss of private property and large infrastructure costs. From the perspective of adaptation to sea level rise, Laguna Salada is perhaps the greatest opportunity for maintaining an accessible beach in the region stretching from San Francisco to Pedro Point.

The restoration vision includes future actions to improve habitat by modifying the barrier formed by HWY 1. The primary objective is further improving SFGS habitat, although other ecological benefits are likely and recreational/social and economic benefits may also accrue. Creating additional CRLF/SFGS ponds as well as restoration of upland habitat areas for SFGS along Sanchez Creek and east of HWY 1 past Arrowhead Lake are valid “stepping stones” towards the goal of sustaining viable, not isolated, SFGS populations at Sharp Park. The idea of connecting populations and expanding species range back within original range areas is both consistent and essential with endangered species recover plans. Therefore, additional work is recommended to:

- Respond to the need for the long term viability of existing SFGS populations at Sharp Park by considering genetic flow to outside populations.
- Set aside areas of Sharp Park that could have profound positive impact for the SFGS, so that when opportunities arise in the future, recovery actions for the SFGS are not missed.
- Identify areas worthy of future and collaborative SFGS restoration, which are expected to include the eastern portion of Sharp Park which extends up to, and past, Arrowhead Lake, and areas contiguous with Mori Ridge and GGNRA lands.
- Consider the adverse effects to SFGS resulting from Highway One, and consider elements to mitigate these adverse effects as part of future Highway modifications.

6.7 COMPARISON WITH SFRPD'S PREFERRED PLAN

The restoration plan presented here has several fundamental distinctions from the SFRPD preferred plan (Alternative A18):

- **Pre-existing land use constraints.** All SFRPD alternatives save one were constrained by existing land uses. The plan proposed here is not constrained by existing land uses, and instead presents a long-term restoration vision for the site.
- **Sustainability of restoration plan.** The SFRPD plan places critical habitat in a vulnerable position in the landscape (i.e., directly behind a coastal levee). The cost of maintaining CRLF and SFGS habitat in this configuration will increase over time. The viability of maintaining the habitat will decrease as sea level rises in the future. The plan proposed here creates a dynamic natural system that will evolve in response to sea level rise.
- **Location of endangered species habitat.** Under existing conditions, CRLF habitat is primarily concentrated in the freshwater wetlands at Horse Stable Pond. The proposed SFRPD plan attempts to enhance this existing habitat and promote expansion of CRLF and SFGS into Laguna Salada proper. Locating this critical habitat along the levee in a coastal flood hazard zone, especially considering possible salinity seepage into the lagoon with sea level rise, is not sustainable. In 1986, McGinnis found that this area was hypersaline and not viable for either SFGS or CRLF. Over time, this habitat will become increasingly difficult, if not impossible, to protect. The restoration vision presented here locates critical habitat along the eastern edge of Laguna Salada – where it existed historically and is most resilient to sea level rise, while maintaining connectivity to Mori Point. The expanded and deeper lagoon serves as a buffer to protect the freshwater habitat from salinity pulses due to wave overtopping and salinity intrusion.
- **Designate a corridor area and land bridge for SFGS**. We concur that there is a need to create suitable upland habitat for SFGS near the water's edge. There is ample room to do this along the east side of the proposed lagoon area. This approach would be consistent with the previous analysis and need for SFGS upland habitat as well as maintaining a connective corridor to the Mori Point SFGS populations.
- **Scope of restoration/enhancement.** The SFRPD plan was too narrowly focused on specific minor habitat enhancements for target species within the constraints of the existing landscape, and did not have an opportunity to consider a larger restoration vision. The plan proposed here seeks to restore the full ecosystem function – including ecologic and geomorphic processes – to benefit the endangered species and ecosystem-level function.
- **Increased open water extent.** A chronic problem at Laguna Salada is the loss of open water habitat due to encroachment by emergent vegetation. This is primarily due to existing water level management (i.e., pumping) within the site. The SFRPD plan proposes increasing open water depth and extent by dredging accumulated sediment and biomass. The plan proposed here would increase open water depth and extent passively by simply allowing the lagoon water level to increase, thereby progressively expanding the lagoon footprint over time.
- **Reliance on pumping and seawall.** The SFRPD plan relies on pumping to provide flood protection from rainfall runoff due to impoundment behind the coastal levee. The plan proposed here allows natural breaching and drainage of high lagoon levels through a natural restored barrier beach.

- **Loss of beach.** The SFRPD plan proposes to maintain the coastal levee/seawall at the Sharp Park beach. Over time, coastal erosion will result in loss of the fronting beach. The plan proposed here allows natural inland migration of the beach, thereby maintaining its width over time in response to sea level rise.
- **Cost of full restoration.** The restoration plan presented herein is estimated to cost about $5 million dollars over a 50 year time frame. In contrast the SFRPD plan costs between $6 and $11 Million, with another $6 to $7 Million for levee upgrade (called "seawall" in other reports) construction, totaling approximately $12 to $18 Million. The SFRPD "full restoration" alternative was estimated to cost between $9 and $22 Million, without an explicit treatment of costs associated with the levee /seawall. The costs of the SFRPD plans do not include ongoing land management operations by SFRPD, or the costs needed to adapt to sea level rise. Consequently, the plan proposed herein has lower initial and total costs, and has a longer design life. From a cost perspective, the plan proposed herein is greatly superior to the SFRPD plans.
- **The restoration plan presented here is broader than the SFRPD plan**. While the detailed plan presented here is primarily limited to the SFRPD lands, we identify a broader restoration objective for future consideration. The objective is to restore a connective corridor for the Sharp Park/Mori SFGS populations to the east side of HWY 1 and ultimately to Crystal Springs.

6.8 INTERIM HABITAT MANAGEMENT ACTIONS

Interim management actions are those actions considered to be applicable during continuation of existing operations or the transitional time period prior to long-term restoration actions.

I-1. Stop mowing marsh. Discontinue marsh mowing along eastern and northern Lagoon. Allow existing fresh-brackish marsh vegetation at lower edge of golf greens to regenerate marsh canopy cover all year.

I-2. Allow higher winter lagoon levels. Increase winter surface water elevation of Lagoon: allow higher winter-spring lagoon stands (to approximately 10 ft), increase wetted area of lagoon during winter (Dec-March), widen perennial and seasonal fresh-brackish and fresh marsh, riparian scrub (see I-3); wetlands recapture wider shallow flooded edge of floodplain, increase consolidated (unfragmented) primary marsh area remote from risk of back-barrier saline seeps or overwash.

I-3. Place large woody debris along upper edge of lagoon. Place large woody debris (obtained from local large tree removal sources) along upper edge of lagoon shores (high water line), providing cover, permanently unvegetated basking sites, moisture refuge for treefrogs, and/or invertebrate prey base for frogs.

I-4. Establish willow thicket nutrient and disturbance buffer. Establish discontinuous but prevalent willow thicket borders around eastern and northern edges of Laguna Salada, creating buffer zones between marsh and golf greens for nutrient (nitrogen fertilizer) seepage and runoff interception, sediment detention and stabilization. Establish sedge-rush meadow vegetation in gaps between willow stands. Place patches of willow thickets to maximize net nutrient assimilation capacity.

I-5. Establish marsh ponds along buffered eastern lagoon. Excavate a series of sheltered depressions well below mean summer groundwater elevations to form isolated marsh ponds with sago pondweed and fringing bulrush/sedge/tule marsh (similar to Mori Point hillslope toe ponds) along the eastern and northern edges of Laguna Salada, within the area that is currently mown marsh. This area should then be sheltered by the willow thicket buffer zone (I-4). Shift CRLF breeding habitat to the landward edge of Laguna Salada, remote from risk of back-barrier saline seeps or overwash.

I-6. Establish upland San Francisco garter snake habitat along buffered eastern lagoon. Use the excavated soils from I-5 to create high elevation mounds, out of the highwater zone, that can be used by SFGS during winter months for hibernation. These areas should be at elevations above natural marsh plant colonization and contain mammal burrows (gopher or ground squirrel). These areas should be then vegetated with native grass and coastal scrub species.

I-7. Facilitate movement corridors for snakes and frogs between lagoon and upper watershed populations. Increase dispersal connectivity for CRLF and especially SFGS between Arrowhead Lake (upper Sanchez Ck watershed) and Laguna Salada through modified design of HWY 1 widening during EIR and permit process; provide either underpass corridors or an overpass land bridge, with cover specific to the needs of SFGS to facilitate dispersal and protection from predators, vehicles (including bikes), and people.

I-8. Replace iceplant and weeds with native scrub and perennial grassland vegetation. Replace iceplant mats and ruderal non-native vegetation on barrier and lagoon flats with native low-growing coastal scrub and grassland assemblages.

I-9. Monitor salinity seeps and groundwater salinity. Monitor salinity seeps and groundwater salinity along back-barrier transects placed along the entire N-S axis of Sharp Park Beach.

I-10. Reduce fertilizer application and risk of lagoon wetland eutrophication. Minimize applications of nitrogen fertilizers to Sharp Park turfgrass.

I-11. Re-establish sago pondweed in lagoon remnants. Re-establish sago pondweed in main Laguna Salada pond following hydrologic modification (I-2).

I-12. No Seawall Construction or Armoring. Allow the existing levee to erode and the beach to restore over time.

I-13. Comprehensive Habitat Planning and Management. Extend habitat management, and particularly species recovery planning, to include natural habitat ranges rather than institutional boundaries. In particular, link with GGNRA actions and consider opportunities associated with the HWY 1 modifications (presently proposed for widening) and Quarry property south of Mori Point (presently proposed for development).

7. NEW FINDINGS

7.1 BACKGROUND

The previous sections of the report present our best interpretation of the historical ecology and natural functioning of the Laguna Salada system, and provide a sound restoration vision. Here, we identify findings that are new or different than prior work. The goal here is to help foster informed discussion and promote a new vision for the restoration of the lagoon, free of previous constraints and assumptions.

7.2 PROBLEM DEFINITION

Previous restoration planning at Laguna Salada has been hampered by an incorrect formulation of the problem. There is a perception that the frog and snake habitat must be defended from the encroachment of the ocean, which would otherwise degrade the freshwater habitat through salinity intrusion and wave overtopping. The true problem is encroachment of development and "squeezing" of the critical habitat into a narrow, vulnerable, non-sustainable location directly behind the coastal levee. The SFRPD restoration planning process is constrained by the existing land use and water management, such that the only apparent feasible enhancement options within the lagoon environment rely on indefinite pumping and levee maintenance. Only by taking a broader view, free of those constraints, can a sustainable, resilient natural system be restored at Laguna Salada.

7.3 FINDINGS

The following findings are new and may contradict prior studies and the public perceptions resulting from the prior studies. While awkward, we feel it is necessary to correct what we feel are misconceptions that may facilitate counter-productive actions.

1. **The historical Laguna Salada was a brackish-fresh lagoon, not a saline tidal lagoon**
   Direct translation of the common place-name "Laguna Salada" (salty lake, lagoon, pond) leads to an incorrect interpretation of its historical ecology (see Appendix G, Laguna Salada Place Name Analysis). In the 19th century, the term "salada" applied to all seasonally brackish or fresh-brackish coastal waters that were frequently too saline for agriculture, stock, or human use. Evidence presented in this report from historical ecology, comparison with present-day reference sites, and analysis of physical processes supports the assertion that Laguna Salada was indeed a fresh-brackish non-tidal coastal lagoon with intermittent overwash – not a saline tidal lagoon.

2. **The seawall/levee did not "create" freshwater habitat for the frog and snake**
   The assumption that the seawall and golf course created habitat at Laguna Salada for the CRLF and SFGS is inconsistent with our findings. We find that habitat is degraded by present land use and restored physical processes will greatly enhance habitat.

3. **A contiguous levee/seawall did not exist prior to 1983 storms**
   Proposed levee modifications (and a categorical exemption from CEQA by the City of Pacifica) are founded upon the assumption that a contiguous levee or seawall existed prior to the 1983 El Niño storms. A review of historical aerials photos and anecdotal evidence from Pacifica residents indicates that such a structure did not exist prior to its construction in the 1980s.

4. **The existing levee/seawall is not required to protect flooding of neighborhoods**
   The general public perception is that the levee and pump infrastructure must be maintained indefinitely to protect existing developments from flooding. This assumption was the primary reason that removal of the seawall was not considered to be a feasible component of the full restoration alternative (Alternative A-0, Tetra Tech et al. 2009). The existing seawall actually prevents natural drainage of the lagoon during rainfall runoff events and necessitates the current pumping practices. If the natural lagoon processes were restored, setback levees could be reconstructed farther inland away from direct wave attack, in sheltered areas. These levees would be lower, narrower, and cheaper to maintain.

5. **The seawall is not required to protect Laguna Salada from sea level rise**
   If the natural lagoon processes were restored, the barrier beach would naturally migrate landward and upward in response to sea level rise. Over time, the lagoon and CRLF and SFGS habitat would naturally migrate inland and upslope as well. Setback levees could be raised at some point in the future as ocean and lagoon water levels increase.

6. **The seawall is not required to protect the frog and snake habitat**
   The existing seawall does protect the existing frog and snake habitat – in its present non-natural location at Horse Stable Pond – but this protection is not complete and is difficult to maintain. If the natural lagoon processes were restored, a greater expanse of freshwater wetland habitat would be created in the floodplain along the eastern side of Laguna Salada and along the restored Sanchez Creek riparian corridor – where it likely existed historically and will be more sustainable in the future.

7. **Sedimentation is not the primary cause of reduced lagoon extent**
   Artificial management of lagoon hydrology (e.g., pumping, artificial drainage, elimination of natural lagoon high stands) has allowed emergent vegetation to progressively encroach upon open water, thereby reducing the lagoon extent.

8. **The proposed SFRPD plan is not the most feasible and ecologically superior alternative**
   The restoration proposed herein provides greater ecological benefits; our conceptual analysis indicates it is less costly and more reliable.

9. **Full restoration is the cheapest rather than the most expensive alternative**
   The SFRPD has not had the opportunity to evaluate and compare the costs associated with the full restoration alternative proposed in this report. The restoration plan proposed here would be implemented at a lower cost using construction and phasing methods consistent with other large-scale restoration efforts up and down the west coast. This would also aid in directing unused funds to the

much needed upland wildlife corridor either above or under HWY 1, pond creation, recreation, and educational opportunities, ideas which are consistent with and further support the enhancement opportunities for CRLF and SFGS. Additionally, we believe the costs to construct and maintain the type of coastal structure proposed in prior studies are underestimated and should be re-evaluated.

8. CONCLUSIONS

We propose a new restoration concept not previously considered by prior studies. The new plan restores CRLF and SFGS habitat where it existed historically – along the eastern edge of a non-tidal fresh-brackish Laguna Salada. The plan increases the open water extent and depth of the lagoon, providing a buffer against ocean salinity pulses, while restoring the natural coastal processes at the beach. The plan is resilient with sea level rise, and satisfies flood protection and public access objectives.

A preliminary cost estimate for the conceptual design shows that the plan is feasible and comparable with other alternatives considered by the SFRPD.

The proposed plan offers the following:

1) a new vision (conceptual model) for the Sharp Park's Laguna Salada restoration and maintenance
2) flood protection for surrounding development
3) restoration of a naturally functioning lagoon ecosystem
4) expansion of habitat for federally protected SFGS and CRLF
5) a vision for a designated corridor for future SFGS and CRLF movement and genetic flow from the ocean side of HWY 1 to the inland side of HWY 1 so that these populations have a chance to survive over time
6) Recreation, including a beach / coastal trail and augmentation of the adjacent Mori Point (GGNRA) experience. The existing buildings and parking area could be maintained for public use and private concessions.

The findings presented in this report attempt to fill in gaps in previous research related to historical ecology and coastal lagoon processes to promote well-informed development and evaluation of restoration actions at Sharp Park. Failure to consider these key components of restoration design may result in actions that could limit habitat viability in the future, and in this way would be counter-productive.

The conceptual restoration plan presented here creates enhanced CRLF and SFGS habitat along the eastern side of the lagoon, where it will be naturally buffered and protected from high ocean salinity. Restoration alternatives that attempt to maintain habitat for these salt-sensitive species directly behind the coastal levee (at Horse Stable Pond) run the risk of loss in the event of catastrophic levee failure. Over time, habitat maintained within the coastal hazard zone will become increasingly susceptible to severe wave overtopping events and salinity intrusion – factors which will increase in the future due to sea level rise. We do not believe this approach is consistent with the Endangered Species Act and species recovery plans.

Maintenance costs for the coastal levee and pump station at Horse Stable Pond will increase over time with coastal erosion and rising groundwater, while degrading lagoon and beach habitat, making these elements less feasible over the long term. Previous restoration plans rely on indefinite maintenance of the seawall and pump station and do not address the adverse effect on the beach. The restoration vision presented here utilizes the inherent ability of coastal lagoons to regulate coastal and runoff floods, and sets back constructed flood protection elements where they are less exposed, have lower demands, and protect the surrounding community better.

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11. FIGURES

0 1000 2000 3000 Feet

Source: U.S. Geological Survey.

figure 1

Laguna Salada Restoration Feasibility Study

Project Location and Vicinity Map

Source: KHE (2009)

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#2028 Report/figures

Sharp Park General Features

Sharp Park Conceptual Restoration Plan

Pacifica, CA

Figure 2

TETRA TECH

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figure 3

Laguna Salada Restoration Feasibility Study

1869 USCS Topographic Map

Source: U.S.C.S. 1869

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a) Example tidal lagoon – Bolinas Lagoon, Marin County, CA

b) Example seasonal lagoon/estuary – Russian River, Sonoma County, CA

c) Example non-tidal lagoon – Rodeo Lagoon, Marin County, CA

Source: Google Earth Imagery

figure **4**

Laguna Salada Restoration Feasibility Assessment

Types of Central California Coastal Lagoons

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Source: Geomatrix (1987) Photograph 6. Caption: Recently constructed reinforced earth seawall with armor stone toe protection. This wall extends along Beach Boulevard north of the Fishing Pier in Pacifica (August 1985).

figure ***5a***

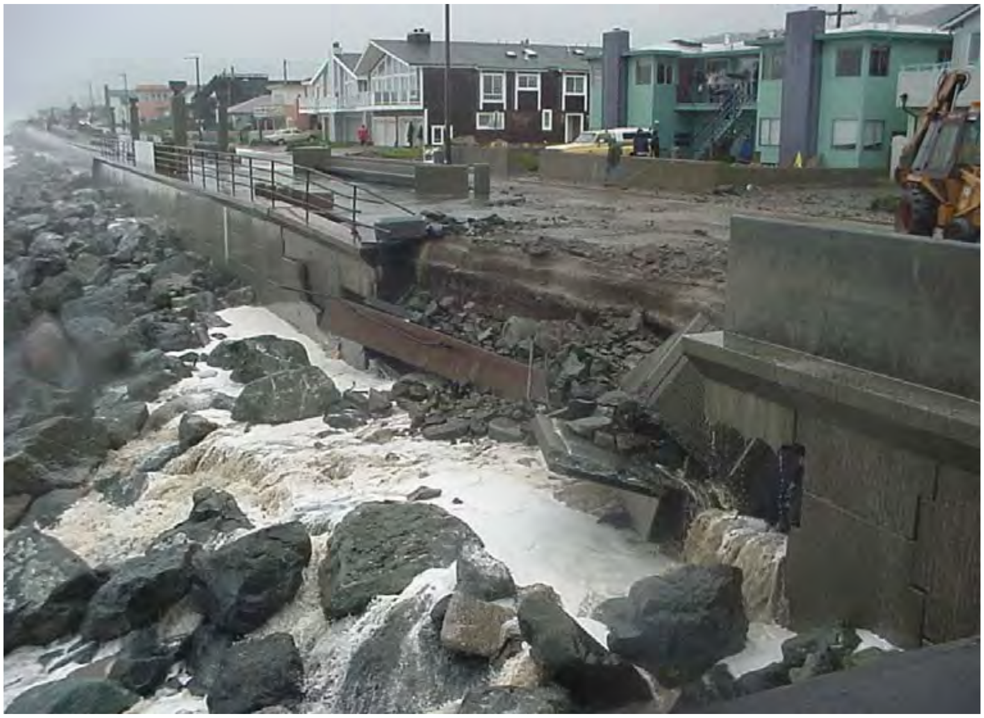
Laguna Salada Restoration Feasibility Assessment

Beach Boulevard Seawall, 1985

PWA Ref# 2028

PWA

(b) Sharp Park Seawall about 20 years after construction, with no beach at high tide.
Typical Winter conditions



(c) Structural failure of Sharp Park Seawall during January 11, 2001 event

figure 5

Laguna Salada Restoration Feasibility Study

Sharp Park Seawall Photos

Photo Source: Bob Battalio

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#2028 Report/figures

figure 6

Laguna Salada Restoration Feasibility Study

Restoration Plan

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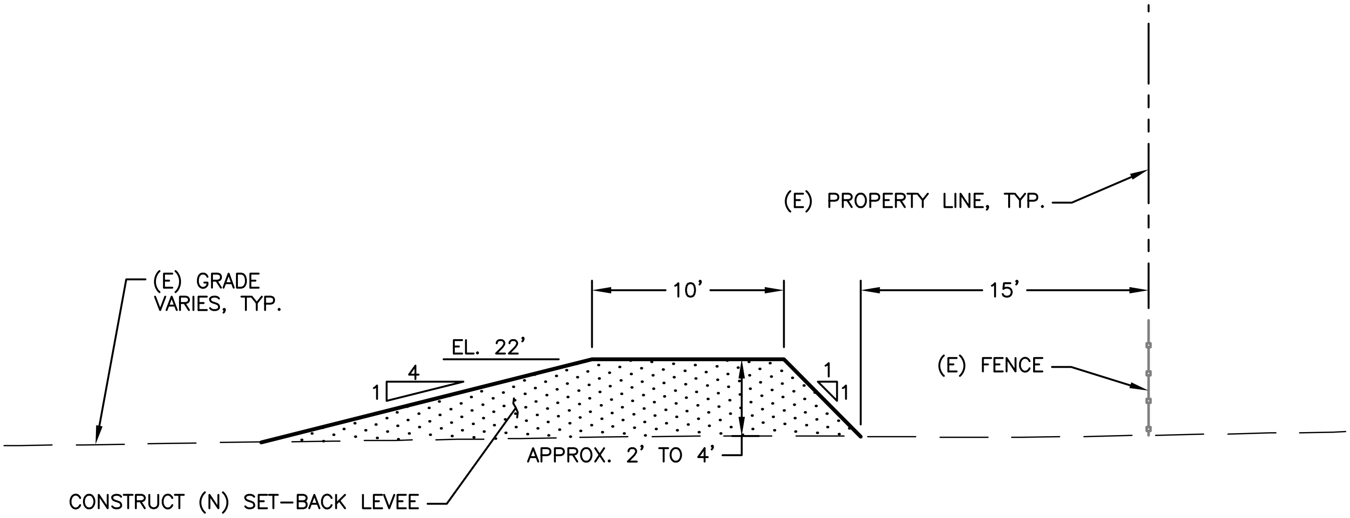
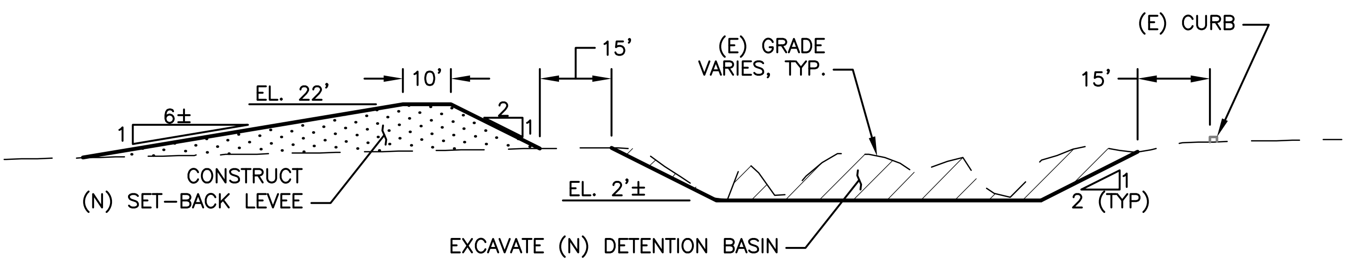


A SET-BACK LEVEE
TYPICAL SECTION @ FAIRWAY PARK
SCALE: 1"=10'



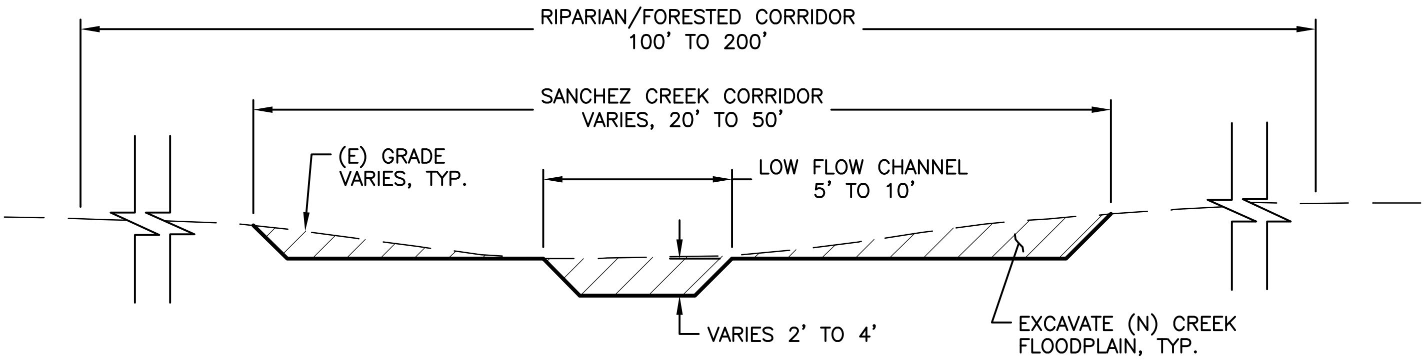
B STORM WATER PUMP STATION
TYPICAL SECTION @ DETENTION BASIN
SCALE: 1"=40'

figure 7a

Laguna Salada Restoration Feasibility

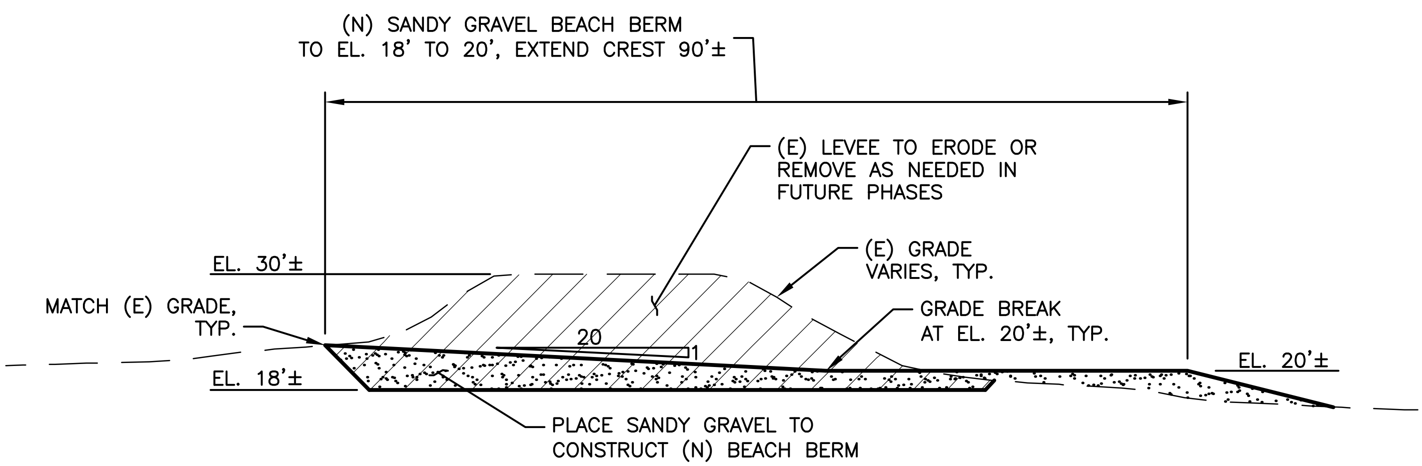
Typical Sections at Fairway Park and Detention Basin

PWA



C SANCHEZ CREEK CORRIDOR TYPICAL SECTION

SCALE: 1"=10'



D BEACH BERM RESTORATION TYPICAL SECTION

SCALE: 1"=20'

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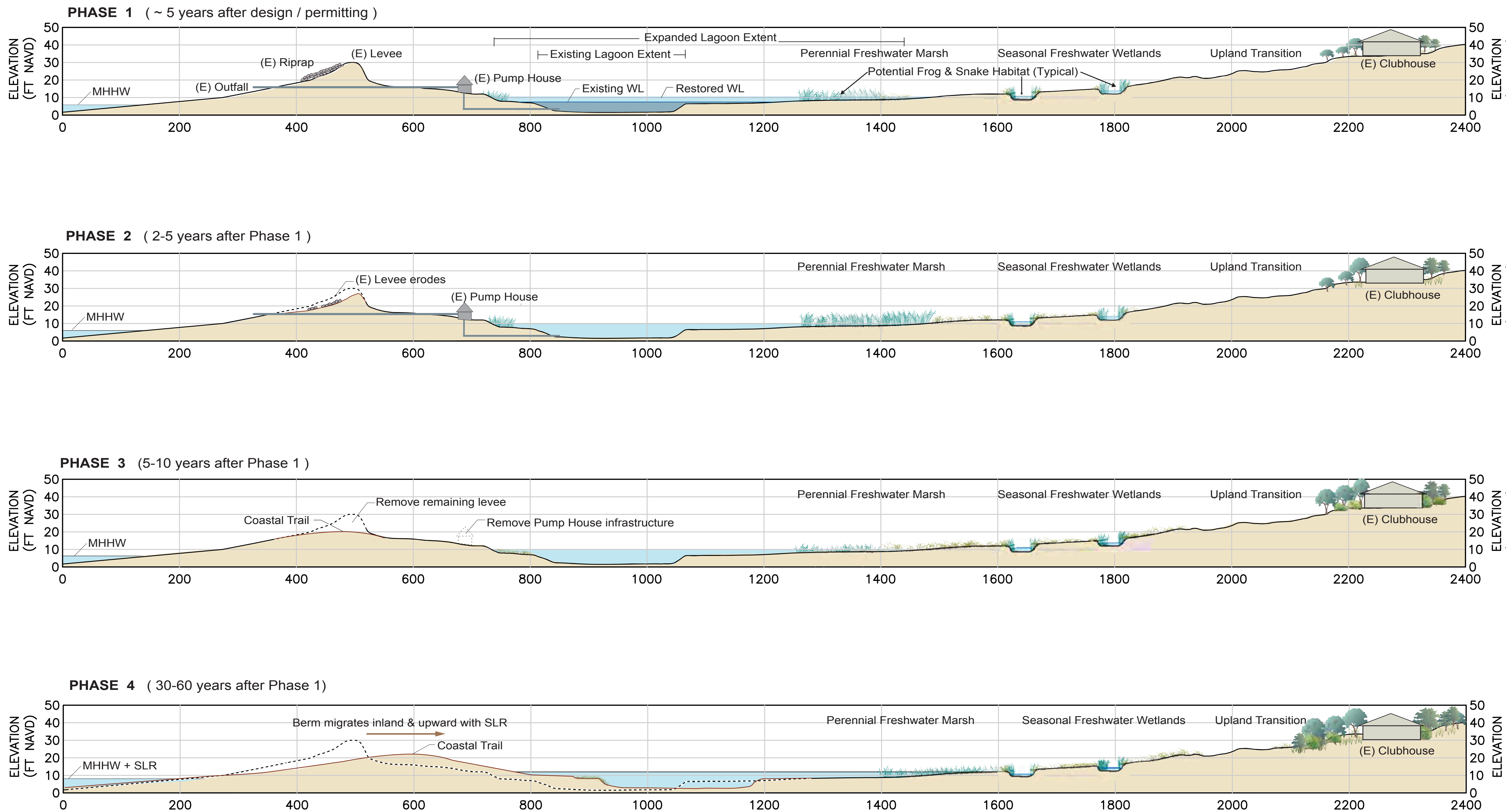
figure 7b

Laguna Salada Restoration Feasibility

Typical Sections at Sanchez Creek and Beach

PWA



E RESTORATION EVOLUTION
TYPICAL SECTION

SCALE
HORIZ: 1" = 200'
VERT: 3x EXAGGERATION

Habitat Types / Compostion
Perennial Fresh (& fresh-brackish) marsh, tule, cattail, bulrush
Seasonal Freshwater Wetlands - sedge rush meadow, woody riparian scrub, ponds
Upland Transition - coastal grassland, sedge, meadow and scrub

figure 8

Laguna Salada Restoration Feasibility Study

Restoration Typical Section and Evolution

PWA # 2028

PWA

Figure 9. Dedicated area along Sanchez Creek for future restoration of a San Francisco Garter Snake movement into and out of the Lagoon at Sharp Park and Mori Point to Lake Arrowhead east of HYW1, with a land bridge, either under or over HWY and roadways.

12. APPENDICES

APPENDIX A: HISTORICAL ECOLOGY AND CONCEPTUAL MODELS

A-1 HISTORICAL ECOLOGY OF LAGUNA SALADA: A PRELIMINARY ASSESSMENT

A-1.1 Introduction

An important first step in assessing impairment of California coastal lagoon wetland ecological functions, and objectives for corrective or restoration measures, is accurate reconstruction of historic ecology (Stein et al. 2010, WWR et al. 2009, WWR et al. 2008, Simenstad et al. 2006, Striplen *et al.* 2004, Engstrom 2004, Goals Project 1999). Foremost among Laguna Salada wetland restoration issues in recent years is the historical ecology of endangered species habitat and population change in relationship to artificial hydrologic modifications. The vegetation, geomorphology, and hydrology of Laguna Salada during its early historical periods of crop agriculture (20th century prior to 1930s, and late 19th century), and relatively "natural" dynamic backbarrier lagoon conditions prior to intensive agriculture and engineered drainage (European settlement and earlier Ohlone occupation during the late Holocene epoch) have not been investigated previously. Limited direct data are available on status of California red-legged frog and San Francisco Garter Snake habitat around Laguna Salada during the later decades of the land-use period defined by golf links construction and use (1930s to present). No local data are currently available on paleoecology or stratigraphy (depositional record of ancient pollen, plant remains, sediment deposition sequences) of Laguna Salada's development during the late Holocene.

Purpose and Scope

The purpose of this preliminary investigation of Laguna Salada's historical ecology is to provide new data and analysis supporting better resolution and understanding of the historical development of habitat changes and geomorphic and hydrologic dynamics. The purpose and scope of this assessment is set within the context of preliminary feasibility assessment for ecosystem rehabilitation. This investigation was prepared to provide sound premises for the alternative ecosystem rehabilitation approach for Laguna Salada, and to test hypotheses and assumptions about historical ecology of Laguna Salada – particularly in relation to marsh salinity, hydrology, vegetation, and habitat suitability for endangered species. It is limited to available historical data from photographic archives, maps, herbarium records, and interpretation guided by comparison with coastal lagoon reference sites and studies of other lagoons in the Central Coast region. Emphasis is placed on evidence concerning early 20th century geomorphology, vegetation structure and composition during the because of their relatively clear documentation, their value as indicators for endangered species habitat suitability, and their strong relationship to environmental controls of salinity, hydrologic processes. This synthesis of historical geography, geomorphology, and vegetation data, and particularly our detailed analysis of aerial and ground photo interpretation, is guided by the PWA team's extensive long-term field experience in California coastal lagoons and barrier beach systems.

Previous assessment of Laguna Salada historical ecology

Two previous reports on Laguna Salada wetland restoration provided very brief assessments of its historical physical geography and ecology. The account of historical ecology presented by the San Francisco Recreation and Parks Department report on Sharp Park marsh habitat restoration alternatives (Tetra Tech et al. 2009) was limited to a brief summary of the earlier PWA Sharp Park resource enhancement plan's conclusions (PWA 1992), an interpretation salinity range from the place-name of the lagoon, and a general reference to "historic aerial photographs":

> Prior to the development of the Sharp Park Golf Course beginning in the 1920s, the Laguna Salada site was characterized by ranch lands, sand dunes, and a large lagoon (PWA 1992). Although it is likely that some freshwater wetlands existed behind the dunes, the common name of Laguna Salada (Salty Lagoon) suggests that the lagoon was formerly brackish to saline. In one of the early photographs of the region, a small channel that connected the lagoon with the Pacific Ocean can be seen, along with a shoreline of relatively low relief. Assessment of historic aerial photographs of the Laguna Salada area indicates that prior to development of the Sharp Park Golf Course and the seawall located west of the wetland complex, environmental conditions at the project site were representative of a coastal lagoon system.
>
> (Tetra Tech et al. 2009, p. 10)

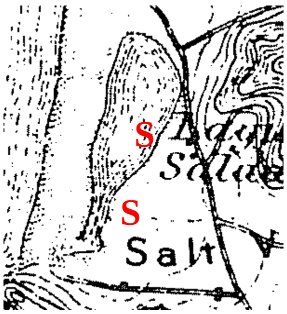
These conclusions require critical re-evaluation based on additional site-specific and regional evidence about historical and modern conditions of coastal lagoons. Some of the key issues raised by the Tetra Tech (2009) assessment of historical ecology include:

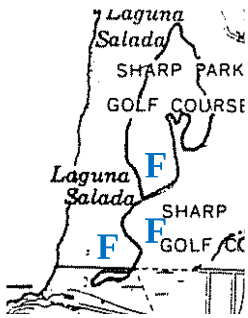
Key questions, concepts and hypotheses

One of the fundamental wetland restoration and historical ecology issues for Laguna Salada is whether its "restoration" to a modified approximation of an earlier historical condition would improve endangered species habitat and population viability in the long-term. If earlier historical or more "natural" states of Laguna Salada were incompatible with endangered species habitat, or provided less reliable or productive habitat than enhanced versions of the existing condition, then ecological objectives for lagoon "restoration" (more accurately, ecosystem habilitation informed by local historical ecological models) would differ from objectives for endangered species habitat enhancement.

Therefore, an outstanding question for of historical ecology of Laguna Salada is whether the pre-golf lagoon wetland complex likely supported suitable and substantial habitats for California red-legged frogs and San Francisco Garter Snakes, and if so, where within the lagoon complex it did so, and when. Prior to golf course conversion, the lagoon's landward floodplain and barrier beach were apparently modified to support crop agriculture, and were not in a "natural" condition when filled for golf course construction. This raises a further question of whether the pre-golf agricultural phase of the Laguna Salada wetlands from the golf-era condition, and earlier ranching or pre-agricultural states, in terms of red-legged frog and garter snake habitat. These questions can be reformulated as testable hypotheses.

One hypothesis is that prior to golf conversion, Laguna Salada, as its name suggests, a saline waterbody with relatively uniform saline to brackish fringing marsh (unsuitable for red-legged frogs and snakes) prior to golf course development. This "saline lagoon" hypothesis predicts a relatively uniform salt marsh vegetation, and implies that prevalent salinity ranges or tidal flooding effectively excluded intermittent fresh-brackish habitat suitable for California red-legged frogs – and therefore also no prey base for San Francisco Garter Snakes. This hypothesis implies that contrasting fresh-brackish marsh habitat that exists now developed following (or as a result of) hydrologic changes caused by golf course development and associated shoreline stabilization.

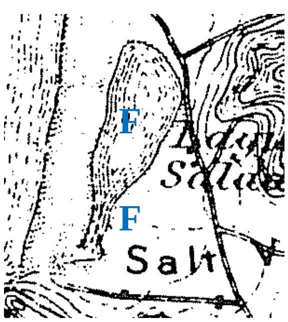


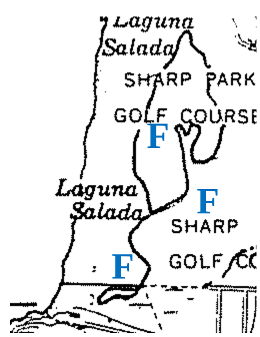


late 19th-early 20th agricultural Laguna Salada 1930s and later Laguna Salada/Sharp Park

SALINE TO FRESH-BRACKISH GOLF CONVERSION HYPOTHESIS: FB – Fresh-brackish salinity range (prevalent bulrush-cattail-tule) S = saline-brackish range (prevalent saltgrass-pickleweed) B = brackish range (prevalent alkali-bulrush/pickleweed/saltgrass/jaumea)

A "null" hypothesis that the marsh types and hydrology of Laguna Salada prior to golf management were not significantly different from conditions in the golf period, regardless of net filling of Laguna Salada for construction of golf links. "Significantly different" in this sense refers to important ecological contrasts in marsh vegetation types, wildlife habitat, salinity regimes relevant to the threshold between fresh-brackish and brackish marsh habitat and viability of California red-legged frog populations.

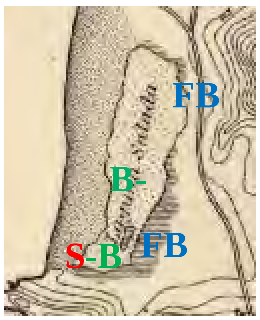




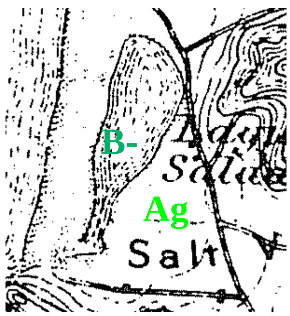
late 19th-early 20th agricultural Laguna Salada 1930s and later Laguna Salada/Sharp Park

NULL HYPOTHESIS (no significant net change): FB – Fresh-brackish salinity range

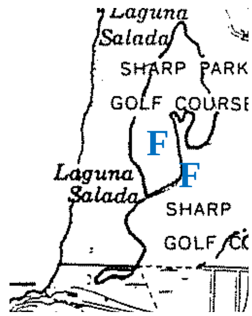
An alternative hypothesis is that a complex and dynamic freshwater-brackish gradient (not a uniform or stable marsh type) prevailed in the "natural", pre-agricultural range of variability of Laguna Salada. This hypothesis, based on the regional conceptual model for coastal lagoons (this Appendix volume), predicts a more complex, graded vegetation pattern between seaward brackish and landward fresh-brackish (oligotrophic) and true freshwater floodplain wetlands above normal tidal elevation range that were associated landward supratidal delta of Sanchez Creek. The marsh structure would reflect a dynamic salinity gradient, including stratified lagoon water (fresher on top, more brackish on bottom), variable emergent lagoon flats within (intermittent) tidal elevation range, and fringing marsh associated with higher lagoon levels, above normal tides. This hypothesis predicts persistent fresh-brackish marsh and amphibian habitats concentrated at the landward edge of the marsh, particularly in association with a creek delta or distributary channel system. This alternative "salinity gradient" hypothesis would be consistent with more saline or brackish marsh nearer the seaward (beach) side of the lagoon.



pre-agricultural Laguna Salada



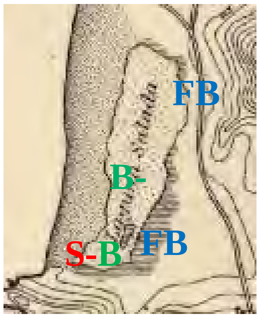
late 19th-early 20th agricultural Laguna Salada



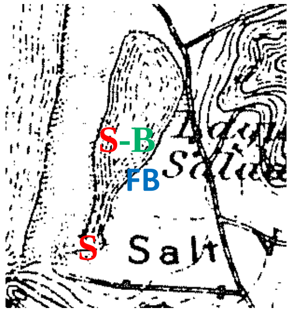
1930s and later Laguna Salada/Sharp Park

DYNAMIC LAGOON SALINITY GRADIENT HYPOTHESIS: FB – Fresh-brackish salinity range (prevalent bulrush-cattail-tule) S = saline-brackish range (prevalent saltgrass-pickleweed) B = brackish range (prevalent alkali-bulrush/pickleweed/saltgrass/jaumea) Ag – agriculture (crop)

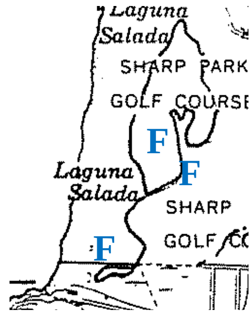
A "hybrid" hypothesis, combining the null and salinity gradient hypotheses with aspects of Laguna Salada's agricultural history, is that the natural salinity range of the lagoon was artificially increased (relative to natural variability) by routine lagoon breaching for drainage of cropland during the growing season. This hybrid hypothesis implies that breaching drained impounded freshwater and caused aseasonal influx of tidewater at lower lagoon elevations, resulting in prevailing brackish open water lagoon and flats, and reduced, marginal fresh-brackish marsh at the landward edge. The transition from breaching to pumping the lagoon for stable drainage and water management (which may have preceded golf conversion, but was at prevalent during golf period) returned the lagoon to a less saline (fresh-brackish) and less fluctuating salinity range.



pre-agricultural Laguna Salada



late 19th-early 20th agricultural Laguna Salada



1930s and later Laguna Salada/Sharp Park

'HYBRID" HYPOTHESIS: pre-agricultural dynamic salinity gradient converted to more saline or brackish lagoon due to agricultural drainage high lagoon levels from impounded freshwater, achieved by barrier breaching during the growing season. FB – Fresh-brackish salinity range (prevalent bulrush-cattail-tule) S = saline-brackish range (prevalent saltgrass-pickleweed) B = brackish range (prevalent alkali-bulrush/pickleweed/saltgrass/jaumea) Ag – agriculture (crop).

Salinity range classification corresponds with the modified Venice system classification of brackish waters in Cowardin 1979: (fresh 0-0.05 parts per thousand [ppt]; oligohaline = below 5 ppt; mesohaline, 5-18 ppt ppt; euhaline, polyhaline 18-30 ppt; euhaline 30-40 ppt)

These hypotheses generate predictions that would be tested by kinds of evidence that could be recovered in historical botanical, photographic, and map information. They could also potentially be tested definitively by direct paleoecological methods (sediment cores revealing marsh stratigraphy, pollen, diatoms, stable isotopes), but no such data are currently available. Some highly useful kinds of data that are readily available from on-line databases, historical floras, and historical photography from local archives, include:

- Plant species records. Plant species with known tolerances for salinity and water depth fluctuations are associated with California red-legged frog habitat today, and may (in part) predict past habitat. Historical herbarium collections (with locality specific to Laguna Salada) are a primary source of plant indicators of past marsh plant communities.

- Historical photographs of vegetation and landforms. Black-and-white photographs from the late 19th or early 20th century often provide identifiable images of vegetation at least to the level of genus or subgenus of dominant species, within the context of landforms (geomorphic features) associated with specific depositional environments and processes. These can be verified by comparison with existing, known reference sites.

- Historical topographic maps. Detailed topographic maps with hydrologic features and major vegetation features were prepared by the U.S. Geologic Survey, and a precursor agency, the U.S. Coast Survey. One map in particular, the USCS 1869 map of the San Francisco Peninsula, provides a simultaneous overview of all mapped coastal marshes and lagoons. The detailed features recorded in this map (a composite based in part on 1850s topographic maps, T-sheets) provide "snapshot" views of shoreline configurations and channel forms that correspond with known forms and hydrologic processes of lagoon outlets or tidal inlets, as well as artificial drainages.

A-1.2 Methods

Preliminary review of historical ecology data was based on comparisons of historical plant records (herbarium label data), available historical ground and aerial photographs, and two historical topographic maps dated 1869 (based on 1850s topography and updated in 1860s) and 1892. The Consortium of California Herbaria database (2011) was queried for all coastal wetland, beach, and dune plant species currently known from Sharp Park and reference coastal lagoons in San Mateo County and Santa Cruz County. Collections with explicit locality references to Salada, Laguna Salada, and Sharp Park were noted, and these localities were queried for all species. Date, collector, and habitat data were noted and compiled into a partial wetland flora and beach-dune flora. Physical herbarium searches in California Academy of Sciences/Dudley-Stanford herbarium specimen collections (not all of which are currently in databases) were not conducted. One flora with specific locality reference to Laguna Salada or Sharp Park was also reviewed for the candidate wetland species (Thomas 1961), after older floras were searched and found to lack Laguna Salada locality references.

Available historical photographs from published sources and private collections (including photos not previously reviewed in coastal engineering and wetland reports on Sharp Park) were enlarged and examined in detail, with qualitative comparisons among photographs and historical maps. Vegetation and plants were identified to the level of family, subfamily, genus or species based on recognizable vegetative characteristics visible in photographs, based on comparison with modern reference photos and reference site floras. Geomorphic features were interpreted based on comparisons with modern reference lagoons and the conceptual geomorphic model (this Appendix volume) and vegetation and botanical records.

The scope of this preliminary historical ecology review did not include new research in geographic descriptions from earliest U.S. history, European explorer accounts, the Mission period, or Mexican land grant sketches (diseños) accounts. The prospects for ecologically informative information from these sources were reviewed in one recent published historical ecology study of a reference lagoon (Rodeo Lagoon). One early explorer account (Menzies) of lagoons of northern San Francisco is included because it provided explicit descriptions of both freshwater and saline backbarrier lagoons of the San Francisco Peninsula.

A-1. Results

Botanical, photographic, and map data were integrated into chronological interpretations of Laguna Salada's ecological development. These were categorized into broad periods based on land uses visually evident in photographs: the 20th century Sharp Park golf course construction and development period (1930s through modern times), the intensive agricultural period associated with row crops in the landward floodplain of Sharp Park and tillage of the marine terraces in the early 20th century before golf development (and likely late 19th); and the pre-(intensive) agricultural period that likely included dairy ranching (grazing) and earlier aboriginal land uses, including vegetation burning. Most detailed data currently available are concentrated in the 20th century intensive agricultural and golf periods.

Mid-20th century Laguna Salada: Sharp Park Golf Course

Vegetation and plant community composition. Herbarium records from Laguna Salada/Sharp Park dated later than 1930 (Table A-1) show that botanical collections included a mix of species adapted to brackish, fresh-brackish (oligohaline), and freshwater marsh soils with variable water depth ranging from deeply flooded to shallow emergent. No golf era records of common or dominant salt marsh species were found with explicit locality reference to proximity or occurrence within Laguna Salada or Sharp Park in the mid-20th century, even though two occur today in local abundance on the west shore of Laguna Salada and Horse Stable Pond (pickleweed, saltgrass). Only one plant typical of brackish or salt marshes was reported from Laguna Salada during golf period (Jaumea).

Most of the historical fresh to brackish species occur at Sharp Park today, but some, notably the submerged aquatic plants (pondweeds, wigeongrass) are apparently now absent within Laguna SaladaSome collectors, such as M. Nobs and S.G. Smith, collected a wide range of wetland plants in 1949, suggesting that their purpose was comprehensive local marsh plant collection. The breadth of the 1949 (golf period) Nobs and Smith Sharp Park plant collection strengthens the interpretation of species presence and absence data as indicative of prevalent fresh-brackish marsh normally lacking prolonged periods of near-marine salinity (polyhaline, euhaline marsh salinity) during the growing season. This is similar to the modern condition of Sharp Park, where fresh-brackish (oligohaline) to brackish marsh is prevalent. This fresh-brackish marsh assemblage is consistent with the records of San Francisco Garter Snakes and California red-legged frogs by Wade Fox as early as the mid-1940s, about the same time Nobs and Smith collected their plant specimens. W. Fox recorded San Francisco Garter Snakes at Sharp Park/Laguna Salada on multiple dates in 1946 (contemporary with the aerial photo), on 3/31 4/6, 4/17, 7/15, 8/13, 8/24, 8/30, 9/12, and 10/11 1946. Fox entry of April 6, 1946 describes the transitional wetland vegetation of the lagoon with regard to snake habitat: “The **narrow band of grass and water plants at the border of the lake** is the only really secure place for the snakes - we found one dead one, presumably killed by golfers - They probably die frequently in this manner.” This evidence indicates that fresh-brackish marsh suitable for supporting an ample population of red-legged frogs (prey base for San Francisco garter snakes) was well-established at least as early as the mid-1940s.

Geomorphic and hydrologic features. The July 1946 aerial photograph of Sharp Park (Figure A-1) shows a relatively discontinuous stand of Monterey cypress plantings remaining from earlier 20th century plantations that extended continuously along the back of the Salada barrier beach. This is consistent with either the artificial creation of gaps in the cypress stands, or the natural development of washover fans, or both. The lagoon in its summer condition appears to be drawn down, exposing emergent flats and vegetation, and retaining little open water. The extent of prevailing seasonal water level fluctuations could be estimated only from a large and seasonally well-distributed sample size of aerial photographs. A photo of Mori Point reportedly from 1966 shows shallow surface channel outlet draining Laguna Salada across the beach, above tide and swash elevation of the beach foreshore (Figure A- 8)

Figure A-1. July 1946 aerial photo enlargement of Laguna Salada,. U.S. Geological Survey Aerial Photo (B&W) 7-29-1946. The beach and foredune zone includes dark grey irregular, continuous woody vegetation, likely Monterey cypress remnants evident in 1930s ground photos (A) on the landward side of the barrier beach. Traces of lightly shadowed lines in the foredune/backbeach zone are likely locations of sand fences and low ridges of European beachgrass remaining from 1930s plantations. At the north end of the foredunes, unvegetated or very sparsely vegetated sand spreads landward among scattered patches of darker (woody) vegetation, indicators of accreting sand from eolian or low-energy overwash processes Most of the lagoon bed is mottled dark gray with variable texture, indicating an emergent (drawdown) vegetated condition with relatively little open water habitat. Lagoon fringing marsh vegetation is fresh and fresh-brackish marsh, based on herbarium collections at "marshes at Sharp Park" by Nobs and Smith in August 1949.

Early 20th century Laguna Salada: intensive agriculture around Laguna Salada

Vegetation and plant community composition. There are fewer botanical records of wetland plants from Laguna Salada prior to 1930, but none of the the five species recorded are emergent salt marsh plants tolerant of brackish to saline (mesohaline to euhaline) soil conditions in the growing season, and two marsh rush species from this era is typical of freshwater to oligohaline marsh, and is intolerant of brackish soil salinity (brown-headed rush, *J. phaeocephalus*). The other rush reported from Laguna Salada prior to 1930, *J. lescurii*, is prevalent in fresh-brackish sandy marsh soils, but is not tolerant of brackish to saline marsh salinity. One of the submerged aquatic plants from the intensive agricultural Laguna Salada era is tolerant of brackish to saline water (wigeongrass, *Ruppia* spp.), but grows better in fresh-brackish salinity range (Kantrud 1990). The other wetland plant recorded from this era, *Chenopodium chenopodioides*, is found on fresh-brackish to brackish sandy flats along the emergent summer bed of Abbott's Lagoon and Rodeo Lagoon today.

The coastal sand dune flora of Laguna Salada prior to 1930 was sampled by W.S. Cooper, who conducted state-wide biogeographic surveys of coastal dune vegetation (Cooper 1930, 1967), as well as other botanists making incidental collections (Table A-2). The dune flora prior to the mass plantings of beachgrass and Monterey cypress included mostly native early-succession beach and foredune species adapted to active sand accretion (yellow and pink sand-verbena, silvery beach-pea, dunegrass,), and at least two species associated with more stable dune vegetation and relatively low rates of sand transport (Franciscan wallflower, dune bluegrass, beach strawberry). Prior to Monterey cypress and beachgrass plantings, photos of the beach seaward of the lagoon show little topographic relief indicating significant dune building, but dunes at the north end of the beach (possibly associated with the low marine terrace) exhibit dune mounds with apparently rapid accretion of fine sand (Figure A-9) – a feature no longer present at Salada/Sharp Park Beach or the shoreline to the north.

Pre-golf photographs of Laguna Salada include one associated with crop agriculture and valley (visible in the in the landward drained floodplain in the background) showing a prevalence of extensive emergent bulrush and cattail vegetation along the landward shoreline of the lagoon. Cattails (*Typha* sp., likely *T. latifolia*) are clearly identifiable; other species are bulrushes including alkali-bulrush (*Bolboschoenus maritimus*), and other bulrush species undetermined, but including likely small patches of tule (*Schoenoplectus acutus* or *S. californicus*) (Figure A-2). Cattail-bulrush marsh is associated with fresh, fresh-brackish, or brackish marsh, but not salt marsh, and robust, vigorous growth of cattails is associated only with relatively low salinity early in the growing season. The date of this key agriculture-period photograph is likely from the late 1920s or early 1930s.

Geomorphic and hydrologic features. Salada Beach during the later crop agriculture period was modified with either windbreak or stabilization plantings of Monterey cypress, forming a continuous young evergreen plantation landward of two sand-fence lines planted with European beachgrass, which formed two low foredune ridges (Figure A-3). The lack of gaps in these plantings indicates a prolonged period in which overwash was not occurring. This may have been due to the modified elevated dune topography, or from insufficient winter storm energy coinciding with high tides. The lagoon appears to have been drained at the south end, adjacent to

Mori Point, where there was a contemporary gap in the beachgrass and Monterey cypress plantation. At this gap, sandy flats (Figures A-2, A-3) occur. Figure A-2 shows a wooden structure (likely a flume and gate) are visible on the beach below Mori Point, next to an electrical utility pole also installed on the beach (Figure A-2). Evidence of the intermittently drained lagoon condition is provided by a photograph showing emergent flats around discrete or coalescing tall emergent marsh stands (likely bulrush, bulrush-cattail), occurring landward of the Monterey cypress windbreak plantation on the beach, associated with the south end gap/bare beach sand flats. Figure B2 also shows the extensive water surface of a flooded lagoon behind the Monterey cypress plantation.

Some cropland-era photos of Laguna Salada and Salada Beach precede the stabilization plantings of beachgrass and Monterey cypress. They show a fringing (dark) marsh along the landward edge of the barrier beach and open sandy washovers, and low dunes at the north end of Salada Beach and northward (Figure A-4). The lagoon photos prior to the Monterey cypress plantation exhibit very extensive (full, deeper) open-water lagoons with little emergent marsh, and at least one narrow, parallel-edged canal extending perpendicular to the shoreline through the fringing marsh and partially across the beach profile (Figure A-5). The canal in Figure A-5 terminates in a dark (likely wooden) linear structure in the beach. This canal feature is associated with a light, linear feature in fringing marsh on the north side of the canal, but not washover fans that would be associated with a natural breach closure.

This channel feature is interpreted as an excavated canal with side-cast sandy dredge spoils. The canal would likely have functioned as a pre-constructed breach, allowing rapid breaching and drawdown of the lagoon on low tides by excavating beach sand seaward of the canal terminal structure (flume gate). No dune topography is visible on the flat-topped beach ridge. Artificial breaching would be expected as necessary for establishing positive drainage or lowering groundwater of the farmed floodplain. Breaching during the agricultural growing season would be expected to allow seawater pulses to enter the lagoon until constructive wave action sealed the breach with a sand (swash) bar.

Above Laguna Salada, perched in the steep lower hillslopes above its lowland crop agriculture fields, is an artificial impoundment (likely a reservoir) (Figure A-6). Below the impoundment is a creek channel draining south (with riparian vegetation descending towards the lowlands), and a smaller ditch (possibly an irrigation ditch) draining west. The impoundment is apparently associated with crop agriculture irrigation below. This freshwater impoundment suggests a potential freshwater pond and wetland habitat capable of providing additional California red-legged frog and San Francisco Garter Snake populations in the watershed. No impoundment or antecedent pond in shown in the 1892 topographic map covering the Laguna Salada watershed (Figure A-7); only the Skyline sag ponds are evident in earlier topographic maps of the Peninsula (Figure A-8).

Figure A-1. Late agricultural period (early 20th c, pre-golf) Laguna Salada. View towards east of landward shore of Laguna Salada with highly visible emergent fresh-brackish to brackish marsh vegetation indicators (cattail and bulrush), simultaneous with truck dumping earthen fill (for perimeter road or berm construction) during agricultural land use (cropland shown in background, prior to golf course construction). Undated photo estimated 1920s to early 1930s. The identifiable wetland and aquatic vegetation visible in the foreground includes vigorous, tall cattail with lax broad blades (*Typha* sp, foreground right, green arrow;, alkali-bulrush (*Bolboschoenus maritimus*), a few straight rigid stems of tule (*Schoenoplectus californicus* or *S. acutus*), with either sago pondweed (*Stuckenia pectinata*), wigeongrass (*Ruppia maritima*), or both, on water surface. The background emergent grass-like marsh vegetation is not identifiable to species or genus, but is consistent with short or deeply flooded cattail or tall bulrush marsh, such as *S. pungens (*fresh to brackish marsh plant that was collected at Laguna Salada in 1908, long before Sharp Park golf course (Table A-1). This vegetation is inconsistent with salt marsh hydrology and vegetation (shrubby pickleweed or prostrate saltgrass). None of the plant species shown (except *Ruppia*) are tolerant of prolonged high salinity. The fresh-brackish marsh species inferred were subsequently vouchered by herbarium specimens from Sharp Park/Laguna Salada marshes in 1949, and are still present in modern fresh-brackish Laguna Salada marshes. All species shown are typical of fresh-brackish coastal marshes inhabited by California red-legged frogs in coastal San Mateo County today.

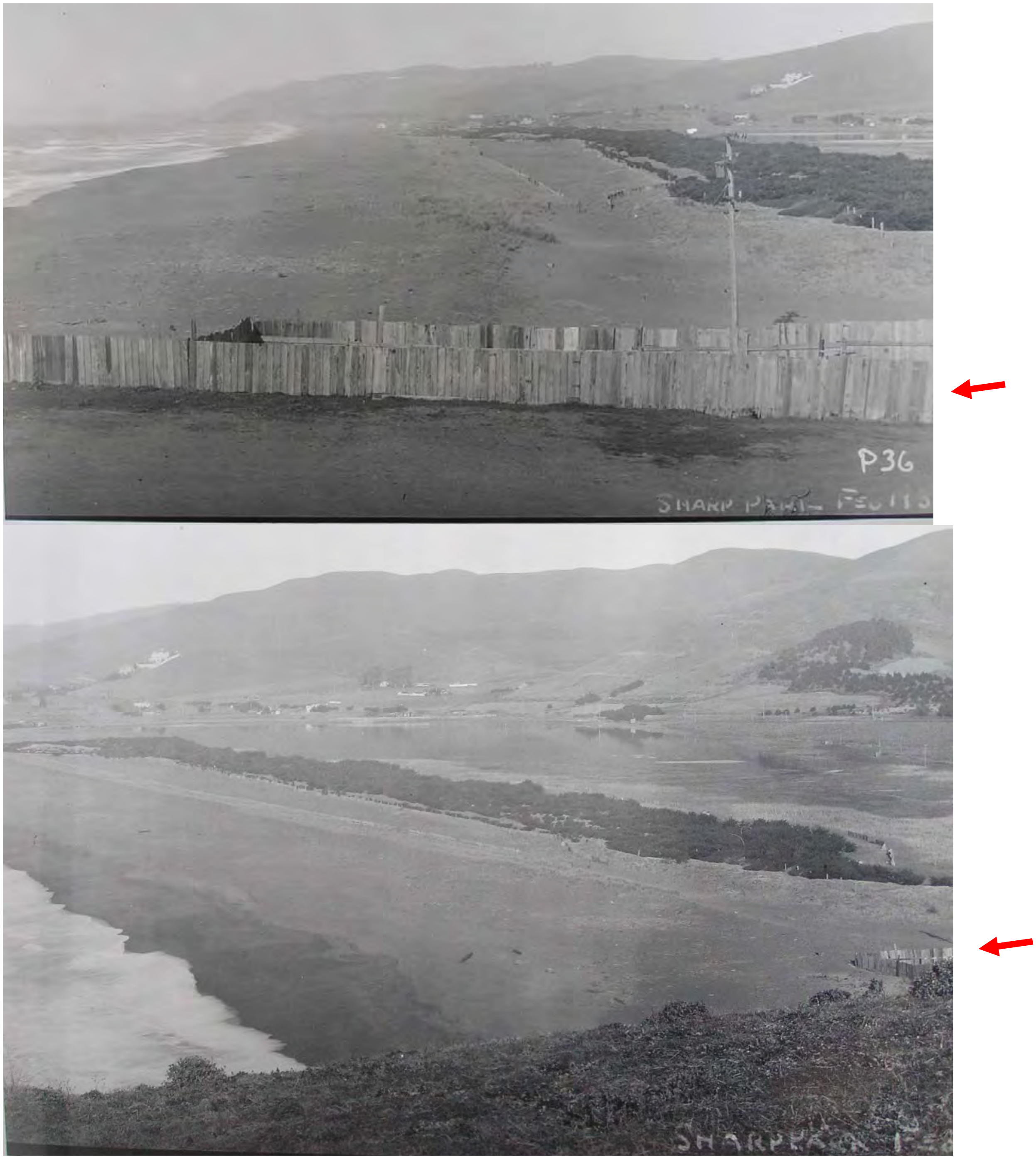


Figure A-2. Late agricultural period (early 20th c) Laguna Salada. Views towards north and northeast. Prominent pre-golf agricultural era features include: a wooden (flume) structure (red arrows) extending into the beach below Mori Point, next to an electrical power line on beach extending to near its seaward end; two outer low artificial wind-fenced foredune ridges with planted beachgrass (*Ammophila arenaria*); and an inner cover Monterey cypress plantation along the barrier beach, nearly continuous (no washover gaps) along its back. A wide flooded lagoon with emergent marsh (compare next Figure A-3), earlier, with sandy gap at south end of beach) and open water lies seaward of cropland. Photo courtesy of private collection.

A B C

Figure A-3. Late agricultural period (early 20^{th} c) Laguna Salada, enlarged cropped views of Laguna Salada to southwest from hillslopes above. Photograph undated, but taken after establishment of nearly closed-cover cypress plantation on beach; likely circa late 1920s, but prior to installation of electrical utility poles to the end of the flume below Mori Point (shown in Fig. A-2). Emergent (drained) unvegetated lagoon flats and emergent marsh vegetation are evident in the lagoon. Row crops (likely artichoke) occupy the lagoon valley floodplain, indicating land use dependent on drainage or low lagoon levels. An unvegetated emergent flat to gently sloping sandy gap in the cypress on barrier beach occurs at the extreme south end of the lagoon (yellow arrow, A), consistent with location washover sedimentation over a breach (potential lagoon outlet position). Dark vegetation on barrier beach corresponds with Monterey cypress plantation in other early 20^{th} c photos. Vegetation structure and pattern on lagoon flats is consistent with bulrush, cattail, tule (tall emergent grass-like morphogy and clonal growth) and incomplete colonization of lagoon flats. Photo courtesy of private collection.

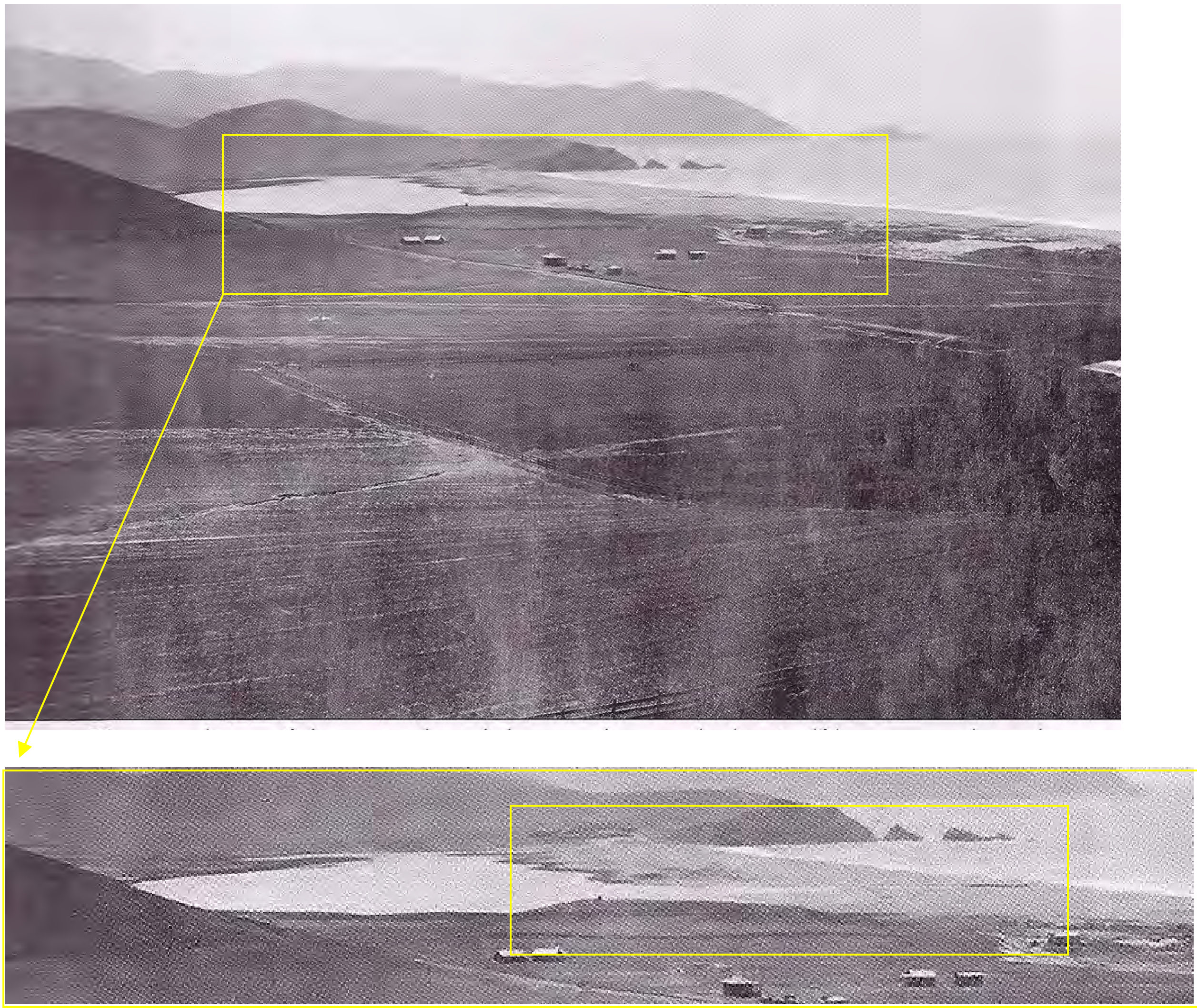
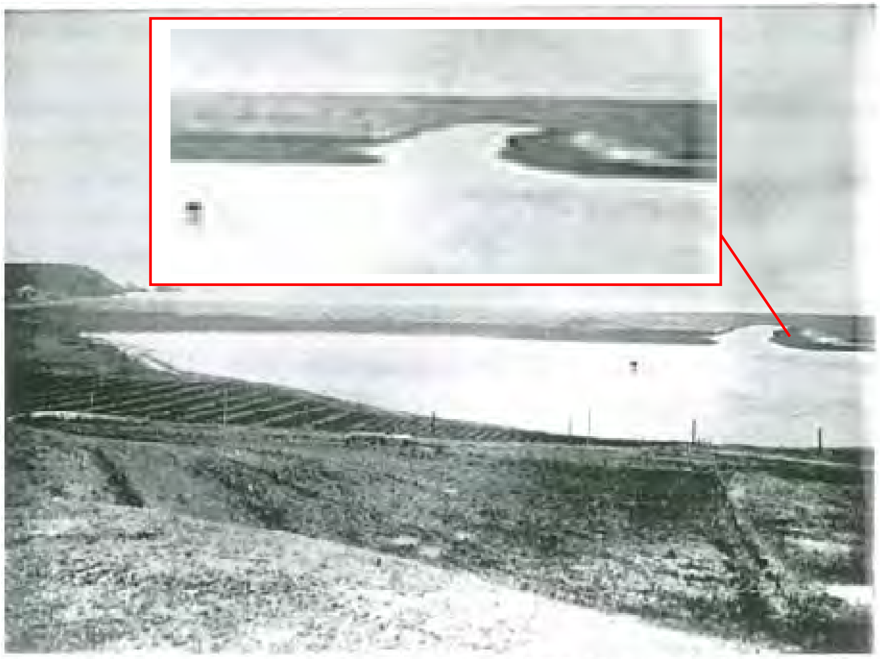


Figure A-4 . Early agricultural period Laguna Salada, undated photograph circa late 19th c – early 20th c prior to cypress plantation on beach, viewed from marine terrace north of Laguna Salada, which lacks natural vegetation patterns and shows uniform cover and plow lines, consistent with cultivation. Dark zone between open water and beach is consistent with fringing marsh. A canal-shaped narrow, linear breach terminating in a dark line (likely wooden structure) is consistent with an excavated canal for a pre-constructed breach to lower the lagoon levels on neap low tides, corresponding with the view shown in the next historical photo of the lagoon prior to cypress plantation establishment (Figure A-5). Lagoon breaching was a common farming practice in floodplains bordering California coastal stream mouths in 20th century (now regulated by federal and state permits).



Photograph 9. Laguna Salada seen as an inland salt water lagoon around 1905. Land east of lagoon used for farming.

Figure A-5. Early agricultural period Laguna Salada, undated photograph circa late 19th c – early 20th c prior to cypress plantation on beach; view to southwest towards Mori Pt (left). Lagoon appears substantially similar to the condition shown in preceding Fig. A-4 . Narrow, nearly straight canal (pre-constucted artificial breach; inset, enlarged) extends partially across beach and fringing marsh, parallel with bright linear feature consistent with placement of sandy dredge spoils to north (right), and in the absence of gently sloping natural washover fans or flood inlet shoals over marsh. The canal is consistent with patterns of artificial excavation. No fringing marsh is visible along the landward edge of the northern half of the lagoon, but marsh (dark) is visible at the south end. Source: Geomatrix 1986.

Figure A-6 . Impoundment, likely an irrigation reservoir, near toe of hillslope above Laguna Salada, with ditch (center) and vegetated channel (right, center) downslope. Photography likely late 1920s, early 1930s, annotated "Sharp Park". Courtesy of private archive.

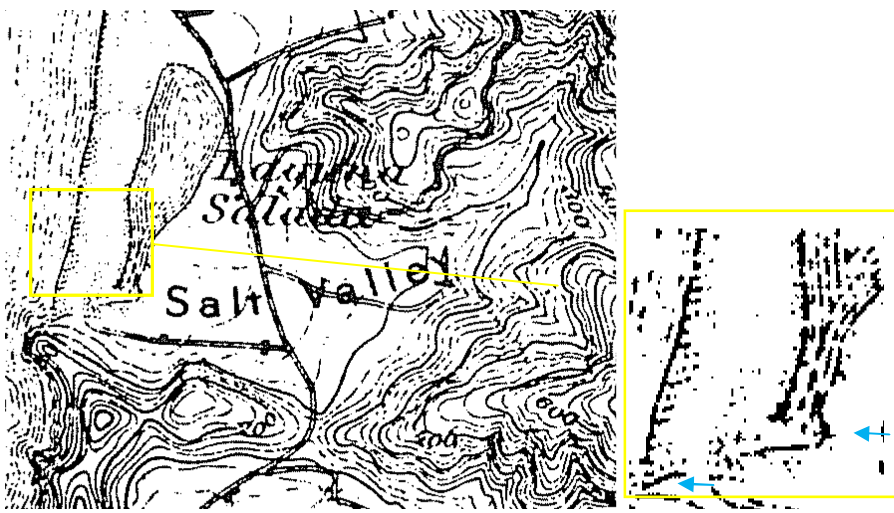


Figure A-7. Topography and shorelines of Laguna Salada, late 19th century; excerpt of 1892 U.S. Geological Survey. No impoundments (artificial ponds) are shown in the watershed above Laguna Salada, and no marsh symbol appears in the former mapped marsh fringe at the southeastern end of the lagoon, where drained row crops are visible in earliest ground photography (Figures A-4, A-5). One road is shown extending from the main N-S coast road Mori Point, and another road extends up the "Salt Valley". A line curving from the east end of the southern neck of the lagoon next extends in a straight path to the wave shelter zone of the Mori Point headland. This line does not appear in the 1869 USCS map, but is consistent with a former outlet position in the mid-20th century (Figure A-8) .

Figure A-8 . Mori Point outlet draining remnant of Laguna Salada at Sharp Park Golf Course, reported date 1966. The shallow channel bed is incised in the beach above the elevation of the swash, with a swash bar forming below the mouth of the outlet. Not tidal inlet morphology is evident. Photo courtesy of private collection.

Figure A-9. Salada Beach, North, circa 1900. Active deposition of wind-blown fine-medium sand in steep vegetated dune mounds with vegetated caps and windward slopes, and unvegetated wind-shadow deposits, and pioneer native perennial prostrate dune forbs. View towards Mori Point and Pedro Point.

Table A-1. Historical Local Wetland Flora of Laguna Salada. Data source: Consortium of California Herbaria, searched by locality (Laguna Salada, Salada, Sharp Park, marshes at Sharp Park), collector, species. Species collected before 1930s (before Sharp Park) are highlighted in red. Additional species found in Sharp Park today but not reported with explicit Sharp Park/Laguna Salada localities are highlighted in blue. Note that salt marsh dominant or indicator species were not historically recorded at Sharp Park prior to 21st century, and all species recorded from 1930 or earlier are intolerant of marine salinity, but are widespread regionally in fresh to brackish coastal marshes. These fresh to brackish species also occur in the mid-20th century and modern golf period. Salinity range classification corresponds with the modified Venice system classification of brackish waters in Cowardin 1979: (fresh 0-0.05 parts per thousand [ppt]; oligohaline = below 5 ppt; mesohaline, 5-18 ppt ppt; euhaline, polyhaline 18-30 ppt; euhaline 30-40 ppt)

Species	Common name	Herbarium Accession no.	Collector & #	locality & habitat	date	2010 local status	Soil salinity range (coastal CA marsh)
Agrostis alba	bentgrass	UC1100106	Malcolm A. Nobs and S. Galen Smith 1550	marshes Sharp Park	Aug 25 1949	Present (syn. *A. stolonifera*)	Fresh to oligohaline
Agrostis exarata	bentgrass	UC1100235	Malcolm A. Nobs, S. Galen Smith 1562	marshes at Sharp Park	Aug 25 1949	?	Fresh to oligohaline
Agrostis stolonifera	bentgrass	UCD53588	Malcolm A. Nobs, S. Galen Smith 1550	Marshes at Sharp Park	08 25 1949	common	Fresh to oligohaline
Artemisia douglasiana	mugwort	UC1537053	Gordon H. True, Jr. 803	along Salada Beach-Skyline Blvd.	Jul 23 1937	not found	fresh
Argentina egedii (syn. Potentilla anserina)	silverweed	no specimens	------	not reported	----	present	oligohaline to mesohaline
Bolboschoenus fluviatilis	River bulrush	UC1100841	Malcolm A. Nobs, S. Galen Smith 1557	marshes at Sharp Park	Aug 25 1949	not found	fresh
Bolboschoenus maritimus	Alkali-bulrush	UC841022	Lewis S. Rose 35565	Salada	Aug 13 1935	not found	olighhaline to mesohaline
Chenopodium chenopodioides	goosefoot	UC463309	L.R. Abrams and I.L. Wiggins 178	Salada Beach; margin of pond	Nov 13 1930	not found	oligohaline to mesohaline
[Distichlis spicata]	saltgrass	No specimens	---	---	---	present (west shore)	mesohaline to euhaline
Epilobium ciliatum subsp. watsonii	Willow-herb	UC1191717	Malcolm A. Nobs and S. Galen Smith 1548	marshes Sharp Park	Aug 25 1949	present	fresh
Isolepis cernua	Club rush	UCD49893	S. Galen Smith, Malcolm A. Nobs 1565	Marshes at Sharp Park	08 25 1949	not found	Oligohaline to mesohaline
Jaumea carnosa	Fleshy jaumea	SBBG28003	L. S. Rose	Salada	Aug 13 1935	present	Oligohaline to euhaline
Juncus lescurii	Coast rush, salt rush	JEPS63809	Unknown 3	Salada	May 28 1925	Present	Oligohaline to mesohaline
Juncus phaeocephalus	Brown-headed rush	JEPS67130	Unknown 2	Salada	May 28 1925	not found	Fresh to oligohaline
Persicaria punctata (syn. P. punctatum	Dotted smartweed	UC1191256	Malcolm Nobs and S. Galen Smith 1560	Sharp Park; marshes	Aug 25 1949	present	Fresh to oligohaline
Parapholis incurva	sicklegrass	UC 1101574	S. Galen Smith & Malcom Nobs 1566	marshes at Sharp Park	Aug 24 1949	not found	Oligohaline to euhaline
Ruppia maritima	wigeongrass	UC279586	W.A. Setchell	Laguna de Salada	August 29 1925	not found	Oligohaline to euhaline
Ruppia cirrhosa	wigeongrass	UC1109006	H. E. Parks	Laguna Salada	Oct 1928	not found	Oligohaline to euhaline
Rumex salicifolius var. *crassus*	seashore willowleaf dock	JEPS3987	unknown 15	Salada	May 28 1925	not found	Oligohaline to mesohaline
[Sarcocornia pacifica, syn. *Salicornia*	[pickleweed]	No specimens	-----	Salada Laguna Salada	[2010]	present	Mesohaline, euhaline to hyperhaline

virginica]				Sharp Park			
Schoenoplectus pungens	Threesquare bulrush	DS61109	W. R. Dudley	Near Laguna Salada	1908-10-04	common	Fresh to mesohaline
Schoenoplectus pungens	Threesquare bulrush	UCD50157	S. Galen Smith, Malcolm A. Nobs 1558	Marshes at Sharp Park	08 25 1949	common	Fresh to mesohaline
Scirpus microcarpus	Small-fruited sedge	CAS418178	Malcom A. Nobs, Stanley Galen [S. Galen] Smith 1559	Marshes at Sharp Park.	1949-08-25	not found (present Sanchez Ck)	Fresh to oligohaline
Stuckenia pectinata (syn. *Potamogeton pectinatus)*	Sago pondweed	UC1099818	Malcolm A. Nobs, S. Galen Smith 1552	Sharp Park	Aug 25 1949	not found (present Mori Pt ponds)	Oligohaline to mesohaline
Typha angustifolia	Narrow-leaf cattail	UC1241808	Malcolm A. Nobs and S. Galen Smith 1556	marshes at Sharp Park	Aug 25 1949	common (nonnative)	Fresh to mesohaline
Typha latifolia	Broadleaf cattail	UC241789	Malcolm A. Nobs and S. Galen Smith 1554	Sharp Park - along ocean coast	Aug 25 1949	common	Fresh to oligohaline

Table A-2. Historical Local Beach and Dune Flora of Salada Beach (Sharp Park Beach). Data source: Consortium of California Herbaria, searched by locality, collector, species.

Species	**Common name**	**Herbarium Accession no.**	**Collector & #**	**date**	**locality & habitat**	**2010 local status**
Abronia latifolia	Yellow sand-verbena	UCD39013	Beecher Crampton 6509	06 11 1962	Pacifica, Sharp Park at Mori's Point	extirpated
Abronia umbellata	Pink sand-verbena	UC577087	Lewis S. Rose 35654	Oct 12 1935	Salada	extirpated
Centromadia parryi subsp. *parryi*	Parry's tarweed	JEPS38137	L. M. Newlon 239	Jan 1 1921	seashore from Salada to Mussel Beach	extirpated
Erysimum franciscanum	Franciscan wallflower	JEPS53557	William S. Cooper 16	May 28 1925	Salada	
Lathyrus littoralis	Silvery beach-pea	POM194716	H. M. Hall 11957	06 17 1924	Salada	extirpated
Lathyrus littoralis	Silvery beach-pea	JEPS22663	Irene Brown 151	May 15 1959	about 50 feet from Ocean, Sharp Park	extirpated
Eriogonum latifolium	Broadleaf coast buckwheat	JEPS56786	William S. Cooper 10	May 28 1925	Salada	extirpated
Fragaria chiloensis	Beach strawberry	UC1536909	Gordon H. True 616	Mar 31 1937	Salada Beach	extirpated
Leymus mollis subsp. *mollis*	Pacific dunegrass	JEPS71209	William S. Cooper 8	May 28 1925	Salada	present
Leymus mollis		UCD64581	Beecher Crampton 6511	06 11 1962	San Mateo County: Sharp Park, Mori's	present
Poa douglasii	Dune bluegrass	UC1537366	Gordon H. True, Jr. 618	Mar 31 1937	Salada Beach	extirpated

Early U.S. historical period prior to Laguna Salada valley/floodplain farming

There are no known botanical data or direct vegetation descriptions currently available to guide interpretation of U.S. Coast Survey maps of the early U.S. historical period, which likely represented the condition of the lagoon in transition from known Ohlone land uses (hunting, trapping, textile vegetation harvest, vegetation management by burning) to ranching (low-intensity agriculture; grazing). New research would be required to provide direct evidence from either pollen/sediment cores (paleoecology) or historical records including explicit, detailed, descriptions or drawings of vegetation and hydrologic features to guide interpretation of the U.S. Coast Survey maps of the mid-19th century covering what is now the Pacific coastline. The USCS topographic maps, and their mapping conventions for drainage and vegetation features, are the only indirect source of information used for the assessment of the early historical wetland landscape of Laguna Salada and its surrounding watersheds.

Distribution of 19th century coastal lagoons and ponds on the San Francisco Peninsula outer coast

The U.S. Coast Survey Map of the San Francisco Peninsula dated 1869 represents the topography of all large perennial pond and lagoon features of the Peninsula, including Laguna Salada, Lake Merced, and the lagoon of San Pedro Creek, as well as the upper hillslope sag ponds (“Skyline sag ponds”; seismic wetland features, natural drainages impounded by earthquake fault blocks) in a single map. Relatively small pond and lagoon features are also shown in San Francisco (Laguna Puerca, Laguna Honda, Mountain Lake, Black Point vicinity lagoons, and two tidal lagoons near Hunters Point; Fort Point lagoon in earlier 1851 USCS T-sheet 314 is shown in Figure A-20).

The 1869 USCS map of the San Francisco Peninsula indicates that large perennial pond habitats were few, sparsely distributed on the peninsula as a whole (only the Skyline sag ponds and Black Point lagoons were closely spaced). Within the known 20th century range of the San Francisco Garter Snake, the only historical (outer/maritime) coastal lagoons north of Montara Mountain and Pedro Point were Pedro Creek lagoon and Laguna Salada. In the absence of any other large coastal ponds, the map suggests that the potential locations of historical core (large, stable) perennial habitats of the pond-breeding California red-legged frog and the San Francisco Garter Snake on what is now the Pacifica coast were limited to these locations in the 19th century, depending on their habitat suitability – particularly their salinity range. Therefore, the analysis of the types of marshes represented in the 19th century U.S. Coast survey maps is of particular relevance to historical wetland ecology.

Figure A-10. Excerpt from the 1869 U.S. Coast Survey map of the San Francisco peninsula, showing distribution of naturally impounded waterbodies (lagoons, ponds shown in blue arrows) along the outer coast and in the lee of the first coastal ridge (Pacific coast watersheds) . Shown are fault-controlled ridgetop Skyline sag ponds, backbarrier lagoons at Laguna Salada and San Pedro Creek mouth. Riparian vegetation is shown discontinuously distributed along Calera Creek (Calera Valley); no riparian vegetation is shown in the creek of Salt Lake Valley (Laguna Salada watershed), which terminates before reaching the lower valley.

The only potential major “core” freshwater pond habitats in watersheds surrounding Laguna Salada in 1969 are shown at the mouth of San Pedro Creek (lagoon) and the Skyline sag ponds. If some portion of Laguna Salada wetland complex did antecedent natural local populations of red-legged frogs and San Francisco Garter Snakes in suitable fresh-brackish marsh in 1869 or before, then the 20th century populations of Laguna Salada red-legged frogs and San Francisco Garter Snakes would have to represent new colonization events of both species. Both species presumably would have had to disperse jointly, or fog prey species first, to Laguna Salada from the nearest source populations and habitats either during the subsequent farming period or during the 20th century golf development period, when wetlands were apparently greatly reduced by farming and filling of wetlands and floodplains. The long-distance dispersal distances required for new colonization of Laguna Salada from the locations of original, natural 19th century freshwater pond habitats would have been extreme, particularly for San Francisco garter snakes, which are not known to occur today in the San Pedro Creek watershed (inhabited by a distinct subspecies). This biogeographic context is a consideration for interpretation of the Laguna Salada wetland complex illustrated in the 1869 USCS map.

U.S. Coast Survey wetland symbols within Laguna Salada and regional reference coastal lagoons

Laguna Salada is represented in the 1869 U.S. Coast Survey Map with map conventions (symbols) denoting landform and vegetation features (Figure) including beach (stippling over shoreline), marsh (horizontal hatching, parallel lines closely spaced at or near sea level bordering open lagoon flats and flat adjacent terrestrial lowland topography, small marsh channels (lines following drainage patterns or connected to water bodies) and valley lowland flats (widely spread contours and low elevations in valley).

The interior of Laguna Salada, in contrast with Lake Merced and San Pedro Creek lagoon (the only other outer coast lagoons), is uniquely mapped with stippling with lower density than the adjacent beach, in contrast with the darker uniform gray tone denoting open permanent water of all other coastal lagoons and interior ponds and lakes on the same map. In context of the small Laguna Salada watershed (relatively low stream discharge compared with Lake Merced and San Pedro Creek watersheds), termination of the tributary creek channel above the marsh, and closed lagoon outlet at the beach, this feature likely indicates a very shallow lagoon bed with either seasonal or episodic emergence of lagoon flats. Emergent lagoon flats are also evident in an early 20th c photograph (Figure A-3), and are known to occur in modern lagoons during post-breach lagoon drawdowns, and during summer drought periods (WWR 2007).

Coastal landform and vegetation symbols not represented in the 1869 map of Laguna Salada include dunes (concentration of stippling in mound or hillock pattern on or behind beaches), tidal marsh channels (sinuous, dendritic channels connected to open tidal waterbodies), and woodland (tree/shrub canopy symbol), but woodland was mapped within the marsh-floodplain complex of nearby San Pedro Creek mouth and adjacent upper Calera Valley (Figure A-10). This suggests that the terrestrial or seasonal wetland vegetation surrounding Laguna Salada was principally grassland, forbs and low-growing coastal shrubs, or other low-growing vegetation.

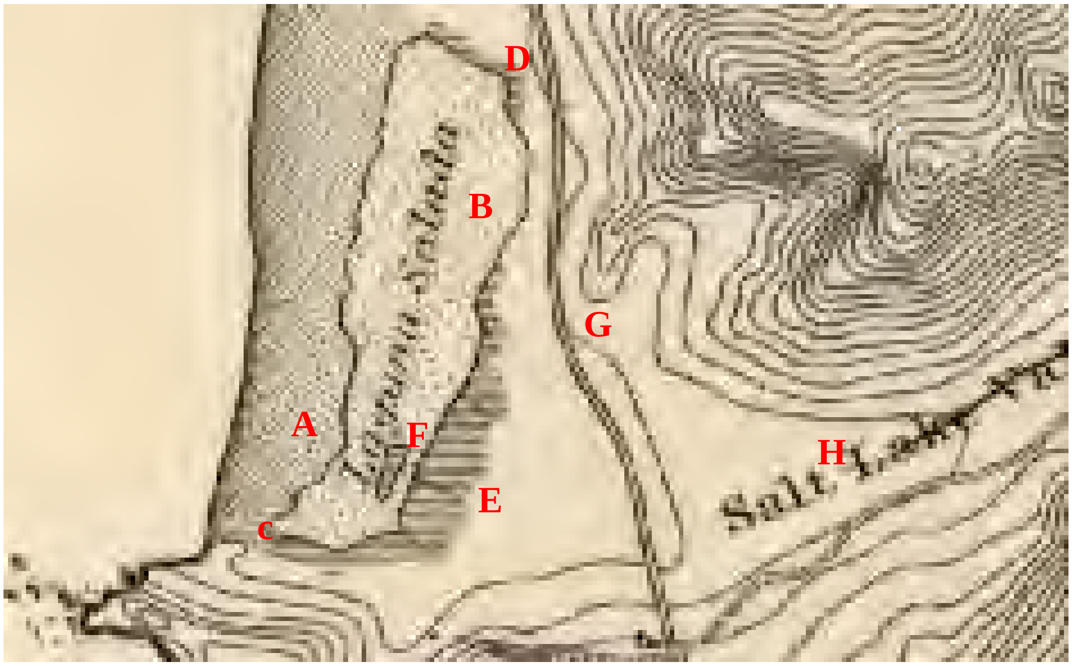


Figure A-11 . Excerpt of 1869 U.S. Coast Survey Map of San Francisco Peninsula, showing Laguna Salada and “Salt Lake Valley” with lower portion of creek (now Sanchez Creek). A. Beach. B. unvegetated lagoon – seasonal pr intermittent emergent bed, unvegetated flats in bed of open seasonal shallow water lagoon (stipple). C. closed remnant outlet position. D. northern end, fringing marsh. E. southeastern marsh with three channels connected to lagoon. F. Marsh islet opposite middle channel (likely delta lobe remnant). G. coastal road. H. terminus of Sanchez/Salt Lake Valley Creek.

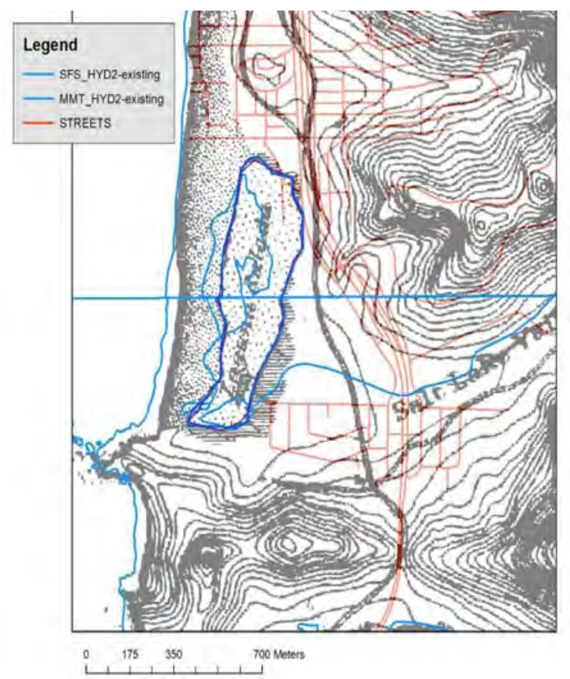
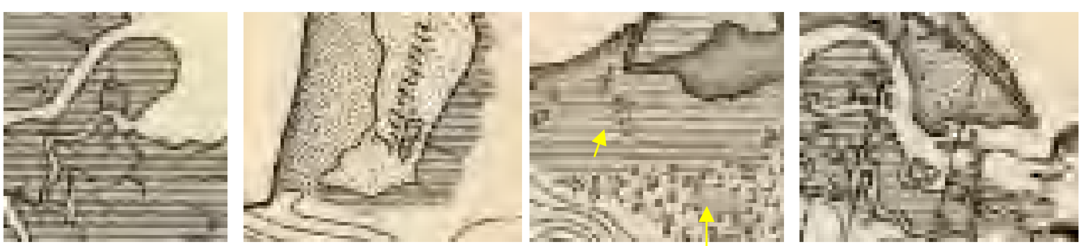


Figure A-12. Overlay of modern U.S. Geological Survey topographic data for streets, shorelines and streams of Mori Point and Laguna Salada on U.S. Coast Survey topography (1869) for San Francisco Peninsula, prepared by Golden Gate National Recreation Area. All historic marsh (horizontal hatching) is located in areas of modern fill. (Courtesy of National Park Service).

The habitat and vegetation interpretation of the marsh symbol mapped at the fringes of Laguna Salada, particularly at the southeastern corner below the creek channel in the upper watershed, is uncertain. The range of coastal marsh types represented locally by the general horizontal hatching symbol in coastal lagoons is indicated in part by their most widespread applications in the 1850s-1860s U.S. Coast Survey maps of the San Francisco Bay area, but also by "inter-calibration" (Striplen et al. 2004) of their context with other mapped hydrologic and geomorphic features in specific local wetland settings on the adjacent outer coast.

The most widespread application of the horizontal hatching marsh symbol is in tidal salt marshes of adjacent San Francisco Bay, where they are associated with dendritic tidal creek mouths that were clearly represented as open to the tidal waterbody of San Francisco Bay (Figure A-12). The contemporary horizontal hatching marsh symbol was also applied to other coastal lagoon and marsh geomorphic settings of the Peninsula, San Francisco Bay, and adjacent outer coast where it was not consistent with tidal salt marsh. Two coastal lagoon contexts incompatible with tidal salt marsh interpretation of the hatching symbol are (a) adjacency to closed tidal inlets of barrier beaches, excluding regular tidal flows, and (b) enclosure within contrasting vegetation symbols representing woody vegetation. Woody vegetation (including swamp and riparian vegetation in or adjacent to waterbodies) in California is intolerant of brackish or marine soil salinity levels. Hatched marsh surrounded by riparian woodland, and disconnected from tidal channels, is inconsistent with interpretation as tidal or non-tidal salt marsh. A key example of this non-conforming use of the horizontal hatching marsh symbol is found at San Pedro Creek lagoon. An additional non-conforming example of hatching representing brackish to fresh irregularly tidal or seasonally tidal to nontidal marsh is from Rodeo Lagoon (Striplen et al. 2004). These are examined in detail to check interpretation of marsh mapped at Laguna Salada in the 1869 USCS map.



A B C D

Figure A-13. Comparison among marsh representations in 1869 U.S. Coast Survey map of San Francisco Peninsula. San Bruno tidal salt marsh (A), Laguna Salada landward fringing marsh (B), San Pedro Creek mouth lagoon (C; see also full view, Figure A-14), mouth of San Francisco Presidio Marsh, with possible impoundments (now near modern Crissy Field; D). Tidal salt marshes at San Bruno and Presidio (A, D) are shown with open tidal channel connections to the bay or Golden Gate, and exhibit sinuous, dendritic channel patterns, with no inclusions of woodland vegetation symbols within tidal marshes mapped by horizontal hatching – a general feature of San Francisco Bay T-sheet representation of tidal salt marsh. The horizontal hatching marsh symbol is also applied to San Pedro Creek lagoon mouth marsh near the outlet, where it includes island-like "strings" of (salt-intolerant) riparian scrub, and borders extensive riparian scrub within the creek floodplain. The same hatching symbol is also applied to southeastern Laguna Salada marsh (B, and Figure A-11) with non-sinuous channels oriented in a pattern consistent with relict stream mouth delta drainage and a marsh-capped delta shield islet. The use of this symbol in contrasting salinity settings (compare Figure A-14) indicates a wide range of coastal marsh vegetation, hydrologic settings on the region (fresh, brackish, saline) to which it was applied at the time.

The horizontal hatching marsh symbol at the landward end of Laguna Salada 1869 U.S. Coast Survey map is associated with a closed lagoon outlet (beach impoundment of the lagoon) at the south end of the barrier beach. The lagoon outlet is also shown as closed in the and 1892 U.S. Geological Survey Map (Figure A-7). This closed beach and lagoon indicates intermittent, irregular tidal connection, and is consistent with the 19th century U.S. Coast Survey mapping of Rodeo Lagoon's intermittent channel outlet or tidal inlet (Striplen et al. 2004).

The horizontal hatching marsh symbol at Laguna Salada is widest at the southeast corner of the lagoon, below the terminus channel of what is now Sanchez Creek (terminating under the "L" of the printed "Salt Lake Valley"), which did not extend as a single-thread channel through the marsh to the edge of the lagoon. The channel termination is consistent with patterns of canyon creeks that descend in their own alluvial fans or break into diffuse distributary channels with poorly defined, shifting beds and banks. Striplen *et al*. (2004) inferred a similar discontinuous creek, alluvial fan, and delta pattern in the U.S. Coast Survey-mapped mouth of Rodeo Creek discharge into Rodeo Lagoon in the same time period (Figure A-14), prior to diking of the freshwater gradient in the delta marsh.

At the landward edge of the hatching-mapped marsh in the 1869 USCS map representation of Laguna Salada, there is no adjacent representation of woodland (freshwater riparian scrub, willow swamp) , in contrast with the mouth of San Pedro Creek lagoon and Calera Creek (Figure A-10). The lack of riparian vegetation in the lower valley and terrestrial flats bordering the lagoon are possibly due to cattle grazing (consistent with lack of scrub mapped on adjacent hillslopes), cattle grazing following Ohlone grassland burning, or seasonal wetland sedge-rush meadow and grassland. Seasonal wetlands (dry in summer, wet in winter-spring) are expected where stream discharge shifts from channelized flow to diffuse sheetflow and subsurface flow into valley slopes above lagoons (Shaw 2005). The discontinuous channel of Salt Valley (Sanchez) Creek is evident in Figure A-11 at point H.

The 1869 USCS San Francisco Peninsula map represented San Pedro Creek lagoon with the horizontal hatching marsh symbol embedded within irregular areas of woodland/shrub canopy symbol, within the creek's riparian (floodplain) zone (Figure A-15). Woodland species in California are generally intolerant of brackish to saline soil, and in wetlands, they represent freshwater swamp or riparian woodland/scrub. Willow and alder are dominant woody vegetation of coastal stream valleys of the San Mateo coast today, including modern San Pedro Creek. Thus, the multiple patches of horizontal hatched marsh surrounded by the woodland symbol-mapped areas, lacking channel connections to any potential tidal source, must be interpreted as including freshwater marsh or fresh-brackish marsh. The same hatching symbol borders the seaward edge of the woodland symbol, and small isolated "stringers" of woodland symbol (relict channel pattern, not connected to defined channels) occur at the west end of the lagoon marsh. This also indicates that adjacent portions of the marsh are not locally representing saline wetlands at this location.

The geographic context of the horizontal hatching marsh applied to the stream mouth lagoon at San Pedro Creek in the 1869 U.S. Coast Survey Map indicates the freshwater-brackish range of marsh salinity to which this symbol was applied in coastal lagoon settings near Laguna Salada. The horizontal hatching symbol in U.S. Coast Survey maps was where it is most often associated with the characteristic geomorphic "signature" of sinuous, dendritic tidal creek patterns. This symbol was otherwise conventionally used to represent general tidal marsh (mostly saline to brackish) in San Francisco Bay and U.S. Coast Survey maps throughout the U.S. (Shalowitz 1963, Askevold 2005). The use of the symbol at San Pedro Creek lagoon and Rodeo Lagoon indicates that this symbol was not exclusively used to distinguish salt, brackish or fresh-brackish marsh gradients vegetation in coastal marshes.

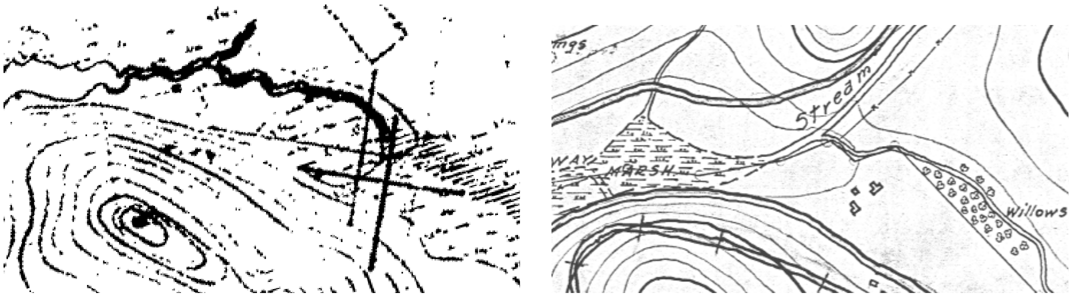
As Striplen *et al*. (2004) noted, historical U.S Coast Survey maps and historical mapping conventions for wetlands did not use modern wetland habitat classifications, but they generally used conventional terminology and symbols that were consistent within their historical context (Striplen *et al*. 2004). The Coast Survey symbols were not always standardized, and individual surveyors for the Coast Survey had wide latitude in the depiction of symbols representing various vegetation types and cultural features on maps (Askevold 2005). The generalized use of hatching to represent marshes with geomorphic signatures that are clearly tidal (dendritic sinuous creeks associated with open bays or open tidal inlets) as well as those with discontinuous straight channel segments or none (Laguna Salada and San Pedro Creek) adjacent to freshwater swamp/riparian woodland, indicates that the 19^{th} c hatching representing coastal marshes did not regularly distinguish tidal salt marsh from, brackish, fresh-brackish marshes, in fully tidal, "semi-tidal" or nontidal coastal wetland settings, at least in the outer coast lagoons.

The Laguna Salada marsh in the 1869 U.S. Coast Survey map is also consistent with the position, morphology, and channel of a broad deltaic marsh discharging into the lagoon, and at least seasonal freshwater discharge or groundwater seepage associated with a fresh-brackish salinity gradient. Within the horizontal marsh hatching at southeastern Laguna Salada, three relatively straight lines perpendicular to the hatching) extend from the edge of the lagoon and converge towards the valley contour line pointing towards the terminus point of the creek. The broad marsh and channel segment patterns are consistent with the geomorphic signature of relict distributary channels of the creek (remnants of erosional high flow events) embedded within its marsh-capped delta. An elongate marsh islet lies immediately seaward of the central distributary channel, consistent with the outline of a former (drowned) marsh-covered delta lobe's outer edge. Marsh is not drawn along the backbarrier edge, in contrast with the photograph in Figure A-4. A small, narrow marsh symbol borders the north end of the lagoon.

The interpretation of a fresh-brackish marsh gradient at the head of Laguna Salada in association with a creek delta is also consistent with the Striplen *et al* (2004) interpretation of the U.S. Coast Survey Map hatching symbol for coastal marsh (contrasting with adjacent wet meadow) at the head of Rodeo Lagoon, and subsequent U.S. Army Corps of Engineers mapping of expanded deltaic marshes at the head of Rodeo Lagoon in the 1920s, prior to construction of a levee/road and weir that isolated a freshwater marsh:

In the 1850s, Coast Survey maps distinctly show the channel of Rodeo Creek stopping just upstream of the Lagoon, fanning out into a wet meadow complex (crosshatching) with no riparian trees ..[series of maps including 1925] ….illustrates the development of a brackish/freshwater marsh at the head of the Lagoon (3 in 14b), most likely in response to grazing-related sediment deposition [Striplen *et al*. Figure 14, p. 25]

…based on similar features (symbols) shown as tidal marsh on USCS maps of other lagoons, we would expect that this feature was semi-tidal and at least seasonally brackish [Striplen *et al*. p. 17]



(a) 1850/53: US Coast Survey (T-321/400) (b) 1925: US Army Corps of Engineers

Figure A-14 . Historical changes at head of Rodeo Lagoon/Rodeo Creek delta showing horizontal hatching in USCS map Rodeo Lagoon at mouth of Rodeo Creek. Excerpt from Striplen et al. (2004) figure 13.(a) hatching marsh symbol marsh within wet meadow (grassland) at the lagoon head, connected with the narrowing open water lagoon; (b) deltaic marsh progradation into the former open-water lagoon, with willows (freshwater swamp/riparian) expanding over former lagoon head wet meadow/marsh. These hatching-represented marshes were interpreted by Striplen *et al*. as brackish to freshwater marsh gradients that were at least intermittently influenced by tides.

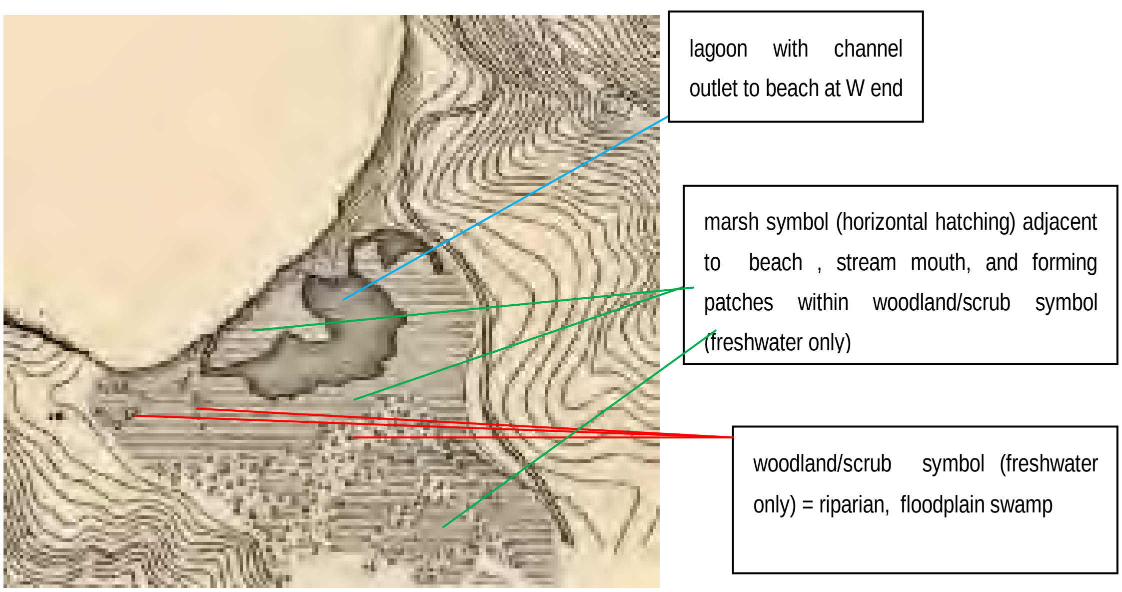


Figure B-15 . San Pedro Creek lagoon (now Linda Mar, Pacifica), U.S. Coast Survey 1869 San Francisco Peninsula map excerpt. Other than Laguna Salada, this is the only other lagoon represented in what is now Pacifica. Here the horizontal hatching symbol surrounding the lagoon, representing marsh, is also shown contiguous and interspersed among irregular areas mapped with a woodland symbol, indicating riparian scrub or swamp, which is exclusively a freshwater (salt-intolerant) vegetation type. Short, irregular linear segments of riparian scrub are represented directly behind the west end of the beach, indicating proximity of freshwater conditions to the backbarrier wetland. The horizontal hatching symbol for marsh extends up to the beach and lagoon outlet. San Pedro Creek lagoon mapping conventions indicate that conventional symbol applied to coastal tidal marshes in San Francisco Bay

> was also applied to marshes surrounded by freshwater riparian or swamp vegetation that must have been free from saline tidal influence – i.e, freshwater or fresh-brackish marsh was included in areas represented by the horizontal hatching symbol applied to the San Francisco Peninsula map of 1869. The same horizontal hatching symbol was applied to the southeast corner of the Laguna Salada marsh (Figure).

Additional evidence supporting the interpretation of fresh-brackish marsh gradients at the landward edge of Laguna Salada in the 1869 U.S. Coast Survey map is provided by reference conditions at the heads of modern reference lagoons of the Central Coast from the Golden Gate to north of Monterey Bay. Even where freshwater discharges to lagoons have been altered in the past, there is still a prevalence of salinity gradients with fresh-brackish bulrush and tule marsh at the heads (stream mouth/delta or groundwater seep locations) of most modern coastal lagoons. Representative examples include:

- Laguna Creek Lagoon (Figure A-16): the landward (upstream) ends of these lagoon is generally dominated by fresh-brackish marsh species dominants (bulrush, cattail, tule, spikerush) or riparian scrub, despite seasonal tidal flows at the lagoon mouth. This fresh-brackish landward wetland gradient is associated with red-legged frog habitats (WWR 2007). At Laguna Creek, formerly saline pickleweed marsh is being invaded by fresh-brackish cattail and tule marsh following cessation of crop agriculture in the lagoon floodplain that depended on draining the lagoon (WWR 2007).

- Pillar Point Harbor, San Mateo County (Figure A-17): even at this small beach-choked saline-brackish tidal lagoon with seasonal stream inflows, the landward edge of the brackish marsh grades to fresh-brackish and freshwater marsh maintained by subsurface flows and small stream discharges.

- Rodeo Lagoon, Marin County (Figure A-18): The historic delta of Rodeo Creek and the upper lagoon have been diked by a road that impounds and converts them to freshwater marsh and willow swamp, but the overwash-influenced lagoon below still develops fresh-brackish sedge, cattail, and bulrush vegetation at its truncated head (Striplen et al. 2004).

- The modern San Pedro Creek mouth lagoon in Pacifica (Figure A-19), freshwater to fresh-brackish marsh and pond habitats, extending seaward to the beach, have developed in the absence of a protective high dune, beach ridge, or seawall, despite winter overwash events during major storms. The perennial lagoon’s freshwater supply is recharged in summer by low streamflows that are partly impounded by the growth of the cobble and sand berm. Red-legged frogs and terrestrial garter snakes (subspecies similar to the San Francisco Garter Snake) have been confirmed present in and around the lagoon.

There are no modern examples of a seasonally tidal or predominantly nontidal coastal lagoon in this region that lacks a significant fresh-brackish landward wetland gradient. There are no modern or historical examples of nontidal or seasonally (wet season) coastal lagoons in the San Mateo-Santa Cruz region that are predominantly saline or hypersaline, outside of San Francisco Bay tidal marshes.

A

B

Figure A-16. Laguna Creek Lagoon, Santa Cruz County. A. Succession from salt marsh to fresh-brackish marsh following cessation of former drainage for farming in the lagoon floodplain, 2007. Cattail (*Typha latifolia*) and California tule (*Schoenoplectus californicus*) invade pickleweed marsh that was formerly saline due to reduction in freshwater flooding associated with past agricultural drainage. B. Formerly saline pickleweed marsh (foreground) invaded marginally and internally by cattail and tule, grading landward towards open fresh to brackish lagoon and fringing freshwater tule marsh at the landward edge. The lagoon pond at this time was occupied breeding habitat for the California red-legged frog. The lagoon wetland complex is non-tidal in summer, semi-tidal in winter.

A

B

Figure A-17 . Head of Pillar Point Harbor lagoon, San Mateo County, exhibiting salinity-correlated marsh vegetation gradient within a small, sheltered backbarrier lagoon with salt-brackish marsh, pools and flats (pickleweed, alkali-bulrush dominants. (A), bordered by dominant fresh-brackish tule and cattail marsh grading to freshwater marsh (B) at the landward end of the gradient, fed by groundwater seepage and a small seasonal stream. April 2007.

Figure A-18 . Head of Rodeo Lagoon, Marin County, a predominantly non-tidal brackish lagoon grading to fresh-brackish marsh at its landward end, despite partial isolation from its freshwater stream delta. The head of the modern lagoon is here dominated by threesquare bulrush, cattail, spikerush, with slough sedge, typical of fresh-brackish coastal marsh; the adjacent vegetated shallows are dominated by submerged sago pondweed. This marsh is cut off from the freshwater former head of Rodeo Lagoon and the delta of Rodeo Creek, which now form a freshwater marsh above (left of) the road and culvert shown. The seaward end of the lagoon supports more brackish-saline weltands dominated by alkali-bulrush, saltgrass, salt rush, pickleweed, jaumea, and threesquare bulrush, with wigeongrass replacing sago pondweed as the dominant submerged aquatic vegetation.

Figure A-19. Modern San Pedro Creek mouth lagoon, Pedro Point, Pacifica in 2008-2009, showing freshwater marsh established directly behind the low barrier beach (A) with an open stream outlet subject to infrequent winter overwash (B). Fresh-brackish and freshwater marsh regenerate annually at the seaward edge of the marsh, and perennial freshwater marsh (bulrush, tule, cattail dominants) is maintained in the low-flow summer season by partial impoundment of the mouth by a low cobble and sand beach berm. The lagoon was excavated as part of the San Pedro Creek flood control and stream restoration project, completed before 2004. California red-legged frog adults and adult terrestrial garter snakes (subspecies similar to the rare San Francisco garter snake) have been confirmed present in the lagoon and its immediate vicinity.

Pre-U.S. historical period (European explorer, Mission, Mexican land grant eras)

The scope of this preliminary historical ecology investigation does not include site-specific analysis of historical geographic descriptions by early explorers of the San Francisco Peninsula, and subsequent settlers of the Spanish mission and Mexican land grant eras. One early explorer account of discovery of a freshwater lagoon in San Francisco (Archibald Menzies' journal, November 1792) is cited here, however, because it provided relevant descriptions of contrasting freshwater and saline to brackish backbarrier lagoons of the northern San Francisco peninsula (Golden Gate and adjacent San Francisco Bay):

> [San Francisco 15th Novr 1792] I met no fresh water stream in all my walk, what they filld our Casks with was from a standing Pond in a Marsh behind the Beach & which provd very good & wholesome.
>
> [San Francisco] In the morning of the 17th…we found a low track of marshy Land along shore, with some Salt Water Lagoons that were supplied by the overflowing of high Tides & oozing through the Sandy Beach: On these we saw abundance of Ducks & wild Geese. The watering party who/landed before us could meet with no fresh water stream, they were therefore obliged to dig a Well in the Marsh to fill their Casks from, but the Water thus procurd was afterwards found to be a little brackish, which might indeed be expected from the nature of the Soil which was loose & sandy & the little distance it was from the sea on the one side & salt water ponds on the other.

The freshwater "pond in a marsh behind the beach" was likely within the Golden Gate next to Fort Point, corresponding with the location of a cuspate barrier lagoon shown in later U.S. Coast Survey maps of the 1850s (Figure B-20) and a freshwater spring/seep in the cliffs that exists today.

The significance of Menzies' discerning observations of "fresh…good & wholesome", "a little brackish" and "salt" water observations associated with beach and lagoon waters sources in San Francisco is that not all lagoons were either saline or tidal during the early Mission era, and that nontidal freshwater "standing pond" lagoons and "salt water lagoons" with only high tide overtopping were readily observable coastal features.

Menzies' interest in lagoon hydrology and water quality was apparently motivated by searches for shore-accessible potable water to supply his ship. He presented explicit contrasting descriptions of lagoons formed behind sandy barrier beaches in San Francisco, identifying a nontidal freshwater marsh-fringed lagoon, and a "salt" (saline or brackish) water lagoon with seepage and spring tide overtopping connections to the bay:

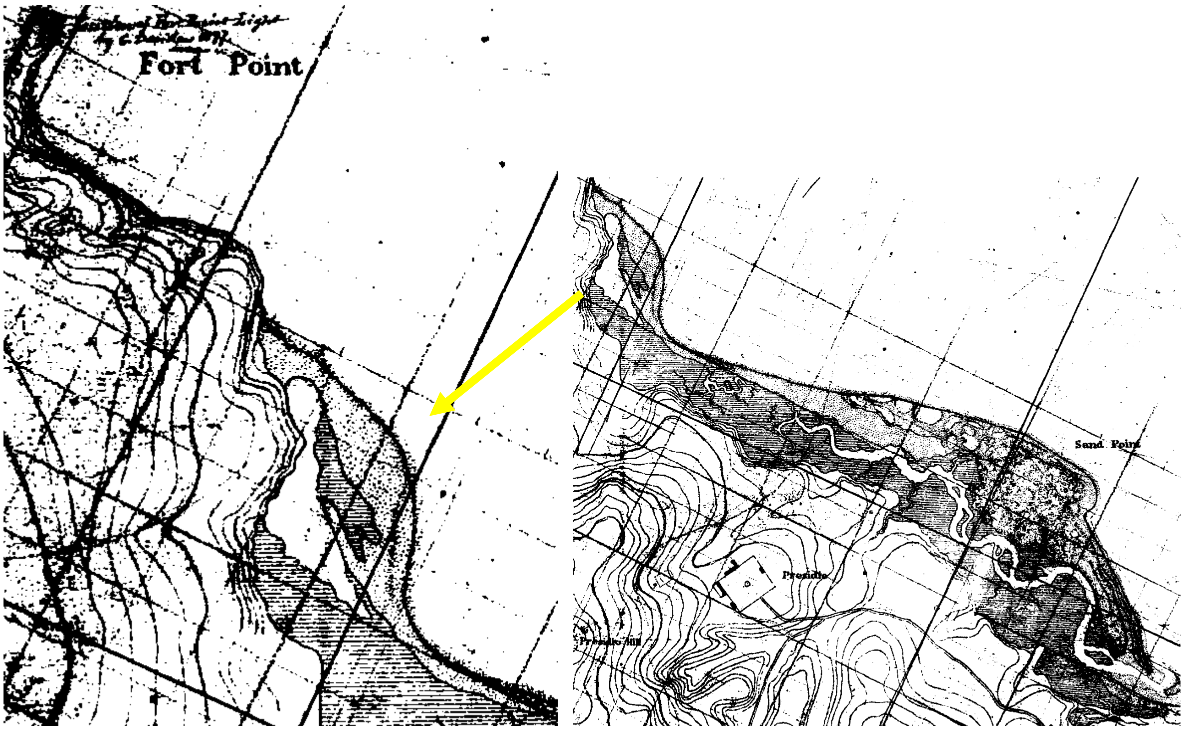


Figure A-20. Fort Point lagoon (nontidal) and adjacent Sand Point/Presidio Marsh tidal lagoon, San Francisco, within the Golden Gate shoreline, represented in U.S. Coast Survey map T-314, 1851. The Fort Point lagoon was located near the position of modern seasonal freshwater springs and seeps in cliffs. These historical lagoons correspond with Menzies' 1792 descriptions of freshwater and saline/brackish lagoons in San Francisco.

No new research in historic geographic descriptive accounts of the San Mateo Coast from the early U.S., Mexican land grant, or Spanish Mission period was conducted for this report. Diseños (Mexican land grant sketches) in general provide some of the earliest detailed maps of some aquatic habitat features in parts of California (often including wetlands and streams; Stein *et al.* 2010). A recent historical ecology investigation of Rodeo Lagoon, Marin County, however, found that the diseño covering its watershed omitted any reference to the lagoon, and revealed little detail about the watersheds associated with Rodeo Lagoon (despite recording Big Lagoon of Redwood Creek, a major freshwater stream with salmon runs), suggesting Rodeo Lagoon's perceived minor importance as a resource at the time of colonization (Striplen *et al*. 2004). Rodeo Lagoon's watershed of 2837 acres is significantly larger than that of Laguna Salada/Sanchez Creek (844 acres). It is uncertain, therefore, whether Mexican land grant historical data would reveal ecologically significant geographical descriptions of Laguna Salada. Additional research beyond the scope of this feasibility report would be required to provide comprehensive historical land use analysis of the Mexican land grant period.

Paleoecological and paleoclimate data from the estuarine wetlands of the San Francisco Bay estuary region indicate that modern (late Holocene) coastal wetlands were associated with slowing sea level rise rates that approached modern sea level in the last 3000-4000 years, and were associated with highly variable climate conditions including extreme droughts and wet periods lasting decades to many centuries (Malamud-Roam and Ingram 2004). The prolonged drought periods, including the periods 1600-1300, 1000-800, and 300-200 years before present, were associated with relatively high salinity conditions in the estuary, including upstream reaches that are brackish to fresh-brackish wetlands today. Prolonged wet periods associated with higher freshwater inflows to coastal wetlands, including the period before 2000, 1300-1200, and ca. 200 years before present, were associated with relatively low salinity in many tidally influenced marshes (Malamud-Roam and Ingram 2004). The 19th century and preceding six centuries were relatively wet and corresponded with low salinity tidally influenced wetlands in the northern San Francisco Bay estuary (Byrne et al. 2001). Comparable wet climate influences at Laguna Salada in the late Holocene (early historical period and Middle to Late archaeological periods) would likely have amplified the freshwater discharges within fresh-brackish gradients of stream deltas or groundwater seeps associated with coastal lagoons.

Conclusions

The summarized chronology of Laguna Salada historical ecology evidence and interpretation is shown in Table B-3. Botanical records and photographic documentation of Laguna Salada vegetation and landforms from the early 20th century indicate that the wetlands of the lagoon supported extensive marsh typical of fresh-brackish wetlands prior to the early Sharp Park Golf era. Despite evidence of artificial breaching when Laguna Salada valley flats were farmed, there are no associated records of salt marsh plants or visible signs of salt marsh dominance in the marsh, and there is strong photographic evidence of tall emergent grass-like marsh vegetation with structure like bulrush or cattail. This evidence is consistent with the hypothesis of relatively little change in fresh-brackish salinity range of wetland types between the agricultural and golf periods of 20th century Laguna Salada.

Typical dominant salt marsh species like pickleweed and saltgrass were not recorded at Laguna Salada in the decades prior to golf conversion. The “saline lagoon” hypothesis – the literal interpretation of Laguna Salada’s place-name as a salt pond rather than a seasonally brackish waterbody, is inconsistent with strong floristic (botanical) and photographic evidence. Accordingly, the hypothesis that Laguna Salada was converted from a saline lagoon and marsh system to a predominantly freshwater-influenced wetland by golf development is not supported by historical ecological evidence. The null hypothesis that Laguna Salada supported a fresh-brackish flora and marsh vegetation before and after it was converted from farming to golf is consistent with available historical evidence (not rejected). Evidence of artificial breaching of the lagoon to improve agricultural drainage, however, suggests that agriculture management of the lagoon may have reduced freshwater influence during the growing season and increased growing-season brackish salinity, compared with pre-agricultural conditions. The dynamic fresh-brackish salinity gradient hypothesis is more consistent with the widest range of evidence about Laguna Salada’s condition before Sharp Park was constructed.

We conclude that the antecedent condition of Laguna Salada wetlands in the early 20th century during agricultural land uses of the Laguna Salada valley was most likely a dynamic, seasonally variable wetland gradient between fresh-brackish to brackish marsh, lagoon flats, and open water, with a prevalence of emergent fresh-brackish marsh dominated by bulrush and cattail species. The same wetland vegetation types and marsh species indicated for historical Laguna Salada prior to golf conversion are associated today with coastal lagoon reference sites in the Central Coast region that support red-legged frog habitats, at least at the landward end of the fresh-brackish wetland gradient.

The detailed 1869 U.S. Coast Survey map of the San Francisco Peninsula shows that Laguna Salada was one of very few, widely distributed pond and lagoon habitats along what is now the Pacifica coast: Skyline sag ponds, Laguna Salada, and San Pedro Creek mouth. Laguna Salada was relatively isolated from potential neighboring core freshwater pond habitats and populations sources of California red-legged frogs and San Francisco Garter Snakes in the late 19^{th} century and later. If Laguna Salada did not support antecedent native populations of these species, joint or sequential long-distance colonization by both species (frog/prey first) would be necessary to explain their mid-20^{th} century joint occurrence during the early Sharp Park golf era. The large-scale 19^{th} century distribution of potential core pond habitats of CRLF on the southwestern San Francisco Peninsula, combined with evidence consistent with fresh-brackish marsh at Laguna Salada, suggests that red-legged frogs and garter snakes were pre-existing natural populations at Laguna Salada, rather than the result of s joint colonization events during the 20^{th} century due to long-distance dispersal.

The 1869 U.S. Coast Survey of the San Francisco Peninsula represents Laguna Salada enclosed by Salada Beach, with no open tidal inlet or traces of one. It also shows a wide marsh aligned with a discontinuous creek in the valley above. The marsh is dissected with three channels perpendicular to the marsh/lagoon shoreline, and is fronted by an elongate shore-parallel marsh islet – features consistent with a relict delta and distributary channel system. The marsh type symbol is the same convention used to map coastal marsh at San Pedro Creek mouth embedded within floodplain freshwater woodland, and also identical with the symbol used for Rodeo Lagoon delta marsh at the mouth of Rodeo Creek. The same symbol is more widely used in context of sinuous, dendritic tidal creeks to represent tidal salt marsh in San Francisco Bay. The interpretation of the marsh symbol at mid-19^{th} century Laguna Salada is uncertain, but most consistent with a gradient between seaward brackish and landward fresh-brackish marsh. This interpretation is well-supported by modern reference coastal lagoons in the region.

Table A-3. Synthesis of historic photographic and herbarium data: chronology of Laguna Salada ecology, geomorphology hydrology. Chronology covers historic period, documentary data sources; no paleoecological data specific to this site are currently available.

Date, period	Data sources	Beach and dune	Barrier outlet/drainage	Lagoon & marsh	Lagoon floodplain
1869 pre-cropland (ranching)	USCS topography originally 1850-57, revised 1867 (inland)	Continuous washover; no dune topography shown	Closed; no narrow channel; wide beach across neck of relict outlet at Mori Pt; no tidal inlet or flood tidal delta morphology	No backbarrier fringe marsh shown; broad marsh with 3 shore-normal channels and marsh islet at SE lagoon. USCS coastal marsh symbol (hatching) matches symbol at San Pedro Creek lagoon	Not represented; not tule marsh. Likely cattle- grazed lowland grassland, sedge-rush meadow, riparian scrub
1892 likely cropland	USGS topography	open sand, sparse vegetation; no Monterey cypress or beachgrass	Closed; linear narrow channel, elongate J-shape, extends from SE end of lagoon to beach; location of 1960s outlet channel and 1930s wide breach	no marsh symbol in USGS 1892 map of Laguna Salada; possible fill or conversion to agriculture	road extends E-W west of coast road
1900s row crops	Historical photos, herbarium record	Low hummock foredunes, native vegetation, active sand accretion, at N end; sparsely vegetated washover on barrier beach, no significant dune topography. No European beachgrass or cypress	Closed; Artificial channel cut into barrier, wood weir/retention structure at NW end of lagoon for managed breach. Artificial breaching, lagoon drainage for agriculture in floodplain.	Extensive open water lagoon with fringing marsh. Narrow discontinuous and patchy emergent marsh including threesquare bulrush at lagoon backbarrier shore & partially submerged flats of S and E shore.	Artichoke fields occupy ditched, drained floodplain adjacent to lagoon.
1920s row crops	Historic photos, herbarium label data	Barrier beach stabilized with Monterey cypress grove on landward side of barrier behind double line of sand fence & foredune ridgeplanted with European beachgrass foredune. Native foredune and stable backdune plants present.	Closed; likely breach location at south end at Mori bluff (vegetation gap, beach flat). Managed breaching for necessary for draining artichoke fields during spring.	Extensive open water and flats. Cattail, bulrush marsh fringing shore; discontinous in fluctuating emergent lagoon flats. Submerged wigeongrass present in lagoon No salt marsh species records.	Artichoke fields occupy ditched, drained floodplain adjacent to lagoon.
1930s Farm-golf transition	Historic photos, herbarium label data	Barrier beach stabilized with continuous 2-row sand fence, outer European beachgrass, inner Monterey cypress grove. Wind-shadow sand deposition behind fences. No overwash.	Closed. No breach evident; wooden rectangular structure on beach at S end with electric powerline indicates pump drainage.	Fresh-brackish cattail, bulrush marsh widespread in S lagoon flats and shores. submerged sago pondweed present with cattail marsh; No salt marsh species records.	Artichoke fields occupy drained floodplain; filling, conversion to golf begins. Salada & Brighton Beach become “Sharp Park”
1940s Early golf	Historic photo, herbarium	Barrier beach retains remnants of beachgrass foredunes and Monterey cypress groves, but washover gaps in vegetation occur at N and S end.	Closed. unvegetated or sparsely vegetated gap at Mori Pt (pump location or washover pass? Both?).	Fresh-brackish marsh assemblage (cattail, bulrush with tule), comprehensive herbarium collection 1949; No salt marsh species records. CRLF, SFGS confirmed present	Golf links cover floodplain and N backbarrier flats.
1980s-2010 Golf era	Historic photo, site-specific studies (literature cited)	Levee constructed on foredune, crest 3-8 ft above beach, 1980s. Monterey cypress dieback; iceplant prevalent	Closed. 1982-3 El Niño overwash fans & throats evident. Pump drainage sets stable low (+7- +8 NGVD) maximum water level.	Fresh-brackish marsh assemblage (tule-cattail-bulrush) prevalent, saltgrass-pickleweed local at W lagoon. No submerged aquatic vegetation. CRLF, SFGS confirmed present	Golf links cover floodplain and N backbarrier flats.

A-2 CONCEPTUAL MODEL OF CENTRAL CALIFORNIA COAST LAGOONS

A-2.1 California Central Coast lagoon systems

The Laguna Salada wetland complex is one variation within a spectrum of coastal lagoons in the northern California Central Coast region with similar fish, wildlife, vegetation, and physical processes. Lagoon wetlands form on the landward side of barrier beaches that enclose and shelter them from Pacific Ocean swell. Lagoon wetland physical dynamics and ecology are distinct from inland ponds, even though inland ponds and coastal lagoons support overlapping species. The spectrum of backbarrier lagoon types in the Central Coast region ranges from **tidal lagoons** (also known regionally as **"esteros")** to **seasonal tidal lagoons,** to **nontidal lagoons.** Tidal lagoons are systems with persistent and relatively stable tidal inlet channels that exchange mostly saline ocean water through an open inlet. Examples include Bolinas Lagoon, Drakes/Limantour Estero, and Bodega Harbor (Table A-4). **Seasonal tidal lagoons** are systems with seasonally or intermittently open inlet connections to estuaries, stream or river mouth channels, and floodplain wetlands. Seasonal tidal lagoons are usually closed in the summer and fall seasons due to high beach berms and low river discharge, and open to variable tidal flows in the late fall to spring due to high runoff. Examples include Salmon Creek, Redwood Creek (Muir Beach), and Laguna Creek (Table A-4). **Nontidal lagoons** are back-barrier lagoons with intermittent and ephemeral outlet channels following episodic storm events that increase lagoon water levels by wave overwash and rainfall runoff. Examples include Abbott's Lagoon and Rodeo Lagoon in Marin County. Laguna Salada is among the few historic nontidal lagoons in this region, and has few analogous counterparts.

Lagoons are water bodies entrapped behind coastal barriers with surface or subsurface connections to the sea. Lagoons form where coastal depressions or embayments are separated from the adjacent sea by a **barrier beach**. There are multiple types of lagoons, ranging from **marine embayments** (sounds), **estuaries** (with significant freshwater inputs), **partly closed lagoons,** and **closed (seepage) lagoons**, including near-freshwater, brackish, and hypersaline lagoons or salt ponds (salinas, sabkhas).
Sources: Carter 1988 & Cooper 2004

Existing nontidal lagoons in the Central Coast include Abbott's Lagoon and Rodeo Lagoon (Marin County) and Laguna Salada (Table A-4). Of these, only Abbott's Lagoon is relatively unaltered within the lagoon basin, but its barrier beach has been converted from low foredunes to a continuous high foredune ridge dominated by invasive European beachgrass that alters its breach and washover dynamics. Rodeo Lagoon has retained its natural low native foredune vegetation, washover terrace, and breach dynamics. At its end, a road and culvert separates its upstream freshwater gradient from the main fresh-brackish lagoon, and has endured relatively little artificial filling in its floodplain. The outlet of Rodeo Lagoon is unaltered, and closely resembles its condition represented in U.S. Coast Survey maps of the 1850s (Striplen et al. 2004). Laguna Salada, in contrast, is one of the most highly altered of the region's major nontidal lagoons (Appendix A-1, above).

A-2.2 Regional reference ecosystems for empirical conceptual models

Ecological restoration and management of coastal wetlands requires basic understanding the dominant natural processes, variability, and dynamics of unimpaired ecosystems over long periods of time to provide scientifically sound guidance. To provide a sound basis for ecological restoration and management of Laguna Salada, a valid, empirical conceptual model of this type of coastal lagoon system is needed that is calibrated for regional variability and coastal environmental settings. Building a reliable applied conceptual model of specific coastal lagoon types requires integration of multiple assessment approaches (WWR et al. 2008, 2009) including:

a) examination of data or investigations from a regionally representative variable suite of analogous reference ecosystems, or partial, approximate ecological equivalents of the target ecosystem;
b) understanding of long-term ecosystem variability (boundary conditions, rates and patterns of change) through paleoecological or historic ecology investigations, or both;
c) critical review of the relevant scientific literature on physical, biological, and ecological aspects of the target ecosystem and its underlying physical structures and processes; and
d) critical review of restoration and management plans or monitoring reports from analogous lagoon ecosystems.

The PWA team has carefully reviewed the regional applied environmental scientific literature on coastal lagoons, applied its collective professional experience with regional coastal lagoons, and assembled the best available historic data about Laguna Salada (providing additional data and analysis that deepens understanding of its historic development). These are synthesized as a general conceptual model of regional nontidal coastal lagoons (summarized below), and adapted to site-specific data on Laguna Salada and its environmental setting. The scientific literature basis for this conceptual model is shown in Table A-5.

Our working assumption about the use of local, regional, historic, or modern ecological data is that no single reference system state or historic static "snapshot" of a coastal wetland can provide adequate understanding of the underlying mechanisms that maintain it and modify it, particularly complex artificial modifications or impairments occur in its history. We do not develop ecological restoration models or objectives based on specific, arbitrary historic set-points of presumed "equilibrium" or "natural" states, particularly in view of changing baseline conditions, such as sea level rise acceleration, and wave climate change. For this reason, we have assembled an empirically-based conceptual model of nontidal barrier beach lagoon ecosystems of the Central Coast region, and a site-specific reconstruction of natural Laguna Salada conceptual model that integrates its physical and ecological dynamics. These integrated, dynamic physical-ecological conceptual models are used to guide the assessment of existing conditions, future trends, and restoration design options for a sustainable, resilient, diverse rehabilitated Laguna Salada wetland ecosystem supporting special- status fish and wildlife species and naturally high native species diversity.

A-2.3 Dynamics, structure, and composition of seasonally tidal to non-tidal backbarrier lagoons of the Central California Coast north of Monterey Bay

The dynamics of Central California coastal lagoons result from the interaction of coastal processes (wave and wave-induced current transport of sand), watershed hydrology (stream discharge, surface runoff, and groundwater hydrology, including valley, hillslope groundwater), barrier beach seepage outflow, lagoon breaching, and storm overwash. The general conceptual model outlined below is based on a synthesis of background information on coastal processes developed from the scientific literature, reference seasonal estuary/lagoons in their nontidal (low streamflow, dry season) phases, and our knowledge of reference nontidal lagoons – in particular, local investigations of the Rodeo Lagoon (the most similar reference nontidal lagoon) and seasonal backbarrier lagoons in the San Mateo-Santa Cruz coastal region. These sources of the conceptual model, including regional and general studies, are summarized in Table A-5. This conceptual model is integrated with key vegetation and wildlife habitat components of primary biological conservation interest at Laguna Salada.

Central coast lagoons generally include the following highly dynamic geomorphic, vegetation, and wildlife habitat features:

- **Barrier beach with seasonal or intermittent outlet channel or tidal inlet**. The primary hydrologic control of lagoon hydrology is the semi-permeable sand barrier beach that impounds freshwater discharges from the watershed (streamflow, runoff, groundwater discharge) and either chokes or prevents tidal flows into the backbarrier wetland complex. The barrier beach supports its own internal groundwater that mediates subsurface seepage flows between the lagoon and beach face, typically net seaward seepage of impounded freshwater. The barrier beach (including summer and winter berms, washover fans, and dune fields) is the primary structure that dissipates wave energy and creates a sheltered, low wave energy backbarrier environment in which wetlands establish. Barrier beaches adjust to sea level rise dynamically by landward migration, or "rollover", primarily through overwash and low dune deposition. Barrier crest elevations control the upper limit of lagoon impoundment and are approximately controlled by the 1-yr wave runup height (Table A-6). Berm crest elevations of medium-coarse sand beaches of the Central Coast commonly range between +12 to +20 ft NAVD (Table A-6). Shoreline orientation and offshore topography control wave energy gradients alongshore. Wave runup transports sediment onshore and builds a natural berm that dams small, unstable tidal inlets or lagoon and stream outlets with low-energy dry-season outflows. This encloses the backbarrier lagoon and establishes the hydrology of its nontidal phase.

- **Submerged basins or floodplain marshes**. Barrier-impounded streamflow, runoff, and groundwater inundate lowlands landward of the barrier beach. Backbarrier floodplains may lie mostly within still-water tide elevation range or above tidal range. Lagoon levels in non-drought conditions are typically impounded above high tide elevations, causing inundation of floodplain marshes or increased open-water (or submerged aquatic vegetation bed) depths. "Perched" lagoons (drowned stream valley floodplains or basins; water surface elevations above tide, extensive marshes at or above high tide) are typical in the region, and contrast with tidal lagoons with predominantly intertidal substrates. Often the stream or outlet channel itself is the main intertidal habitat estuary within the backbarrier wetland of seasonal estuaries.

- **Salinity gradients between brackish and freshwater wetland habitats**. Even seasonal estuaries with open tidal inlets during winter months of high fluvial outflows support gradients between fluctuating brackish to freshwater salinity ranges near the tidal salinity source (breach; tidal inlet or ephemeral outlet channel, overwash pass) and landward freshwaters discharges (stream channels, seeps, swales). Salinity gradients in nontidal lagoons fluctuate among rainfall years. Relatively stable freshwater wetland habitats generally occur along the landward end of the lagoon gradient, often indicated by local dominance of mature woody riparian or obligate freshwater (salt-sensitive) wetland vegetation.

- **Seasonal salinity inversion relative to permanent estuarine lagoons**. Estuarine salinity in Mediterranean climates fluctuates seasonally, with more dilute brackish salinity ranges in winter rainfall seasons, and more concentrated polyhaline or euhaline to hyperhaline salinity range in the arid, warm summer. In seasonal estuaries with lagoon closure and perennial freshwater streamflow in summer (or nontidal lagoons), however, backbarrier wetlands that impound freshwater may become stratified and less saline in the upper water column and marsh elevation range than in winter when tidal mixing occurs daily. Oligohaline or freshwater conditions may prevail in seasonal estuaries during their summer non-tidal phases during non-drought conditions. Riparian woodland (willow scrub) and oligohaline to freshwater marsh habitats (cattail, tule, bulrush, spikerush, rush) may occupy summer lagoons even near the backbarrier shoreline.

- **Marsh, wet meadow, submerged aquatic vegetation, and riparian scrub vegetation**. Lagoon wetland complexes in the Central Coast support a recurring set of plant species assemblages and vegetation structures that are distributed in relation to fluctuating salinity gradients, topographic gradients and drainage patterns, and sediment/soil properties. They include the following widespread assemblages, each of which may intergrade with adjacent ones:

    - **Wigeongrass submerged aquatic vegetation (SAV) bed** (*Ruppia maritima*, incl. *R. cirrhosa*): seaward brackish to intermittently saline lagoon bed, permanently submersed or late-summer emergent.
    - **Sago pondweed submerged aquatic vegetation (SAV) bed** (*Stuckenia pectinata*, syn. *Potamogeton pectinatus*): interior or landward oligohaline to intermittently brackish lagoon bed, permanently submersed or late-summer emergent. Occasionally with *P. pusillus, P. nodusus* (freshwater-oligohaline), *Zannichellia palustris* (oligohaline).
    - **Saltgrass-pickleweed-Jaumea salt/brackish marsh** (*Distichlis spicata, Sarcocornia pacifica, Jaumea carnosa*): seaward brackish (mesohaline) to euhaline seasonal marsh, sandy or peaty mud substrates. Infrequent *Polypogon monspeliensis, Cotula coronopifolia* (non-native) in disturbed brackish marsh.
    - **Saltgrass-threesquare bulrush marsh** (*Distichlis spicata, Schoenoplectus pungens* dominant; associated species include alkali bulrush, *Bolboschoenus maritimus*, salt rush, *Juncus lescurii*): seaward brackish sandy backbarrier shorelines, relict washover fan

gradient mesic seasonally emergent below OHWL; saltgrass grading into terrestrial washover fan

- **Threesquare bulrush-alkali bulrush marsh**: seaward brackish marsh, saturated or flooded; mixed or single-species clonal stands; *B. maritimus* more frequent in organic or more saline soils with higher seasonal fluctuation in lagoon level or salinity; S. pungens more frequent in sandy substrates.
- **Cattail-tule marsh** (*Typha latifolia* (native), *T. angustifolia* (non-native), *Schoenoplectus acutus, S. californicus*: landward oligohaline to freshwater emergent marsh, natural tall monospecific or mixed clonal stands with high shoot density; semi-open stands only in early stages of colonization or recovery; perennial saturation or submergence up to ca. 1 m depth during summer. Ground layer of creeping bentgrass, *Agrostis stolonifera* (nonnative), silverweed (*Argentina egedii*) or club rush, *Isolepis cernua* (native) in seasonal wetland edges.
- **Salt rush-silverweed meadow** (*Juncus lescurii-Argentina egedii* (syn. *Potentilla anserina* ssp. *pacifica*): landward or seaward oligohaline or brackish seasonally drained marsh plains. Occasional western dock (*Rumex occidentalis*), field sedge (*Carex praegracilis*), threesquare bulrush; Common spikerush (*Eleocharis macrostachya*) Baltic rush (*J. arcticus* ssp. *balticus*) occasionally landward, freshwater-oligohaline.
- **Saltgrass-creeping wildrye-salt rush meadow** (*Distichlis spicata-Leymus triticoides (*and/or *L.* x *vancouveriensis)-J. lescurii*): landward or seaward Oligohaline seasonal wetland (summer mesic to dry) of floodplain/splay or washover.
- **Marsh baccharis-western goldenrod** (*Baccharis douglasii-Euthamia occidentalis*): landward oligohaline to brackish seasonal wetland, terrestrial ecotone.
- **Slough sedge-small-fruited sedge marsh** (*Carex obnupta, Scirpus microcarpus*): landward obligate freshwater-oligohaline assemblage, perennial saturation or shallow flooding.
- **Willow-blackberry riparian scrub** (*Salix laevigata, S. sitchensis, Rubus ursinus*): landward freshwater-oligohaline banks on terrestrial soil or heterogeneous coarse alluvium and silt.

- **Debris deposits.** Major fluvial flood events transport coarse and fine woody debris and floodplain marsh leaf litter into lagoons, where they deposit as wracks, usually along extreme high water lines. Ocean transport of macroalgae and driftwood (sometimes from long-distance sourcs) also introduce abundant organic debris to lagoons after storm events. Litter mats and coarse woody debris can dominate segments of lagoon shorelines, where they provide important habitat structure (cover, unvegetated surfaces, moisture refuges, perches, thermal refuges and basking sites, etc.). Urbanized or agricultural watersheds, culverts, bridges, levees, and seawalls may screen out or eliminate important debris sources, leaving lagoons starved of debris inputs.

- **Backwater sloughs and ponds**. Relict cut-off channel segments and undrained depressions isolated from sediment sources or organic accretion leave shallow open water features in marsh floodplains, either withn the summer lagoon (submerged during high lagoon stands), or in portions of the floodplain that lie outside the main lagoon. These isolated sloughs and ponds may become important local habitats (refuges from fish predators, high velocity turbulent flows, salinity or sediment pulses, etc.)

- **Terrestrial ecotones and marginal landforms**. Central Coastal lagoons have variable terrestrial margins, ranging from gentle lowland gradients supporting ecotones (gradual ecological transition zones) to abrupt discontinuous edges, depending on slope, depositional and erosional processes, and antecedent geology. One ubiquitous terrestrial edge landform of lagoons is the *backbarrier shoreline*, consisting of active or *relict washover fans* (mesic upland-wetland ecotones subject to episodic overwash), or *dune slopes*. True *terrestrial uplands* (arid to mesic, well-drained, terrigenous soils) occur in some settings where lagoon valleys form steep erosional *scarps* in uplifted *marine terraces* or resistant *headlands*. Transitional uplands (ecotones) develop on toes of *alluvial fans* of hillslopes (widespread), talus slopes (rare), rock outcrops (rare), or gently *sloping marine terraces*. Transitional uplands form terrestrial ecotones at lagoon *floodplain edges* and within floodplains, where splay and overbank deposits or creekbank levees form. Native vegetation associated with these lagoon terrestrial edges ranges from *coastal bluff scrub, dune scrub, dune forb* and *grassland*, *lowland (alluvial valley and floodplain) grassland* and *sedge-rush meadows* (rhizomatous dominants), and *riparian scrub*. Coastal bunchgrass/forb vegetation may occur above the actual lagoon edge, not in the ecotone. The most frequent natural vegetation types bordering landward edges of lagoons are alluvial grassland/sedge-rush meadows, riparian scrub, and coastal bluff scrub.

- **Dominant discharge and extreme coastal storm event structures**. Lagoons and barriers are formed by processes with long and short return intervals, including very rare high-energy fluvial flood events and coastal storm (extreme high tides and waves) events occurring over decades. These inevitable extreme events often form essential and major structures of the barrier lagoon complex (washover fans, channels, splays, debris deposits, creekbank levees).

Multispecies dynamic wildlife habitat distribution in coastal lagoons. Smith (2007) concluded from several decades of wildlife investigations of Central Coast lagoons (primarily San Mateo County) that restoration and management efforts should recognize that lagoons provide a variety of habitats for multiple species of concern, and that all habitats do not have to work for all species at all times. He cautioned that focus on single-species hydrologic management may have unnecessary detrimental consequences wildlife communities that seasonally inhabit different sub-habitats within lagoon wetland complexes (Smith 2007). Smith emphasized the importance of isolated or semi-isolated backwater sloughs, ponds, deep scour pools, and channel-disconnected seasonal wetlands within lagoon wetland complexes; these provide breeding habitat for red-legged frog, over-wintering habitat for pond turtles, and rearing and flood and drought refuges for tidewater gobies. Expanded areas of backwater habitat may improve conditions for red-legged frog (Smith 2007). He cautioned that single-species. This perspective is consistent with multiple draft and final recovery plans for federally listed species and associated species of concern (USFWS 2002, USFWS 2005, USFWS 2010).

Wildlife habitat and species distributions within coastal lagoons correspond with vegetation composition, structure, salinity gradients, topography, and flooding/drainage patterns. Special-status species utilizing sub-habitats within Central coast lagoons include the following life-history, physiological, and habitat relationships that are basic to lagoon management or restoration.

- **Coast marsh milk-vetch** (*Astragalus pycnostachyus* ssp. *pycnostachyus*): tall perennial forb (Fabaceae) of oligohaline to brackish sandy high tide line vegetation assemblages (often with *Juncus lescurii*) and drift-lines, and terrestrial ecotones of backbarrier shorelines, scarps, creekbank levees and splays, adjacent mesic bluff scrub; San Mateo County and Marin County (disjuct Humboldt County – 1 population). CNPS List 1B; USFWS species of concern.

- **Tidewater goby** (*Eucyclogobius newberryi*) Contrary to its name, the tidewater goby is a short-lived small fish found primarily in shallow seasonal estuarine brackish lagoons and intermittent or nontidal brackish (mostly 12 ppt or less), discontinuously distributed along the California coast.. San Francisco Bay area (southern Sonoma to San Mateo Counties) supports a genetically distinctive series of isolated populations; Rodeo Lagoon is the nearest and largest population. The recovery plan for the species (USFWS 2005) identifies Laguna Salada as one of a few suitable unoccupied potential introduction sites in the San Mateo coast recovery subunit (p. B-7, C-11). Federally listed as endangered. An introduction of tidewater goby to Laguna Salada in existing or restored conditions is not currently proposed by USFWS. It could serve as an isolated redundant population for the nearest neighbor population in the San Mateo Unit at San Gregorio Creek (J. Smith, pers. comm. 2010).

- **California red-legged frog** (*Rana draytonii, syn. R. aurora draytonii).* The California red-legged frog is a pond frog widely distributed and locally abundant in fresh-brackish seasonal estuary lagoons and nontidal lagoons in Marin and San Mateo County, as well as inland freshwater ponds, perennial and seasonal marshes. Wetland habitats occupied by the California red-legged frog generally fluctuate in response to dynamic rainfall, flooding, and drought cycles and the species utilizes a complex mosaic of aquatic, riparian, and upland habitats; populations of this and other pond-breeding frogs are most likely to persist where multiple breeding areas are embedded within a matrix of habitats used for dispersal (USFWS 2002, Hamer and Mahoney 2010). Breeding adults are often associated with dense marsh and riparian vegetation (Hayes and Jennings 1988). Breeding in coastal lagoons occurs in fresh or oligohaline marsh pond edges and in sago pondweed (SAV canopies) within lagoons during winter and spring low salinity phases (salinity < 3-6 ppt for eggs, size-dependent for tadpoles, 5-6.5 ppt upper limit, conservatively estimated lower in some references; Smith 2007, J. Smith pers. comm.. 2010, USFWS 2002) often in the landward end of the salinity gradient within the lagoon wetland complex. Tadpoles develop in freshwater or oligohaline shallow aquatic habitats below a lethal salinity threshold of 7 ppt (USFWS 2002). Foraging by adults occurs in all portions of lagoon wetland complexes except mesohaline to polyhaline marsh (above adult tolerance limit of 9-10 ppt (J. Smith pers. comm. 2010, Smith 2007), usually seaward ends of lagoons). Nitrite, ammonium, and nitrates derived from fertilizer runoff or leachate (risks in coastal lagoons adjacent to either irrigated agricultural or turfgrass dependent on nitrogen fertilizer application) are highly toxic to red-legged frog and other frog species larvae, causing reduced activity, deformity, disorientation, and death (Marco and Quilchano 1999 Schuytema and Nebeker 1999, Nebeker and Schuytema 2000, USFWS 2002). Population size viability are apparently reduced by non-native bullfrogs (Lawler et al. 1999, USFWS 2002), which are usually excluded in coastal lagoons by annual brackish water periods that limit survivorship of salt-sensitive bullfrog tadpoles that require two years to metamorphose.

- **San Francisco Garter Snake** (*Thamnophis sirtalis tetrataenia*). Federally listed as endangered, this garter snake subspecies historically occurred primarily in aquatic habitats and adjacent uplands from Pacifica to Pescadero (Barry 1978, USFWS 1985, Jennings 2000). Its lagoon habitats includes the large seasonal estuary of Pescadero Lagoon (Jennings 2000, Reis 1987, Reis…, Smith 2008) Juveniles spend much of their time feeding in riparian zones, marshes, and aquatic habitats (Barry 1994). Subadults and adults may disperse into uplands during summer, feeding on amphibians in mammal burrows (Jennings 2000, Swaim 2008); the extent to which summer upland dispersal is driven by prey availability in perennial marsh habitat is not known. Raccoons, herons, egrets, hawks, bullfrogs are predators. Prey base in coastal lagoons is primarily wetland-dependent: Pacific treefrog, earthworms (prey base of juvenile snakes), California red-legged frogs (prey base of adult snakes), stickleback, toads. Juveniles refuse most non-amphibian food items. In contrast with coast garter snakes, adults rarely consume small mammals, but feed on amphibians in rodent burrows. Physiological salinity tolerance is unknown; salinity correlations with habitat are likely indirect, related to prey availability (amphibian salinity tolerance and abundance; Larsen 1994). Laguna Salada is identified as a priority for improved habitat management in the 1985 Recovery Plan (USFWS 1985).

- **Western pond turtle** (*Clemmys marmorata*). Western pond turtles are primarily aquatic inhabitants of ponds, marshes, rivers, streams, and Central California coastal lagoons. They inhabit both freshwater to brackish waters, and tolerate brief exposure to marine salinity (Stebbins 2003). Large populations occur in brackish estuarine sloughs and nontidal brackish ponds of Suisun Marsh. In lagoons, they forage in open water, SAV beds, sloughs, ponds, and channels. Pond turtles utilize basking sites provided in estuaries and lagoons by large woody debris, leaf litter mats, or cohesive mud or peaty sand banks. Nesting occurs in spring in well-drained unshaded uplands up to 400 m from riparian zones, but usually close to riparian zones where conditions are suitable; wet substrates are unsuitable for egg survival (Jennings 2000). Western pond turtles of flood-prone inland wetlands often overwinter in terrestrial habitats. Turtle nests are highly vulnerable to predation by raccoons with elevated exurban populations (Jennings 2000). Prey include aquatic insects, fish, amphibians and amphibian eggs, carrion, aquatic vegetation (Stebbins 2003). Western pond turtles are Federal and State species of concern, but have no special legal protective status. A population inhabits the Laguna Salada wetland complex, where it likely breeds.

- **Salt marsh common yellowthroat (***Geothlypis sinuata sinuata*). The “salt marsh” common yellowthroat, also known as the “San Francisco yellowthroat”, is a distinct subspecies of the common yellowthroat. It inhabits salt marshes only in winter, but breeds in fresh and brackish coastal wetlands, including cattail, tule and riparian scrub (Terrill 2000). Yellowthroats are primarily insectivorous, gleaning prey from the ground, leaf litter, and standing marsh or riparian vegetation. They frequently use edge habitats (ecotones) between wetland vegetation types. Breeding habitat was reported from Sharp Park (Foster 1977a, b).

A-2.4 Conceptual model of natural Laguna Salada dynamics, structure, and composition

The general Central Coast nontidal lagoon conceptual model is applied to the specific coastal setting of Laguna Salada to generate an approximate model of the reconstructed "natural" (pre-agricultural) morphodynamic conditions (changes in form and process in response to wave and streamflow and groundwater processes) distinctive to Laguna Salada. There are no paleoecological or stratigraphic data currently available for reconstructing the precontact Holocene development of Laguna Salada, but limited historical geographic data are available to calibrate the general regional lagoon model (A-2.3) to a specific case for Laguna Salada. This reconstruction is intended as a model for long-term physical development of the ecosystem that control species-specific habitat structure, dynamics, and trends. The general model adaptations are based on (a) multiple years of field observations at Laguna Salada, and multiple reconnaissance visits in 2009-2010; (b) direct field observation of seasonal variability of Central Coast reference lagoons by the project team members for more than two decades; (c) site-specific studies of regional reference systems (Shaw 1997, Striplen et al. 2004, Smith 2008, WWR et al. 2008); and local historic ecology data (Section 3.3).

- **LS Barrier beach topography, permeability, and elevation gradient**. The barrier beach is a relatively coarse-grained, permeable barrier exposed to high incident wave energy of Pacific swell, resulting in a high beach crest above tidal range; beach crest elevations correspond with alongshore gradients in wave height, with relatively lower wave height adjacent to headland sheltering (wave refraction from SW and WSW) of Mori Point. The small backbarrier lowland basin is formed by the southward-dipping marine terrace that dips below sea level at Laguna Salada (Cooper 1967, Sloan 2006) and relict alluvial deposits from Sanchez Creek. Medium-fine sand sources (wind-mobile sand fraction) occur to the north of the beach (paleodune and bluff erosion; currently armored); coarser sand sources (wind-immobile fractions) occur at the Mori Point headland. Dune topographic development on the barrier is limited by grain size distribution; low hummock dunes formed by native vegetation (like Rodeo Lagoon) lie at or below the beach crest determined by wave runup. The coarse-grained barrier is highly permeable to groundwater exchange between ocean, beach, and the lagoon, according to local and fluctuating groundwater gradients.

- **LS Barrier beach seepage lagoon and marsh formation.** Laguna Salada is formed by impoundment (damming) of Sanchez Creek outflows and valley groundwater discharge by Salada/Sharp Park Beach (barrier beach). The lagoon wetland complex includes the alluvial floodplain of Sanchez Creek inundated during high lagoon stands Lagoon basin fills with freshwater discharge, raising water surface elevations and hydraulic head above high tide elevations of the adjacent ocean beach. The lagoon discharges by groundwater seepage through the coarse-grained, permeable barrier beach when the outlet is closed, the normal condition of the lagoon except during periods of winter storm rainfall and stream discharge. Nontidal lagoon water surface elevations and fringing nontidal marshes are naturally “perched” above high tide (cf. Rodeo Lagoon, Laguna Creek Lagoon in nontidal phase; Shaw 1995, WWR et al. 2008), except during extreme droughts. The hydraulic head of high freshwater lagoon stands induces seepage outflow (beach groundwater) discharge through the coarse-grained beach.

The fringing lagoon emergent marsh (cattail, tule, bulrush marsh) develop in the fluctuating submergence zone between ordinary high water and low water elevations, all of which are above the still-water tidal elevation range of the adjacent ocean beach. The lagoon bed (submerged aquatic vegetation substrate) occurs at elevations corresponding to tidal range on the adjacent beach. Lagoon valley (landward) floodplain freshwater wetlands (seasonal wetlands inundated by extreme high lagoon stands (freshwater impoundment) below the breach outlet elevation threshold) and depressional floodplain freshwater ponds, sloughs, and marshes stand at elevations above the tidal frame and beyond ordinary overwash surge limits.

- **LS lagoon level equilibration with beach seepage outflow; net freshwater seepage outflow**. Equilibration between total net freshwater stream and groundwater discharge into the lagoon, and lagoon seepage rates through the barrier, maintain lagoon water surface elevations below the critical spill elevation (lagoon overtopping threshold) of the beach. Hydraulic head of impounded freshwater during high lagoon stands (significantly above MHHW) generally causes net seaward seepage outflow of freshwater, inhibiting saltwater intrusion. In natural non-drought conditions, the lagoon water surface elevation is raised above still-water tide elevation range, and often above elevation of wave runup (swash).

- **LS lagoon spatial salinity gradients and temporal variability.** Lagoon salinity in nontidal (non-breach) seepage conditions varies vertically (density stratification: freshest at the upper water column, most saline at the lagoon bed), horizontally (freshest at the landward and upstream edges of the lagoon where creek outflows and hillslope/valley groundwater discharge occurs), and temporally (predominantly freshwater during average and above-average rainfall years, fresh-brackish to brackish in drought years, with highest salinity pulses associated with El Niño high sea level and storm events. Permanent freshwater wetland gradients are maintained locally near the creek mouth and valley/hillslope seeps except in extreme droughts. Isolated freshwater wetlands may occur in depressions within the landward (upstream) reaches of the floodplain east of the open-water lagoon.

- **LS low lagoon stands, beach groundwater gradient reversal**. During low lagoon stands (late summer/fall, droughts) and periods of high wave runup, emergent lagoon flats with low water levels would interact with higher beach groundwater elevations driven by wave runup and tides. During low lagoon stands/lagoon flat emergence, beach groundwater gradients may reverse, and higher salinity brackish groundwater may discharge into the lagoon during seasonal low lagoon stands, raising lagoon salinity in summer, especially at the seaward (backbarrier) end of the lagoon gradient.

- **LS lagoon level and overwash impoundment.** During storms with elevated sea level and high waves, barrier overwash may directly flood the partially drained (post-breach drawdown; Table A-7) lagoon with seawater. Density stratification of salt water is likely to occur when overwash coincides with high lagoon stands (deep standing freshwater); mixing of saline or brackish waters is likely to occur when overwash coincides with low lagoon stands (drawdown, drought).

- **LS lagoon salinity flushing, stratification, and mixing**. Rapid flushing of turbulent, well-mixed brackish lagoon water occurs only in ephemeral Stages 4-5 (Table A-7) while the lagoon outlet channel is open or partially choked. Gradual flushing of overwash-charged lagoon salinity pulses occurs during prolonged high lagoon stands (above tidal elevations) of impounded freshwater in nontidal lagoon conditions (persistent stages 1,2, 6, driven by seepage outflow of stratified brackish (higher salinity, higher density) bottom water through the beach. Overwash occurring during low lagoon stands (drought conditions) is likely to result in retention of high salinity overwash when beach seepage outflow rates are minimal.

- **LS lagoon breaching and unstable outlet initiation.** Lagoon morphodynamics shift to disequilibrium breach conditions during periods of high stream outflow (storms), driven by stream discharge rather than overwash, primarily during ebbing tides when water elevation gradients between lagoon and ocean are steepest. Lagoon breaching and outlet formation occurs when fluvial discharge rates significantly exceeds barrier seepage outflow rates, causing impounded freshwater in the lagoon to rise above spill elevations of the topographic low zones of the beach, overtopping the lowest zone (Table A-7). Overtopping lagoon waters flow down the beachface, causing incision (downcutting). The low point in the beach crest elevation alongshore gradient establishes the critical spill elevation of the lagoon, usually located at the headland-sheltered south end of the beach adjacent to Mori Point.

- **Lagoon breaching and closure** (lagoon outlet development, choking, and beach dam accretion). The rate of incision is influenced by tidal stage and wave height: maximum breach potential increases with steep water surface gradients due to high lagoon stands during low tides and low wave energy (low wave runup, weak wave deposition of sand). Breaching causes rapid release of impounded freshwater and any co-occurring marine overwash. Rapid emergence of shallow lagoon flats follows breaching. Torrential outflows occurring at low tides rapidly cut a steep, deep outlet throat, with vertical beach scarps and rapid slumping; a short-lived ebb tidal delta forms seaward of the breach. Less energetic breaches on high tides (lagoon and ocean levels more equal) form shallower outlets that may continue to through the subsequent ebb cycle. When the lagoon water surface equilibrates with sea level, waves initiate swash bar (berm) accretion across the outlet, forming a sill. The sill establishes a temporary flood-dominant inlet condition, with overwash impounded in the lagoon in low-energy conditions that favor stratification of salinity and accretion of minor flood shoals in the inlet throat. The transient inlet closes as the beach dam accretes above high tide elevation. The rate of lagoon closure and beach dam accretion varies with the energy of swell (wave runup height on the beachface) and local longshore drift rates.

- **Return to fresh-brackish lagoon impoundment and seepage (seaward groundwater discharge)**. After the beach dam crest elevation accretes above wave runup elevation, wave overtopping of the barrier at the outlet/beach dam ceases, and freshwater streamflow impoundment by the barrier resumes. The duration of lagoon flats (bed) emergence varies with rate of stream discharge (freshwater inflows). Dense brackish water remains at the bottom of the lagoon, while freshwater floats in a thickening layer above it; limited wind-mixing declines as the lagoon deepens with freshwater. Brackish mixing due to wind-stress currents occurs during shallow lagoon conditions (drought or post-breach). As lagoon freshwater depth increases, lagoon seepage outflow rates through the lower beachface increase to equal or slightly exceed stream inflow, preventing lagoon overtopping and breaching during the low flow season. The flooded lagoon edges (ordinary high water level and fringing marshes) are submersed with fresh or oligohaline, and gradual drawdown may occur in summer.

A-2.5 Conceptual model of Laguna Salada natural habitat structure

The habitat structure of the natural Laguna Salada was very likely similar to that of most seasonal and nontidal lagoons of the central coast that retain mostly natural streamflow, barrier beach or tidal outlet topography, and are free from (or recovering from) past agricultural conversion. Lagoon habitat and vegetation structure is patterned along seaward-landward gradients of freshwater influence and salinity dilution (stream mouths and groundwater, oceanic overwash and barrier overtopping), sedimentation (coarse fluvial sediment of floodplains, splays, fine fluvial suspended sediment gradients; coarse sediment of beach overwash, dunes) established by the dynamic processes explained in the model. This habitat structure can be summarized for application to restoration and management as follows:

- **Landward upland ecotones**: transition zones between stream floodplain valley and valley wall or terrace uplands, above storm surge elevation. Riparian scrub and lowland (sod-forming) grassland, sedge meadow on soils formed from marine terrace and floodplain sediments. Seasonally wet to mesic soils grading to upland coastal scrub and grassland. Buffered from storm surge by dense marsh and woody vegetation. Continuous vegetation transition to drier coastal scrub and grassland. Small mammal burrows provide winter (hibernation) refuge and summer foraging for San Francisco Garter Snake, Western Pond Turtle (drier upper end of gradient). Potential summer moisture refuges for California red-legged frog, tree frog; storm surge refuge for California red-legged frog. Migration/dispersal corridor between Laguna Salada frog, snake populations and upper watershed; snake dispersal corridor along wide peripheral wetland/upland ecotone of Laguna Salada wetland complex (meadows, riparian scrub cover).

- **Floodplain seasonal wetlands**: landward seasonal marsh with embedded slough and ponds (shallow depressional remnants of former braided stream channels), rush and sedge meadow, spikerush meadow, creeping wildrye-meadow barley meadow; pools may include sago pondweed. Off-channel, peripheral landward freshwater lagoon breeding habitat of California red-legged frog; foraging habitat of San Francisco Garter snake.

- **Lagoon fringing marsh - landward (**tule-cattail-bulrush marsh). Tall emergent freshwater marsh at landward, freshwater end of lagoon gradient, influenced by seasonally high fresh groundwater and high lagoon stands. Foraging habitat of California red-legged frog adults; breeding habitat at edges of lower vegetation ecotone with seasonal wetlands (rush, sedge grassland and meadow).

- **Large woody debris drift-lines** (drift-log wrack lines, piles). Variously patterned at inner landward and outer edges of lagoon fringing wetlands, depending on storm intensity and lagoon water surface height. Basking sites of San Francisco Garter snake, Western Pond Turtle (bordering open water); roosting sites of waterbirds, raptors.

- **Lagoon open water/Submerged Aquatic Vegetation bed**. Sago pondweed dominant in landward, fresher end of salinity gradient; wigeongrass dominant along backbarrier shoreline. Sago pondweed canopy in oligohaline-fresh lagoon waters is potential breeding substrate for California red-legged frog egg masses, floating canopy adjusting to changes in lagoon level without egg stranding; cover for tadpoles. Waterfowl forage in wigeongrass, sago pondweed canopies (dabbling ducks) and beds (diving ducks).

- **Lagoon backbarrier fringing marsh**. Lower fringing wetlands are threesquare bulrush or alkali bulrush; upper zones saltgrass, salt rush. Lower edge at bare sand substrate is tidewater goby habitat; submerged bulrush canopy is escape cover for tidewater goby.

- **Barrier beach and washover**. Wide semi-open flats are potential backshore roosting or stopover habitat for western snowy plovers. Beach is roost site for Caspian terns (predators of lagoon fish, including potential amphibian egg or tadpole predators)

A-2.5 Fish and wildlife responses to extreme morphodynamic and hydrologic events of coastal lagoons

Ecological events correspond with morphodynamics and hydrology events of the lagoon, and are potentially critical to the life-history of special-status species. During high lagoon stands through late spring, the lagoon floodplain seasonal wetlands are shallowly submerged after most rainfall has ceased. The depressions in the floodplain receive a late spring flooding, favoring isolated pool habitats favorable for tree frogs breeding and red-legged frog foraging (aquatic prey base of juvenile and adult San Francisco Garter Snakes). Deep flooding during high lagoon stands inhibits and delays the growth of tules and cattails at the lowest fringing marsh elevations around the lagoon, restricting their rate lateral spread. Lagoon high stands also promote dominance of sago pondweed over the lagoon bed (waterfowl foraging habitat and red-legged frog breeding habitat in Central Coast lagoons), and high groundwater favoring growth of riparian scrub bordering landward portions of the lagoon.

During rare extreme storm storm events, large amounts of coarse woody debris (driftwood) can enter the lagoon (from fluvial and overwash flooding) and deposit along the landward (downwind) edge, forming a concentrated band of flood refuges, basking habitat, summer moisture refuges, and roosts. Extreme storm overwash events naturally may cause mortality of red-legged frogs adults or eggs in winter along the west side edge of the lagoon. Red-legged frog adults survive overwash flooding along the landward freshwater reaches (refugia) of the lagoon, and in the adjacent floodplain and upland ecotone. Full breach events in late winter are also likely to cause mass mortality of red-legged frog tadpoles. Red-legged frog populations rebound from subsequent reproduction of long-lived adults in years of low-intensity storms and low-energy breaching or none. San Francisco Garter Snakes and western pond turtles mostlly hibernate in upland-edge mammal burrows during the winter storm season (stable mammal burrows are infrequent in unconsolidated beach sand of the washover substrates at the backbarrier lagoon edge. Brackish lagoon pulses during storms are likely limiting factors for persistence or population growth of non-native predatory bullfrogs (*Rana catesbiana*) with salt-intolerant tadpoles generally require two years to metamorphose. Breach events are also potential marine dispersal windows for tidewater gobies. Gobies would primarily inhabit the submerged backbarrier lagoon edge.

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Table A-4. Major backbarrier lagoons in the northern Central California Coast (Southern Sonoma County to northern Santa Cruz County)

Coastal lagoon	Lagoon type, hydrologic regime	Tidal inlet, outlet type	Salinity regime	Geomorphic signature, vegetation
Salmon Creek, Sonoma County	Seasonal estuary (winter) and nontidal seepage lagoon (low streamflow seasons)	Stream mouth, dry season beach dam; wet season choked tidal inlet	Mesohaline(seaward) Oligohaline-freshwater gradient upstream	Flood tidal delta fresh-brackish marsh
Estero Americano, Sonoma County	Seasonal estuary (winter) and nontidal seepage lagoon (low streamflow seasons)	Stream mouth, dry season beach dam; wet season choked tidal inlet	Polyhaline (seaward) Mesohaline-Oligohaline gradient upstream	Flood tidal delta shoals, brackish marsh
Estero San Antonio, Sonoma County	Seasonal estuary (winter) and nontidal seepage lagoon (low streamflow seasons)	Stream mouth, dry season beach dam; wet season choked tidal inlet	Polyhaline (seaward) Mesohaline-Oligohaline gradient upstream	Flood tidal delta shoals, marsh
Bodega Harbor, Sonoma County	Tidal, marine dominant estuary in drowned fault co-seismic subsidence basin	Flood-dominant tidal inlet, drowned fault subsidence basin (navigational dredging)	Euhaline; localized oligohaline-freshwater gradients, small seasonal stream mouths	Flood tidal delta shoals eelgrass or unvegetated; fringing salt marsh
Abbott's Lagoon, Marin County	Nontidal, barrier-impounded lagoon in lowland marine terrace and dune sheet	Intermittent storm overwash pass (foredune gap); Episodic (decadal) breach, transient outlet	Mesohaline (seaward) Oligohaline (landward) localized oligohaline-freshwater gradients, small seasonal stream mouths	Relict outlet channel landward of breach site outlet/persistent beach dam, no relict flood tidal delta shoal; fringing and deltaic fresh-brackish marsh
Drakes/Limantour Estero, Marin County	Tidal lagoon, marine-dominant estuary, drowned stream valley	Flood-dominant tidal inlet	Euhaline-Polyhaline; localized oligohaline-freshwater gradients, small seasonal stream mouths	Flood tidal delta shoals (massive); eelgrass or unvegetated; salt marsh
Bolinas Lagoon, Marin County	Tidal lagoon, marine dominant estuary in drowned fault co-seismic subsidence basin	Flood-dominant tidal inlet (navigational dredging)	Euhaline-Polyhaline; localized oligohaline-freshwater gradients, Pine Gulch Creek delta and unnamed tributaries	Flood tidal delta shoals marsh-capped, dune-capped, eelgrass, unvegetated, salt marsh

Redwood Creek (Big Lagoon; Muir Beach), Marin County	Fluvial dominant, seasonal choked tidal, dry season nontidal seepage lagoon in drowned stream valley	Seasonal outlet open in wet season, weakly ebb-dominant; choked or closed in dry season, nontidal beach seepage	Oligohaline-fresh to freshwater gradient	Fluvial bedform dominant; minor pondweed; riparian woodland, fresh-brackish marsh
Rodeo Lagoon, Marin County	Nontidal, barrier-impounded lagoon in drowned stream valley	Intermittent storm overwash prevalent, outlet channel Episodic (decadal) breach, transient outlet	Mesohaline (seaward) Oligohaline (landward) to freshwater gradient (Rodeo Creek)	Relict outlet channel landward of breach site outlet, no relict flood tidal delta; persistent beach dam; fresh-brackish marsh
Presidio Marsh (historic Crissy Field), San Francisco County	Tidal lagoon, marshplain dominant with sinuous tidal creek network; choked tidal flows	Flood-dominant choked tidal inlet (throat bed above MLW)	Polyhaline-Mesohaline (floristic proxy data)	Salt marsh, complex sinuous tidal slough network
Lake Merced, San Francisco County	[Historic] Nontidal, barrier-impounded drowned stream valley in marine terrace	[Historic] (?) overwash pass (foredune gap) and outlet channel Episodic (decadal) breach, transient outlet	Oligohaline-freshwater gradient (floristic proxy data)	Isolated lake due to urban fill; fringing tule marsh
Laguna Salada, San Mateo County	[Historic] Nontidal, barrier-impounded lagoon in lowland marine terrace	[Historic] Intermittent storm overwash prevalent; Episodic breach, transient outlet	[Historical] Mesohaline (seaward) Oligohaline (landward); local freshwater-oligohaline gradient at Sanchez Creek mouth inferred (floristic and photographic proxy data)	Relict outlet channel landward of former intermittent outlet; relict washovers, no relict flood tidal delta shoal; fringing and deltaic fresh-brackish marsh
Pillar Point Harbor, San Mateo County	Choked tidal lagoon, marsh channel and upper lagoon pond	Persistent choked upper intertidal inlet and channel	Mesohaline	Brackish marsh, simple tidal channel
Pilarcitos Creek, San Mateo County	Fluvial-dominant supratidal delta and floodplain above tidal frame (non-estuarine) in marine terrace; lagoon restricted to backbeach runnel or aggraded channel	Drift-deflected seasonal outlet, seepage dominant; backbeach lagoon north-offset from mouth (intermittently merged with Frenchman's Creek mouth)	Freshwater marsh and riparian woodland	Berm (swash bar)-dammed backbeach, stream channel; no flood tidal delta; Braided deltaic backbeach fluvial deposition, coarse sediment
San Gregorio Creek, San Mateo	Seasonal estuary in mainstem channel;	Stream mouth, dry season beach dam	Mesohaline (backbeach) Oligohaline to freshwater	Berm (swash bar)-dammed

County	choked tidal/nontidal seepage lagoon in low streamflow seasons; aggraded floodplain	with extensive backbeach lagoon, impounded stream channel; choked tidal inlet in wet season	stream gradient (floodplain, stream channel)	backbeach, stream channel; no flood tidal delta
Pescadero Creek, San Mateo County	Seasonal estuary in shallow tidal basin, drowned stream valley, floodplain marsh, backwater sloughs, ponds; choked tidal/nontidal seepage lagoon in low streamflow seasons	Stabilized (armored Hwy 1 bridge) seasonal tidal inlet position, dry season beach dam (variable)	Polyhaline-Mesohaline-Oligohaline to freshwater stream gradient; extensive marsh impoundments (diked, tidegate choked flows).	Flood tidal delta, sinuous tidal sloughs; brackish-fresh marsh gradient
Waddell Creek, Santa Cruz County	Seasonal estuary in mainstem channel; choked tidal/nontidal seepage lagoon in low streamflow seasons; floodplain marsh	Stream mouth, dry season beach dam with small backbeach lagoon, impounded stream channel; choked tidal inlet in wet season	Mesohaline (seaward) Oligohaline to freshwater stream gradient	Berm (swash bar)-dammed backbeach, stream channel; no flood tidal delta
Scott Creek, Santa Cruz County	Seasonal estuary in mainstem channel; choked tidal/nontidal seepage lagoon in low streamflow seasons; floodplain marsh, backwater sloughs, ponds	Drift-deflected seasonal tidal inlet, stabilized (armored Hwy 1 bridge) mouth; dry season beach dam	Mesohaline (seaward) Oligohaline to freshwater stream gradient	Berm (swash bar)-dammed backbeach, stream channel; no flood tidal delta
Laguna Creek, Santa Cruz County	Seasonal estuary in mainstem channel; choked tidal/nontidal seepage lagoon in low streamflow seasons; floodplain marsh, backwater sloughs, ponds	Stream mouth, dry season beach dam with small backbeach lagoon and impounded stream channel; choked tidal inlet in wet season	Oligohaline to freshwater steam gradient	Berm (swash bar)-dammed backbeach, stream channel; washover fan, no flood tidal delta; post-agricultural reversion to fresh-brackish marsh

Notes: Major coastal backbarrier lagoons in the north-central California Coast (southern Sonoma County to northern Santa Cruz County). Data sources: USGS quadrangle sheets, Google Earth (accessed August 2010), PWA [dates], Shaw 200? [Rodeo], Cooper and ? [Rodeo], [Geol Pt Reyes] WWR et al. 2008, WWR et al. 2009, Baye, unpublished data, Battalio, unpublished data [Geologic map refs] USFWS [goby]

Table A-5. Basis of Central Coast and Laguna Salada conceptual model

Conceptual model component	**Literature cited**
Lagoon outlet and breach processes, depositional and erosional processes and structures of stream mouth lagoons, Pacific Coast USA	Clifton et al. 1973, Warme 1971, Webb et al. 1991
General backbarrier lagoon outlet and breach processes	Price 1963, 1970
Control of outlet position by wave refraction and beach berm crest elevation gradients alongshore	Bascom 1954, Davies 1980
Coastal seepage lagoon general model, dynamics	Carter 1988, Carter et al. 1984, Jennings et al. 1993
Tidal inlet morphodynamics, instability, choking, closure in relation to stream power and tidal prism	Carter 1988, Davis and FitzGerald 2004, FitzGerald 1996, Ranasinghe et al. 1998, 1998, Webb et al. 1991
El Niño storm effects and regional long-term wave climate change, shoreline change	Allan and Komar 2006, Hapke et al. 2009, LaJoie and Mathiesson 1998, Storlazzi and Griggs 1998, Storlazzi and Griggs 2000
Barrier beach transgression, sand shoreline response to sea level rise	Carter 1988, Davis and FitzGerald 2004, Davidson-Arnott 2005, Woodroffe 2002
Beach slope, height, grain size response to waves	Bascom 1982, Komar 1976
Washover and inlet sediment transport and dynamics	Fisher 1979, Price 1963, 1970, Davis and FitzGerald 2004,
Beach groundwater dynamics in relation to tide, wave runup, lagoon head, seepage	Isla and Bujalesky 2005, Nielsen 1999, Turner et al. 1997
Central Coast regional reference lagoon investigations, models and data	Grossinger et al. 2010 (S. California), PWA et al. 2004 (Big Lagoon), Smith 2008 (Central coast multispecies habitat model), Shaw 1997, Striplen, Grossinger & Collins 2004 (Rodeo Lagoon), WWR et al. 2008 (Laguna Creek Lagoon), WWR et al. 2009 (Pilarcitos Creek Lagoon).

Table A-6. Summary of beach berm and runup elevations for coastal lagoon reference sites

	Typical Beach Berm Elevation[1]			**Outlet Channel Elevation**			**Coastal Flood Elevations**		**1-yr Runup Elevations**[5]	
Lagoon	2002 (ft NAVD)	1998 (ft NAVD)	1997 (ft NAVD)	2002 (ft NAVD)	1998 (ft NAVD)	1997 (ft NAVD)	100-yr TWL (ft NAVD)[2]	FEMA BFE (ft NAVD)[3]	Lowest Maxima (ft NAVD)	2/3 Rule Runup (ft NAVD)
Stone Lagoon, Humboldt	25 (22-26)	N/A	N/A	15	N/A	N/A	27.5	34.5	18.5	21.0
Big Lagoon, Humboldt	26 (25-27)	N/A	N/A	15	N/A	N/A	32.0	34.5	20.0	23.5
Abbott's Lagoon, Marin	28 (20-35)	28 (20-35)	28 (20-35)	4	15	9	28.0	36.5	18.5	21.0
Rodeo Lagoon, Marin	N/A	18 (15-20)	17 (15-20)	N/A	14	12-13	25.5	30.5	17.0	19.5
Laguna Salada, San Mateo[4]	-	-	-	-	-	-	29.0	30.0	17.0	20.5
Laguna Creek, Santa Cruz	N/A	13 (12-15)	12.5 (12-13)	N/A	6	No Outlet	28.0	30.5	16.5	19.5

Notes:

[1] Typical (average) beach berm elevation given for each site and Lidar survey. Range of berm elevations given in parentheses.

[2] PWA estimates of 100-yr TWL in Year 2000 were taken from the nearest available model output location, rounded up to nearest 0.5 ft: Stone Lagoon (27.4 ft NAVD), Big Lagoon (31.6 ft NAVD), Abbott's Lagoon (W Point Reyes = 27.7 ft NAVD), Rodeo Lagoon (Point Bonita = 25.5 ft NAVD), Laguna Salada (Pacifica = 28.1 ft NAVD and Rockaway = 29.9 ft NAVD), Laguna Creek (Davenport Landing = 27.7 ft NAVD). Values are rounded to nearest 0.5 ft.

[3] FEMA Base Flood Elevations (BFE) estimated by PWA (2008), as reported in Pacific Institute (2009). Laguna Salada BFE estimated from preliminary FEMA Flood Insurance Rate Map (FIRM), San Mateo County, Map number 06081C0038E (April 18, 2008).

[4] Laguna Salada seawall crest elevation ranges from 29-35 ft NAVD based on 1997 and 1998 Lidar. Surveys following the January 1983 storms indicated a back beach berm elevation of approximately 18 ft NAVD (Geomatrix 1987).

[5] 1-yr runup elevations were estimated using two methods: (1) lowest annual maxima of 100-yr modeled TWL time series, and (2) the annual maximum TWL exceeded 2/3 of all years of 100-yr modeled TWL time series (PWA 2009).

Table A-7. Modified 6-stage barrier breach and closure lagoon cycle, reconstructed natural model Laguna Salada, adapted from 10-stage seasonal estuary lagoon model of Laguna Creek Lagoon (WWR et al. 2008).

Stage 1: Spring-summer high lagoon stand, nontidal seepage lagoon impoundment phase (outlet closed; low flow (spring-summer) growing season

- Freshwater stream discharge, groundwater inflow impoundment; net beach seepage outflow < stream inflow; rising or equilibrium high lagoon stand
- Lagoon floodplain wetland and fringing marsh inundation with upper water column of lagoon (stratified freshwater)
- High lagoon seepage rate through beach; lagoon maximum hydraulic head
- Gradual summer drawdown during declining spring-summer streamflow, net seepage outflow > stream inflow; supratidal lagoon levels fall
- Ordinary high water lagoon levels and fringing marsh elevation range maintained above tidal frame (except during extreme drought)

Stage 2: Fall/winter increased stream discharge, nontidal seepage lagoon impoundment phase

- Lagoon water level rise to beach crest, >> lagoon ordinary high water level
- Maximum floodplain wetland inundation extent and depth
- Lagoon levels rise rapidly after precipitation events; net beach seepage outflow << stream and runoff inflow
- Cumulative increase in lagoon levels following successive precipitation events

Stage 3: Beach crest overtopping by lagoon, breach initiation (winter, non-drought years)

- Overtopping during high tide, high wave runup: minor outlet incision
- Overtopping during ebb or falling tide (steep water surface elevation gradient): barrier breaching, outlet channel erosion (incision, head cut), localized beach erosion
- Rapid high energy turbulent discharge of impounded freshwater, ebbing tide; transient high-energy ebb dominance
- Rapid lagoon drawdown *below* lagoon ordinary high water and fringing marsh elevations; marsh emergence; *lagoon marsh zones at/above high tide elevation*

Stage 4: Breach phase: unstable outlet (winter, non-drought years)

- High tide tidal inflows or wave bores enter lagoon; marine salinity pulse, turbulent mixing, brackish non-stratified lagoon; ephemeral estuarine conditions (dispersal window for marine organisms; salinity pulse mortality event for terrestrial organisms)
- Lagoon marsh salinity pulse during to wave bore/surges during extreme perigee high tide only, open outlet phase
- Winter wetland vegetation dormancy – minimal sensitivity to salinity outside growing season (no transpiration uptake, no soil porewater infiltration of brackish water)
- Transient impoundment of turbulent brackish water near high tide elevations << lagoon ordinary high water line and marsh elevations, floodplain elevations
- Breach open during storm wave beach erosion phase
- Swash bar accretion (sill) across outlet post-storm constructional swell; outlet instability; shift to low-energy flood dominant outlet, wave overtopping, overwash, at high tide
- impoundment of lagoon during ebb tide as swash bar/sill (tidal choking) increases with bar height

Stage 5: Lagoon outlet closure, beach dam (swash bar) accretion above post-storm wave runup elevation

- Declining, low frequency or cessation of wave overwash, overtopping at beach dam/choked outlet

- Post-breach brackish lagoon water surface elevation near MHHW, << lagoon ordinary high water level and marsh elevation range

Stage 6: Recovery of nontidal lagoon phase, post-closure (winter, non-drought year)

- Freshwater discharge impoundment resumes; lagoon water column salinity stratification initiated
- Stratified fresh-brackish water rises, approaches ordinary high water elevation >> tidal frame, progressively inundates lagoon fringing marsh zones; bottom lagoon water brackish (submerged aquatic vegetation bed).
- Post-breach recovery to Stage 1

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APPENDIX B. COASTAL PROCESSES AND FLOODING

1. COASTAL PROCESSES AND FLOODING

The purpose of this appendix is to address elements of coastal hydrology and flooding that affect Laguna Salada and restoration feasibility.

1.1 COASTAL HYDROLOGY

1.1.1 Local climate and meteorology

The climate of central California is primarily influenced by the Pacific High, a persistent zone of high pressure located over the eastern North Pacific Ocean. The strength and location of the Pacific High varies annually and seasonally. During the summer months, the high pressure zone migrates northward, and diverts most storm tracks to the north (Hapke and others 2006). During the winter months, the North Pacific High migrates southward, allowing intense extratropical storms to follow a more southerly track and affect the central and southern portion of the state (National Marine Consultants 1960). Longer term climate variations are linked to the El Niño-Southern Oscillation (ENSO), which has a cycle of 3-8 years. During El Niño years, Central California's climate is characterized by above average rainfall and increased frequency and intensity of Pacific storms. La Niña years are characterized by lower than average rainfall and less severe storms (Hapke and others 2006). The Pacific Decadal Oscillation (PDO) results in climatic shifts over time frames of 30 to 50 years, and is attributed with changes in beach widths and orientations (Allan and Komar, 2000). Climate change is anticipated to result in warming of the atmosphere and oceans, with an acceleration of sea level rise. The effect of climate change on wave conditions and storms is less certain. Regardless, increased sea level is expected to increase coastal flood and erosion hazards (Heberger et al. 2009; PWA, 2009).

1.1.2 Tidal water levels

The NOAA tidal datums for San Francisco are summarized in Table 1.

Table 1. NOAA Tidal Datums for Presidio, San Francisco, CA (#9414290)

	San Francisco Presidio			
	MLLW (ft)	**NAVD 88 (ft)**	**MLLW (m)**	**NAVD 88 (m)**
MHHW	5.84	5.90	1.78	1.80
MHW	5.23	5.29	1.59	1.61
MTL	3.18	3.24	0.97	0.99
MSL	3.12	3.18	0.95	0.97
MLW	1.13	1.19	0.35	0.36
MLLW	0	0.06	0.0	0.02

Notes: MLLW = Mean Lower Low Water, MLW = Mean Low Water, MSL = Mean Sea Level, MTL = Mean Tide Level, MHW = Mean High Water, MHHW = Mean Higher High Water

The San Francisco coast experiences mixed semidiurnal tides, with two high and two low tides of unequal height each day. The tides exhibit a strong spring-neap variability over a two week cycle; spring tides exhibit a large difference between high and low tides while neap tides show a smaller than average range. The highest monthly tides occur during summer and winter months. The mean tidal range (MLW to MHW) is 4.1 ft and the diurnal range (MLLW to MHHW) is 5.8 ft. Sea level rise over the last few decades at the Presidio tide station has been about 0.2 ft.

1.1.3 Extreme stillwater water levels

The stillwater level refers to the water surface elevation in the absence of waves. It includes the effects of the astronomical tide plus storm surge. We have approximated extreme stillwater levels at Sharp Park using results from a study at San Francisco (PWA 2006). At San Francisco, the 10, 50, and 100-year events were estimated at 8.40 ft, 8.66 ft, and 8.73 ft NAVD, respectively. For comparison, previous estimates have placed the 100-year stillwater level at 8.90 ft NAVD (Knuuti 1995) and 8.69 ft NAVD (USACE 1984). Extreme stillwater levels do not include wave action and wave setup, which can significantly increase water levels temporarily during storms.

1.1.4 Wave climate

The wave climate along the California coast exhibits significant spatial and temporal variability due to seasonal and annual weather patterns, offshore topography, wave-approach direction and coastline orientation. Wave heights generally range from 5-30 ft with periods from 10-25 seconds. North Pacific swell associated with remote extratropical storms dominates the winter months. Longer term variations in wave climate are linked to large scale atmospheric variations, particularly the El Niño-Southern Oscillation (ENSO). During El Niño winter months, storms increase in frequency and intensity, producing waves of exceptional height and period at the shoreline.

Table 2. Return Period and Wave Height for Extreme Wave Events Along Central California Coast

Return Period (yrs)	Significant Wave height Port San Luis (ft)[1,2]		Significant Wave Height San Francisco (ft)[3]	Significant Wave Height Half Moon Bay (ft)[4]
10	23.2	22.2	26.6	29.9
20	25.8	25.8	-	-
25	-	-	29.6	33.2
30	28.0	27.1	-	-
50	29.0	30.0	31.9	35.7
100	31.7	33.1	34.1	38.2

[1,2]Calculated based on Raichlen (1985) dataset at Port San Luis assuming a (1) Gumbel and (2) log normal probability distribution.
[3,4]Calculated by Storlazzi and Wingfield (2005) for NOAA San Francisco (#46026) and Half Moon Bay (#46012) gages.

Table 2 summarizes estimates of extreme deepwater wave heights along the Central California coast (Raichlen 1985; Storlazzi and Wingfield 2005). Estimates of the 100-yr deepwater significant wave height range from 32-38 ft at San Francisco and Half Moon Bay. The shoreline at Sharp Park is very exposed to large waves during coastal storm events. PWA (2009) estimated wave heights corresponding to a 100-yr coastal flood event based on climate model simulations by Cayan et al (2009). Deepwater wave heights for the two closest stations at Pacifica and Rockaway were found to be 36.6 ft and 32.9 ft, respectively, with a peak period of 17 seconds.

1.2 MORPHOLOGY OF BEACH FRONTING LAGUNA SALADA

The beach fronting Laguna Salada is coarse grained and steep, with a slightly arced planform due to the Mori Headland and predominant incident wave direction from the west-northwest. The beach narrows with distance north as its alignment conflicts with the nearly north-south roadway grid and seawalls north of Clarendon Road. The steep foreshore typically projects into a shore-parallel trough, with a shallow nearshore bar farther seaward, consistent with a reflective high energy shore. Alongshore and seasonal variability exist. During large wave conditions, waves can break far offshore, and well beyond the seaward edge of Mori Point. This indicates that sediment bypassing of the Mori Headland headland is possible.

The geology of the Sharp Park area is low and located in a sag/valley just north of Mori Point. Farther north, the seaward expressions of hillsides (ridges) oriented transverse to the shore can be seen, with near vertical bluffs to the north and expressions of bedrock and weaker sedimentary rock (hardpan) underlying the beach sediments. However, borings show the hardpan/bedrock to be relatively deep in front of Laguna Salada (Geomatrix, 1987).

The sediment at Mori Point/Salada beach is dark and coarse, contrasting with the predominant sediment farther north in the Manor District of Pacifica, south of Mussel Rock. Anecdotal evidence indicates that there are several sand sources in the area:

1. The eroding bluffs at Mori and Mussel Rocks, possibly augmented by historical deposits of these coarse sediments derived from generally older sedimentary rocks that are typically lower in elevation except at uplifted and tilted headlands. These are typically coarse (pebble/gravel size to sand size) and dark, and

2. The eroding bluffs or Manor and Daly City comprised of unconsolidated dune sands and weekly lithified sandstone. These are typically fine to medium sands, tan to brown in color, and tend to move over coarser deposits.

A comprehensive study of coastal processes along the Pacifica and Daly City shores has not been accomplished. It appears that the beach immediately north of Mori Point comprises sediment derived from erosion of Mori Point, and possibly accumulated over the last 20,000 years as sea level rose and stabilized. The orientation of the shore indicates that Mori Point is a partial barrier to southward transport, resulting in a rotation of the shore toward the north, and widening of the beach. The coarser sediment can move onshore under high wave action with long periods (relatively low ratio of height to wave length), and northward under westerly and southwesterly swells. The finer, brown sands from the Manor area most likely move southward and offshore at

Mori, unable to remain on the high energy steep beach formed by the predominate coarse sediments. The armoring near and north of the pier inhibits northward movement, creating a littoral divide between the southern subcell (Mori – Laguna Salada-south Sharp Park) and the northern subcell (north Sharp Park Manor to Mussel Rocks). Therefore, except for offshore exchange, the beach in front of Laguna Salada should be relatively stable, neither accreting nor eroding significantly in the long term.

1.2.1 Historical conditions

Historical maps and photographs show that the beach was wide and low, with a washover morphology (rather than dunes) south of the present location of Clarendon Road. The entire area was a sandy deposit, resulting from accretion that occurred as sea level rose and drowned the sag valley north of Mori Ridge. Wave power and sediment supply were sufficient to build a ridge of sand that typically blocked drainage, resulting in the formation of Laguna Salada. Analysis of wave power vs. tidal prism relative to other California lagoons and tidal inlets indicates that the tidal scouring of the lagoon was not nearly strong enough to maintain an open inlet given the strong wave exposure at the site (Figure 1).

Historic shoreline positions indicate shore erosion of approximately 2 feet per year (fpy) over the long term (last 100 years) but rapid erosion of about 5 fpy over the last 50 years, as shown in Figure 2 (Hapke and others, 2006). These studies refer to the shoreline estimated from maps and aerial photographs. The later high rate contrasts to the interpretation of a relatively stable, coarse grained beach described in the previous section. Speculatively, the rapid "short-term" erosion rates are attributed to relaxation of a large accretion event in the mid 1900s, where the shore became wider than that mapped in the early 1900s. There are several processes that could have caused this. Also, there have been anecdotal reports of extensive mining of sands from the beach by the City/County of San Francisco for expansion of the San Francisco Airport runways. While these reports are not substantiated, sand mining of California beaches was prevalent and has been shown to cause massive and lasting erosion. Sand mining can be particularly damaging if coarser sands are selectively mined, which is the typical practice, as the coarse fraction may have accumulated over thousands of years and is not rapidly replaced (PWA, 2008).

A review of historical photographs and documents indicates that the existing levee was constructed in the 1980s. The initial construction was conducted without permitting (personal communication, anonymous source previously employed by City of Pacifica). The remainder of the levee was constructed in 1989-1990, evidently with Coastal Commission approval. However, the approval appears to be partly based on the assumption that a contiguous levee or seawall existed prior to the 1983 event, based on a declaration of categorical exemption from CEQA by the City of Pacifica (see Appendix B, Geomatrix, 1987). The foundational description of a pre-existing levee damaged in 1983 is reinforced by several studies for the City/County of San Francisco (see for example Geomatrix, 1987), without any evidence or description. The ARUP (2009) "seawall" report reiterates that there was a levee/seawall in place in 1983. A review of available photos show an earth embankment at the north and south ends of the shore, with no embankment in the middle third. The embankments do not look to be as substantial as the existing levee and proposed seawall structures. There was not a levee for much of the beach in the 1980s and one could walk directly from the beach to the lagoon (personal observations by Bob Battalio, confirmed with other Pacifica residents). During this period, wave runup occasionally reached the lagoon, and swaths of sand were deposited on the west side of Laguna Salada. Therefore, the assertion that the new levee was a replacement or maintenance of a similar prior structure is dubious, at best.

A response to an inquiry to the California Coastal Commission states that the levee construction in the late 1980s was permitted for a "replacement berm 3500 feet long."

We have not found a review of the potential adverse effects of the berm (or levee, seawall) on the coastal and lagoon habitat. This is astonishing, given its dimensions of over 3,200 linear feet and height approaching +30'NAVD, and its construction more than a decade after the California Coastal Act (1976).

1.2.2 Existing conditions

The existing beach exists in front of an armored coastal structure. The back beach appears to be artificially elevated against the earth levee, which directs wave runup upward. The result is a narrower but locally higher, steeper beach. Another result is a reduction of sand volume, which results in a narrower beach during eroded conditions. This narrow beach incrementally increases wave reflection and increases the size and violence of shore break waves. Several drownings occurred in the vicinity of Clarendon Road and Beach Boulevard in 2009-10, due to being trapped between the large shore break and steep shore. During narrow beach conditions, wave runup reaches the levee. In winter 2010, a large volume of sand (on the order of 30,000 cubic yards) accreted on the beach between Mori Point and the pier, with some moving north to Paloma Street. The wave runup and coarse sand overtopped the seawall at Clarondon and blocked the storm drain outfall, resulting in flooding. The sand and runup nearly overtopped the levee at Laguna Salada. This deposition of sand has incrementally reduced the risk of coastal erosion damage at Laguna Salada.

1.2.3 Future conditions

The future beach conditions will depend on the amount of sand available, climate change and sea level rise, and the back shore condition as affected by man (e.g., whether the levee/seawall is maintained).

A detailed study is required to further diagnose historical conditions and predict future conditions. Pending that, long-term erosion amounting to an average on the order of 1 to 2 feet per year can be expected. However, actual changes will be irregular and likely to deviate from this average.

Relative sea level rise will induce recession of the shore. If the hard edge of the levee/seawall is maintained, the beach will narrow and the levee will be overtopped (or raised to prevent overtopping). If the levee is maintained, the beach will become so narrow that waves will frequently impact the levee/seawall and the beach will be largely lost. This condition has already occurred north of the pier at Beach Boulevard (Figure 5, main report). In this condition, the wave runup elevation will increase substantially as large waves break directly against the armored slope of the levee.

If the levee is not maintained, it will erode and a wide sand barrier beach will form. The elevation of the berm will be close to the existing beach elevation, with relatively gentle, shallow swash overtopping by wave runup occurring annually. The wave action will transport sand inland and build the berm, conceptually rising and migrating landward with sea level rise. A comparison with unaltered barrier beaches indicates that the berm would equilibrate around +18 to +20 ft NAVD. This condition is approximately represented by Rodeo Lagoon Beach in Marin County (Figure 3). Appendix A (Table A-3) provides the data from reference sites. The expected beach berm elevation is close to the annual runup elevation based on calculations conducted by PWA using 100 years of synthetic water level and wave data (derived from PWA 2009). From this analysis, the 1-year return period water level was between +18 and +20 ft NAVD. We expect that the calculations slightly under predict actual values due to the global climate model used, but this high bias is compensated somewhat by the reduction of runup elevation realized with a greater lateral travel distance over a coarse sand berm versus the beach geometry assumed in the calculations.

Therefore, based on a review of other beaches, the conditions at Laguna Salada and calculations we conclude that the beach berm elevation would equilibrate to about +20’ NAVD if the levee (seawall) is removed. The crest of the berm would be farther landward of the levee, and then slope downward into Laguna Salada.

The estimated elevation of +20’ NAVD is lower than the existing top of sand elevation at the toe of the levee at the time of this report (about el +22’). The existing elevation is higher because the levee obstructs wave runup and causes the some of the sand that would have moved inland to deposit at the levee face. If the beach narrows, the runup incident to the levee will increase in intensity and scour, rather than deposition, can be expected.

1.3 COASTAL EROSION

1.3.1 Historical erosion rates and shoreline variability

Considerable erosion of the Sharp Park shoreline has occurred since construction of the golf course in 1932. From 1931 to 1992, it is estimated that the shoreline eroded approximately 200-300 ft, or approximately 3.3-4.9 ft/yr (PWA 1992). A large fraction of this erosion likely occurred during the 1983 El Niño storms.

The U.S. Geological Survey (Hapke and others 2006) estimated historical rates of change along sandy shorelines of the California coast over the past 150 years. USGS estimates of long-term shoreline erosion at Sharp Park from 1899-1998 are higher than the regional rates, on the order of 1.6-2.6 ft/yr (0.5-0.8 m/yr; Figure 2a). Short-term erosion rates at Sharp Park from 1946-1998 indicate even more rapid rates of shoreline recession on the order of 2.3-6.2 ft/yr (0.7-1.9 m/yr; Figure 2b).

1.3.2 Future erosion rates and shoreline response to sea level rise

Future erosion rates are of particular importance to coastal management, infrastructure maintenance, restoration design, and sustainability. Predicting long-term geomorphic evolution, especially considering the effects of sea level rise, is a difficult task.

The rate of erosion is related to the frequency, duration, and intensity of wave impact on the toe of the bluff or dune (Ruggiero and others 2001; Sallenger and others 2002; PWA 2009). Based on our understanding of coastal erosion mechanisms, it is expected that future erosion rates will meet or exceed long term, average historical rates. Presumably, higher baseline water levels associated with sea level rise will result in a greater occurrence of waves impacting the dune or bluff toe, thereby increasing the susceptibility to erosion. The coastal loads and erosion rates at Sharp Park are expected to increase and may increase non-linearly (accelerate) in the future. Certainly, historic rates and costs are minimums that will likely be exceeded in the near term.

1.3.3 Profile response to seawalls

Seawall effects are typically considered to be limited to the vicinity of the structure. Seawall effects are subject to ongoing investigation and a range of views and conclusions exist (Plant and Griggs 1992; McDougal and Kraus 1996; Wiegel 2000; USACE 2006). It is also generally accepted that the beach profile in the surf zone is affected by wave energy dissipation and the concept of an equilibrium profile is widely applied (USACE, 2006). On a receding shore, the position of the seawall can become relatively closer to the water over time, essentially truncating or compressing the area of wave dissipation. As a result, associated effects on nearshore hydrodynamics and sediment transport can modify the equilibrium profile. The impacts of shore parallel structures are typically limited to the area in front of the seawall and a downdrift area (relative to predominant sediment transport direction) unless the recession is so great that the structure starts to block alongshore transport.

Most of the controversy associated with seawall effects is associated with the accusation that “seawalls cause erosion.” This has resulted in a parsing of the impacts of seawall construction to “passive” and “active” effects. Passive effects are generally agreed to exist, whereas active effects are subject to debate and require further research and consensus building. Passive effects refer to the narrowing of a beach in front of a seawall due to the continuation of erosion processes (Figure 4). The passive moniker is applied because the erosion in front of the seawall would have occurred anyway, and the seawall just prevents the land behind the seawall from becoming beach. It is also generally accepted that the footprint of the structure narrows the shore, reducing beach width (this is called “placement loss” and is not considered an “active” effect; Figure 4). It is also generally accepted that beaches can maintain themselves by eroding upland areas and migrating landward, and can also be nourished by sand released during erosion of back beach areas. Therefore armoring incrementally increases erosion potential by reducing sand supply to beaches and incrementally results in narrower beaches by preventing shore migration. These adverse effects of seawalls to the shore are not considered "active effects." Active effects are defined as those that increase the rate of erosion by affecting local hydrodynamics. Active effects under debate include increased erosion caused by the interaction of the seawall with the surf zone, in terms of increased wave reflection, increased pore water dynamic pressure and fluidization of fronting sand deposits, acceleration of alongshore currents, modification of setup and rip current formation, among others. Interestingly, local active effects such as toe scour and end effects are generally considered as design criteria for structures and not debated.

In summary, armoring with a seawall (or similarly, a rock revetment or levee) on an eroding shore can be expected to result in a reduction of beach width over time, as the shore continues to try to recede. Active effects, if they exist, would accelerate the rate and extent of beach loss.

It is unfortunate that the coastal engineering and geomorphology community has been unable to develop a consensus and communicate the effects of seawalls to the public. However, recent research by beach ecologists confirms adverse effects of seawalls on the beach ecosystem (Dugan and Hubbard, 2006; Dugan et al., 2008).

In Pacifica, the result of seawall construction can be seen directly. The most extreme case is just north of Laguna Salada along Beach Boulevard north of the pier (Figure 5, main report). The photographs show the reduction of beach width over time. The seawall south of the pier and the levee fronting Laguna Salada have wider beaches in front of them.

1.4 RAINFALL/RUNOFF FLOODING

Assessments of rainfall/runoff flooding in Laguna Salada were completed by PWA (1992) and Kamman Hydrology & Engineering (KHE 2009). Both assessments integrated the rainfall-runoff, flood routing, and pond storage characteristics for Sanchez Creek, Horse Stable Pond, and Laguna Salada. The details of the more recent KHE (2009) modeling are presented here. KHE developed a rainfall runoff model for the Laguna Salada drainage basin using the WinTR-55 computer program. The model was used with published depth-duration-frequency rainfall data for the San Francisco Bay region (Rantz 1971) to determine the discharge into Laguna Salada for a 24-hr rainfall event with recurrence intervals of 2 to 100 years. KHE used the HEC-RAS hydraulic model to simulate lagoon water levels over a 48-hr simulation period. The modeling assumed operational pumps at Horse Stable Pond and an initial lagoon water surface elevation (WSE) of 6.8 ft NAVD. The results are summarized in Table 3.

Table 3. Summary of rainfall/runoff modeling results

Return Period (years)	Peak Flow Rate (cfs)	Storm Runoff Volume (ac-ft)	KHE (2009) WSE Increase (ft)	KHE (2009) Peak WSE (ft NAVD)	PWA (1992) Peak WSE (ft NAVD)
2	136	77	2.2	9.0	-
5	254	127	4.2	11.0	-
10	348	161	5.2	12.0	-
25	468	199	6.7	13.5	-
50	564	238	7.4	14.2	-
100 (w/ baseflow)	646	263	8.2	15.0	-
100 (w/o baseflow)	Not reported	Not reported	6.7	13.5	13.7

Notes: WSE = lagoon water surface elevation. KHE (2009) peak lagoon WSE estimated visually from Figure 11 (KHE 2009). PWA (1992) peak lagoon WSE of 10.9 ft NGVD converted from NGVD to NAVD using a conversion factor of +2.8 ft.

With no pumping the 100-year water level increases to between 15.5 ft (PWA, 1992), and 17 ft NAVD (estimated based on KHE (2009) by adding 1.5' to represent base flow).

1.5 COASTAL FLOODING

The Sharp Park site is very exposed to large waves. The long period swell incident upon the Central California coast results in strong wave setup, which can elevate water levels at the shoreline and allow much larger waves to impact the beach and levee. As waves break and runup on the beach, waves can overtop the crest of the levee, leading to erosion and landward flooding. While the largest waves break well offshore, run-up during winter storms is also greatly increased, causing erosion and overtopping along the Sharp Park shore, especially north of Laguna Salada. The following sections describe previous coastal flood studies for Pacifica, and evaluates the present day coastal flood hazards at Laguna Salada.

1.5.1 Summary of previous coastal flood studies

The effective flood study is the 1987 FEMA Flood Insurance Study (FIS) for the City of Pacifica, CA, San Mateo County (FEMA 1987a). The FEMA study estimated the Base Flood Elevation (BFE), or 100-yr wave runup elevation, in Pacifica at Paloma Avenue, approximately 4000 ft north of Laguna Salada. The BFE was estimated to be 27 ft NGVD (29.8 ft NAVD), based on the Ott Water Engineers' (1984) study. FEMA is currently in the process of updating the Pacifica Flood Insurance Rate Map (FIRM) for Pacifica. The BFE for the revised preliminary map for Pacifica (Map Number 06081C0038E, April 18, 2008) is 30 ft NAVD.

PWA (2009) estimated 100-yr total water levels (TWL = tides + storm surge + wave runup) along the northern California coast based on climate model simulations by Cayan and others (2009).

The average 100-yr total water level for the two closest stations at Pacifica and Rockaway was found to be 29 ft NAVD.

It should be noted that estimates of total water level or maximum wave runup indicate the highest potential runup elevation attained by waves breaking and running up on a surface, such as a beach or levee face (Figure 5). In reality, the wave overtops the levee and the overtopping jet carries water over the crest of the levee, where it collects and ponds on the landward side. The TWL or wave runup elevation is not the same as the flood inundation level on the landward side of the levee. The ponded water level reached on the landward side of the levee due to "pumping" of water over the crest by breaking waves is the landward coastal inundation flood level. This flood level is different than the FEMA BFE and the majority of previous flood studies (FEMA 1987; PWA 1992; KHE 2009; PWA 2009) have not evaluated this flood hazard for Laguna Salada. Geomatrix (1987) estimated the volume of wave overtopping of the 1980s unprotected coastal embankment; however, modifications to the levee crest and level of armoring over the past 20 years have modified the levee such that this assessment is no longer up to date. The sections below describe analysis conducted for this study to update the landward coastal inundation flood level for existing conditions.

1.5.2 Landward coastal inundation by wave overtopping

Coastal flood hazards for the 100-yr coastal storm event were evaluated for three cases at Laguna Salada:

1) **Existing levee** – wave overtopping of existing levee
2) **Degraded levee** – wave overtopping of existing levee with levee crest degraded by 2 ft during coastal storm event
3) **Natural barrier beach –** wave overtopping of natural wave-built barrier for restored lagoon conditions

All cases assume a 100-yr deepwater significant wave height of 36.6 ft and peak period of 17 seconds, based on total water level results from PWA (2009) (see Section 1.1.4), a maximum wave runup elevation of 30 ft NAVD (FEMA 2008), and duration of overtopping of 4 hours. The overtopping duration is selected somewhat arbitrarily pending a more detailed analysis. A four hour duration conceptually allows for overtopping to occur for two hours surrounding the peak high tide. A design water level of 13.7 ft NAVD was selected, assuming a stillwater level of MHHW (5.91 ft NAVD) with 7.8 ft of static wave setup (calculated using methods in the FEMA Pacific Coast Guidelines for Coastal Flood Hazards (FEMA 2005)). Inundation calculations assume that wave overtopping occurs over 800 ft of levee with average crest elevation of 29 ft NAVD (Figure 6). For the degraded levee case, we assume that erosion of the levee during a coastal storm event would lower the crest by approximately 2 ft to an elevation of 27 ft NAVD.

Overtopping rates for the existing and degraded levee cases were estimated using equations 7-11 and 7-12 in the Shore Protection Manual (USACE 1984; Weggel 1976). Overtopping rates were estimated in units of cubic feet per second per linear foot of levee. Total overtopping volume was estimated by multiplying the overtopping rate by the length of overtopped levee (800 ft) and storm duration (4 hrs). Lagoon storage volumes were converted to equivalent water surface level using the stage-storage relationships from Figure 6 in KHE (2009). Results of the wave overtopping analysis are presented in Table 4.

Overtopping rates of the natural barrier beach (restored lagoon) case for a 100-yr coastal flood event were not estimated, although substantial overtopping would occur. However, the presence of an unarmored natural barrier beach would allow both overtopping and free outflow from the lagoon to the ocean during a storm. As a result, the maximum lagoon flood elevation would be controlled by the elevation of the barrier beach berm. As discussed in Section 1.2.3, we estimate a maximum restored natural beach berm elevation of 20 ft NAVD. Natural breaching and drainage of the lagoon would likely occur under this scenario.

Table 4. Laguna Salada landward coastal inundation flood level for 100-yr coastal event

Scenario	Existing Levee	Degraded Levee	1980s condition (Geomatrix 1987)	Natural Barrier Beach (ft NAVD)
Levee Condition	800 ft @ +29 ft NAVD	800 ft @ +27 ft NAVD	800 ft @ +18 ft NAVD	3200 ft @ +20 ft NAVD
Overtopped Volume (ac-ft)	72	569	401	- (Berm is simultaneously overtopped by waves and lagoon drainage)
Lagoon Flood Level (ft NAVD)	9.6	17.2	14.7	20

Notes: Lagoon storage volume and flood level assume initial lagoon water level of 6.8 ft NAVD.

The results presented above for the existing and degraded levee cases are based on simplified methods which appear to overpredict actual overtopping of the coastal levee. These methods are based on flume studies with regular waves, and do not directly apply to the storm wave conditions along the Pacific Coast. This resulted in a high uniform overtopping rate compared to irregular waves. The SPM method was applied here to obtain a rough estimate of the inland flooding potential due to overtopping of the existing levee, based on a readily available maximum runup elevation from prior studies. Erosion of the beach during a storm event would actually change the profile geometry, thereby affecting the maximum wave runup elevation. These effects were not considered in this analysis. The combined influence of simplified overtopping equations and the relatively steep beach and levee profile assumed for the existing and degraded levee cases resulted in very high overtopping rates, and a conservative estimate of the inland inundation level due to overtopping. Comparison with the Geomatrix (1987) overtopping calculations for the levee and beach condition existing at that time confirms this assessment.

We recognize that these simplified calculations likely overpredict the overtopping rate for the existing levee and may overstate the coastal flood risk due to overtopping. Therefore, a more detailed analysis of coastal flooding is needed to better assess flood risk and evaluated alternative risk mitigation and restoration alternatives.

1.6 COMBINED FLUVIAL AND COASTAL FLOODING

Flood levels within Laguna Salada are due to the combined effects of rainfall runoff, discharge from Sanchez Creek, and wave overtopping of the outboard levee. As previously discussed, the landward coastal inundation flood level has not previously been determined for existing conditions at Laguna Salada. Using the fluvial flood results from Section 1.4 and the coastal flood results from Section 1.5, we estimate the lagoon flood level due to a combined coastal and rainfall/runoff event.

An initial lagoon water level of 6.8 ft NAVD was selected based on assumptions made in KHE (2009) for the rainfall/runoff modeling. The approach taken here is to assume the 100-yr coastal flood event occurs during a 24-hr rainfall event. The results are summarized in Table 5.

Table 5. Laguna Salada landward coastal inundation flood level for combined 24-hr rainfall and 100-yr coastal flood event

	Lagoon Flood Level		
Rainfall Return Period (yrs)	**Existing Levee (ft NAVD)**	**Degraded Levee (ft NAVD)**	**Natural Barrier Beach (ft NAVD)**
2	10.7	17.8	20
5	12.4	18.7	20
10	**13.3**	**19.3**	**20**
25	14.4	20.2	20
50	15.1	20.7	20
100	15.9	21.3	20

Note: Analysis assumes 100-yr coastal storm event coincident with 24-hr rainfall events listed above. For with-levee conditions, initial lagoon water level of 6.8 ft NAVD assumed.

The above analysis indicates that the existing levee results in a lower coastal flood level than the natural condition for coincident rainfall events with a return period less than about 25 years. While the joint probability of coastal flooding and elevated rainfall runoff are not known, a 10-year recurrence rainfall event coincident with a 100-yr coastal event is recommended until more detailed analysis is accomplished (numbers in bold in Table 5). With the degraded levee (some degradation of the levee is likely during a severe overtopping event) the levee provides only a marginal benefit of 0.7 feet, which is within the level of accuracy of the methods used.

The above estimates are approximate. The 1983 coastal flood event was reportedly severe and is sometimes considered to be a proxy for the 100-year coastal flood event. Given that the levee was not present after the event (Geomatrix 1987); it can be assumed it was not continuously in place during the event. Measurements of the actual flood elevations resulting from the 1983 event were not found, but photographs (Geomatrix, 1987) indicate that the elevations were at least several feet below the elevations calculated (calculated elevations are in Table 5). Therefore we conclude that the calculated values probably over-estimate the extent of flooding that would occur. A more detailed analysis of coastal flood potential is recommended.

1.7 GROUNDWATER AND PUMPING

Water levels within Laguna Salada are currently maintained by the operation of a pumping station at the southern end of Horse Stable Pond. The small (1,500 gpm) and large (10,000 gpm) pumps are activated when lagoon water levels exceed 6.9 ft NAVD and 7.5 ft NAVD, respectively. The pumps convey runoff from the ponds to an outfall on the beach and prevent flooding of the golf course by continually pumping down the lagoon to a level below natural levels.

The direct ecological implications of pump operations are discussed in the main report. An indirect effect of artificially lowering the lagoon water level is increased vulnerability to groundwater salinity seepage from the ocean to the lagoon (the typical direction of groundwater seepage is from the lagoon to the ocean). KHE (2009) found no direct evidence of salinity intrusion by beach groundwater in the southern portion of Sharp Park; however, KHE (2009) noted that under certain conditions, the groundwater gradient may reverse and allow higher salinity groundwater to flow into the lagoon. Field observations by the ESA PWA team in February and March 2010 revealed such saline seeps emerging in golf turf patches immediately behind the coastal levee at the north end of Sharp Park (see Appendix F. Salinity intrusion to Laguna Salada backbarrier environments). The saline seeps occurred coincident with high winter tides and storm waves, which act to elevate beach groundwater levels and can cause a reversal in the typical seaward groundwater flow through the beach berm (Isla and Bujalensky 2005; Carter et al. 1984).

Landward salinity intrusion to Laguna Salada by reversal of groundwater gradients at the barrier beach is likely to increase and accelerate as sea level rises, storm wave heights increase in magnitude and frequency in California (Allan and Komar 2000), and as shoreline retreat continues on the San Mateo Coast (Hapke et al. 2006, Hapke et al. 2007).

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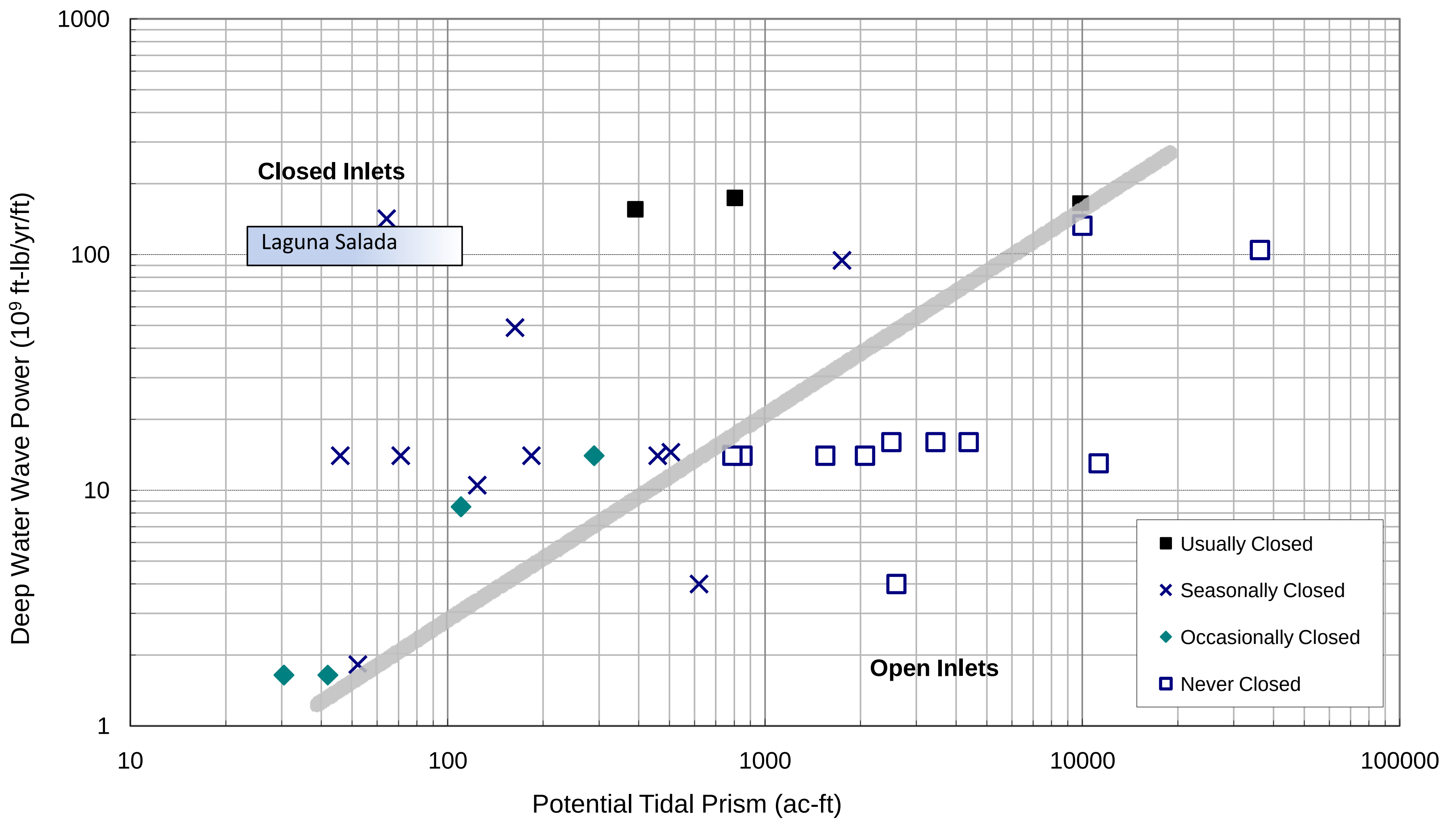
LIST OF FIGURES



Notes: Laguna Salada nearshore wave power = 95-140 x 10^9 ft-lb/yr/ft.
Existing potential tidal prism = 24 ac-ft.
Estimate of maximum historic potential tidal prism = 115 ac-ft (assumes intertidal footprint of 20 acres).

Source: Original methodology developed by Johnson (1973)

figure 1

Laguna Salada Restoration Feasibility Study

Johnson-type Wave Power-Tidal Prism Criterion

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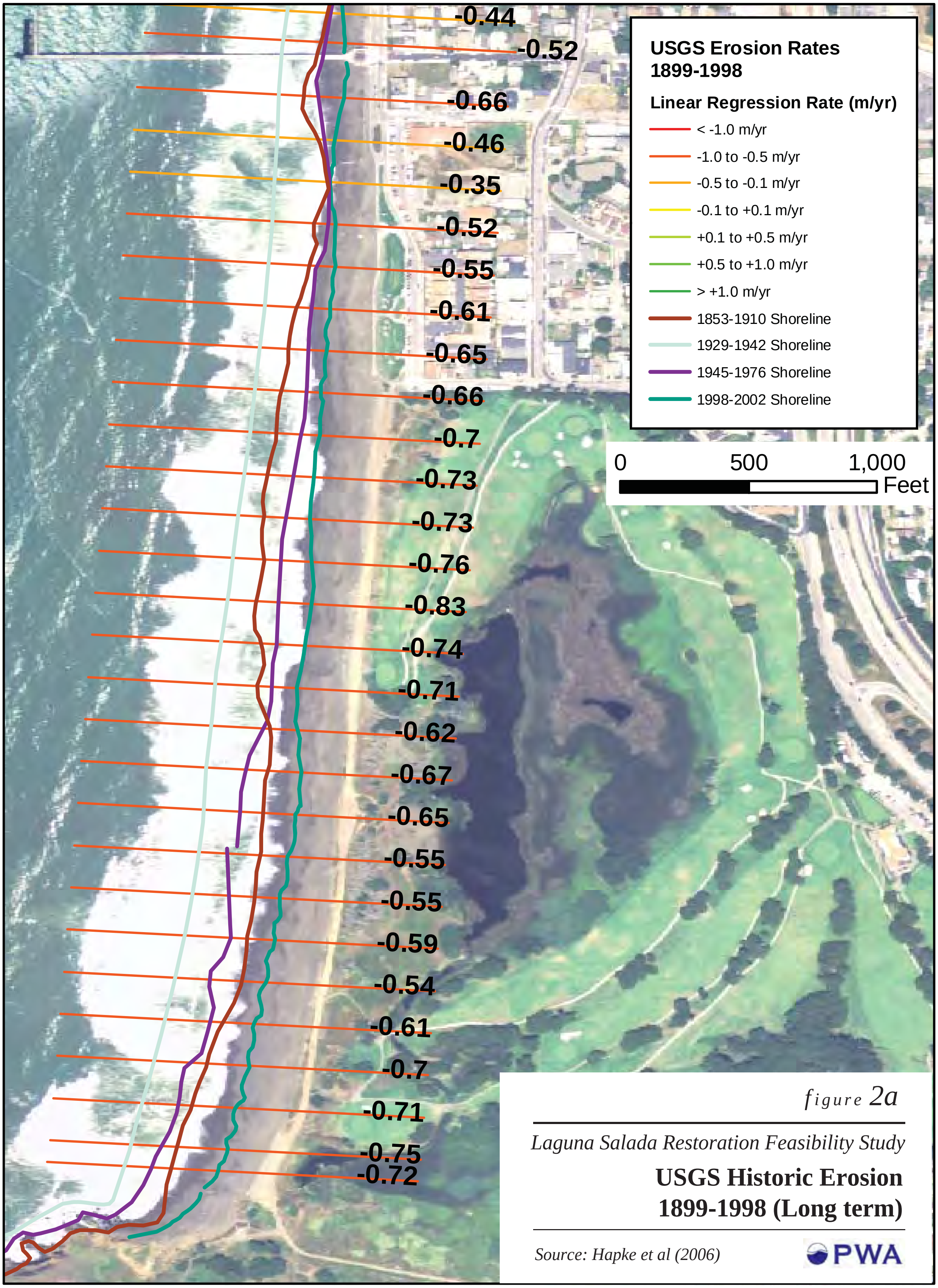

figure 2a

Laguna Salada Restoration Feasibility Study

USGS Historic Erosion 1899-1998 (Long term)

Source: Hapke et al (2006)

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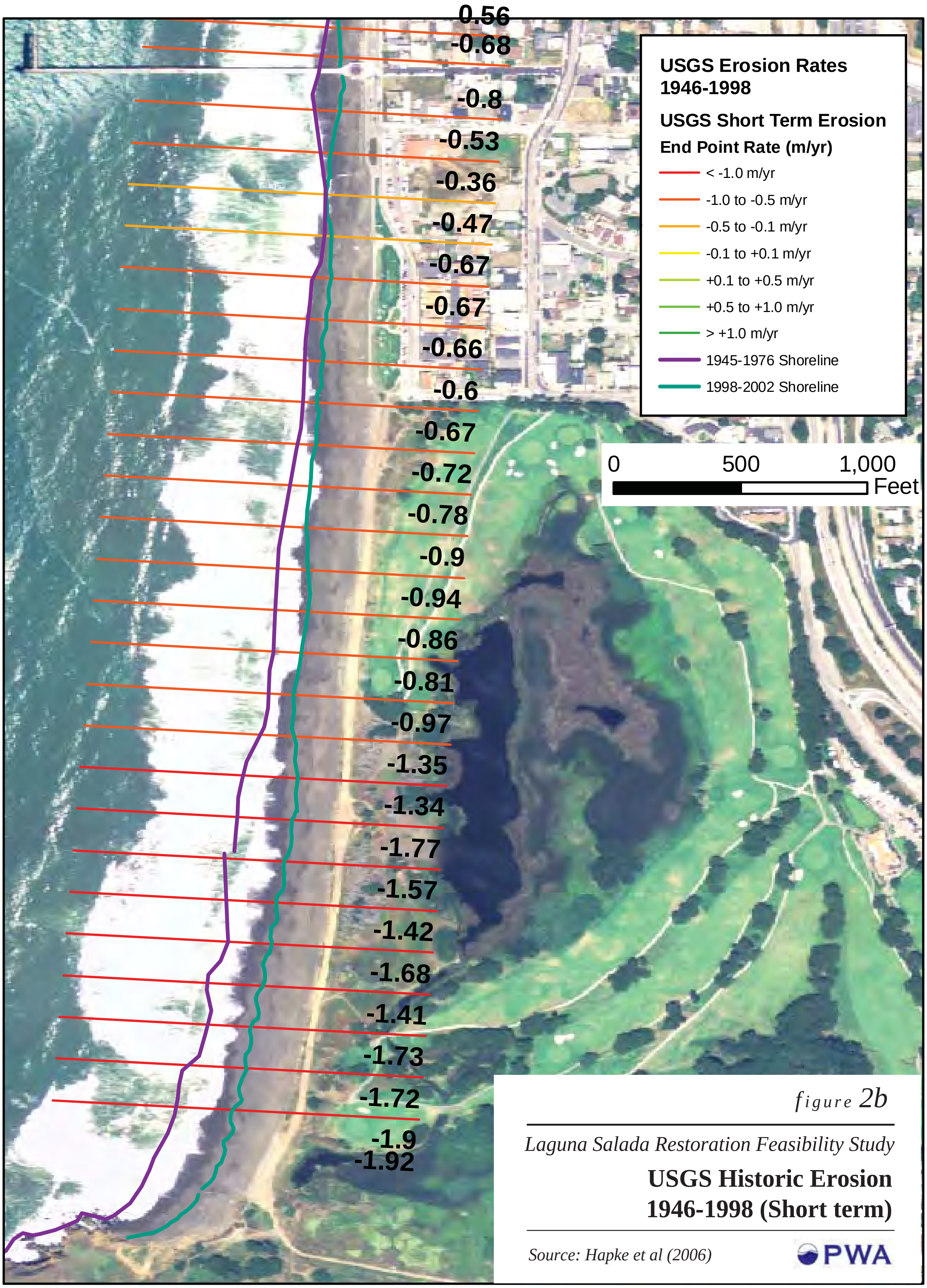

figure 2b

Laguna Salada Restoration Feasibility Study

USGS Historic Erosion 1946-1998 (Short term)

Source: Hapke et al (2006)

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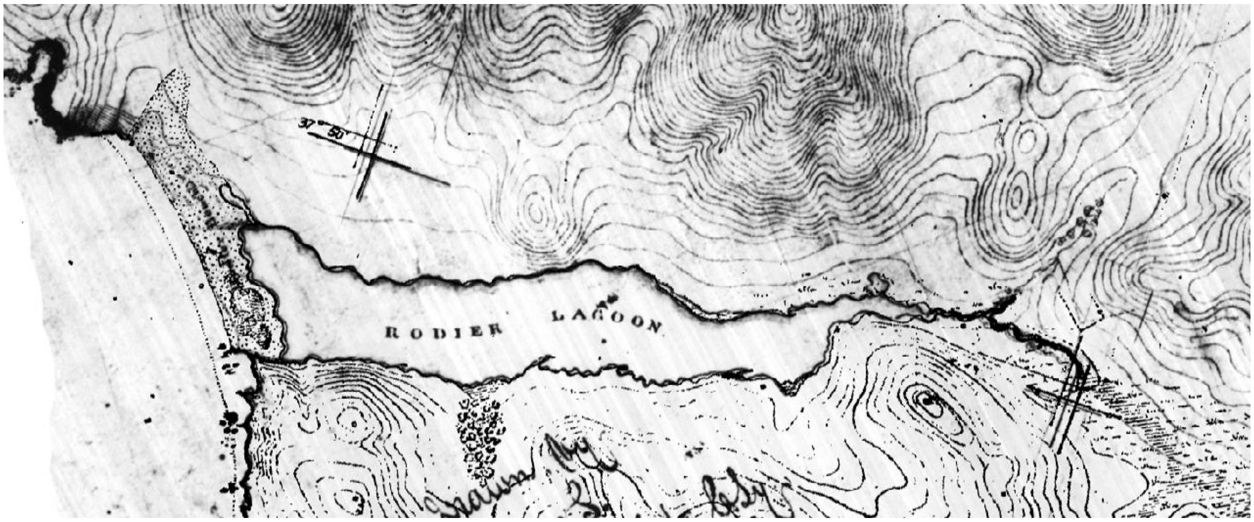
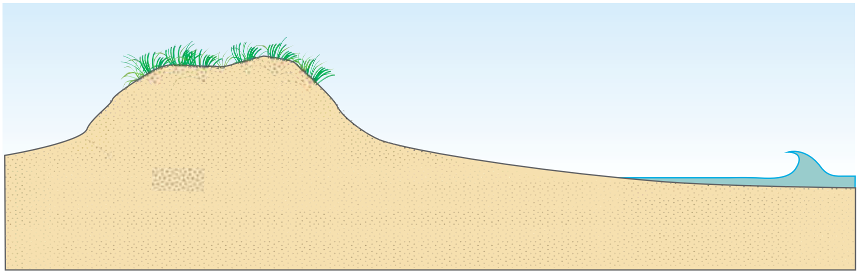


a

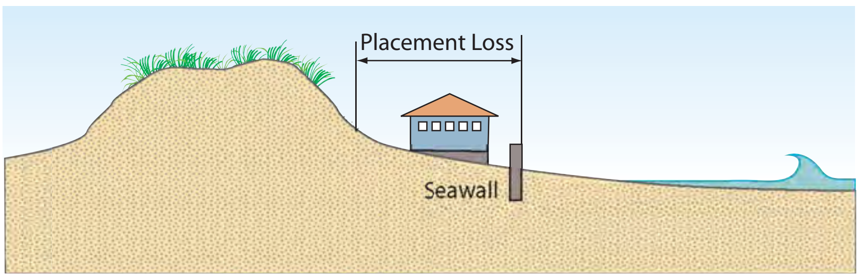
b

Figure 3. (a) Adapted from Striplen *et al*. 2004, Figure 3, USCS mapping of Rodeo Lagoon, Marin Headlands, 1850 and 1853, the first detailed coastal lagoon maps of the region. map shape of the barrier representing a seaward indentation of the backbarrier shoreline at the north end, characteristic of a recurrent outlet channel breach, as in (b) 2007 Rodeo Lagoon outlet morphology. Outlet position in beach planform conforms to headland-shelter wave refraction maximum predicted by Bascom (1954).

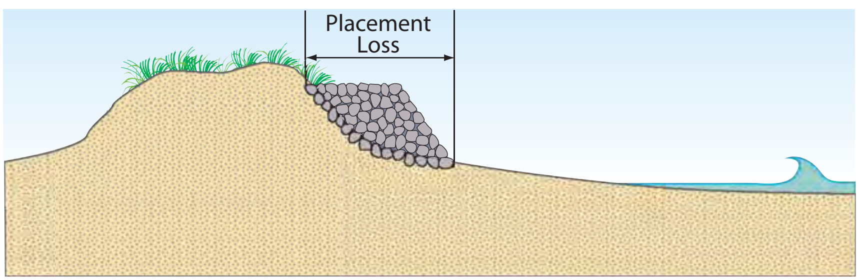
Placement Loss



a) **Existing natural shoreline - no coastal protection**

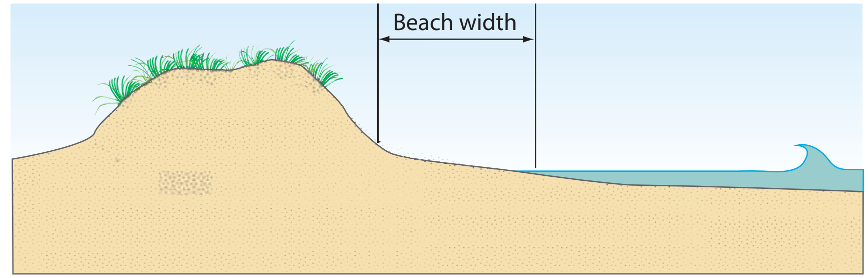


b) **Placement loss of beach due to construction of seawall and house**

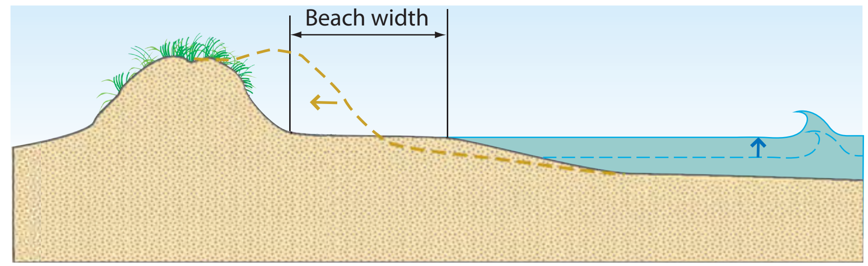


c) **Placement loss of beach due to construction of rip-rap seawall**

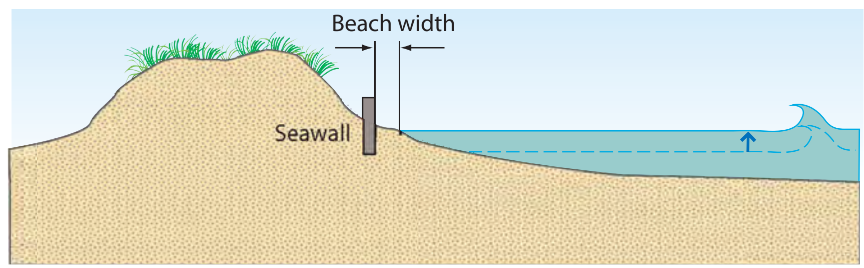
Passive Erosion



a) **Existing natural shoreline - no coastal protection**



b) **Future shoreline with sea level rise and associated dune erosion**
Although the shoreline has moved landward, the beach width remains the same.



c) **Future shoreline with sea level rise - Armored shoreline**
Shoreline after sea level rise where seawall has fixed shoreline position.
Note loss of beach width.

figure 4

Laguna Salada Restoration Feasibility Study

Seawall Effects - Conceptual Profile Response

PWA

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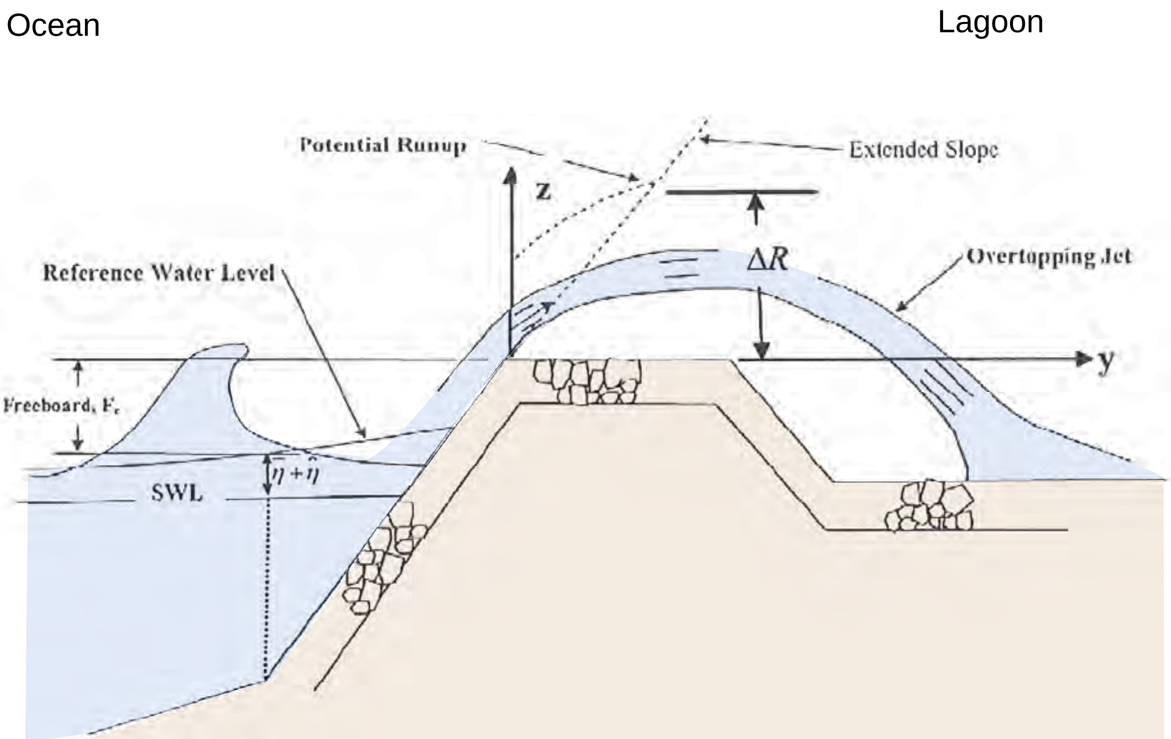

Parameters Available for Mapping BFEs and Flood Hazard Zones

Overtopping Parameters Used in Hazard Zone Mapping

Parameter	Variable	Units
Total potential runup elevation	R	ft
Mean overtopping rate	q	cfs/ft
Landward extent of green water and splash overtopping	$y_{G,Outer}$	ft
Depth of overtopping water at a distance y landward of crest	$h(y)$	ft

Source: FEMA Guidelines & Specifications for Flood Hazard Mapping Partners (January 2005)

figure 5

Laguna Salada Restoration Feasibility Study

Wave Runup and Overtopping Schematic

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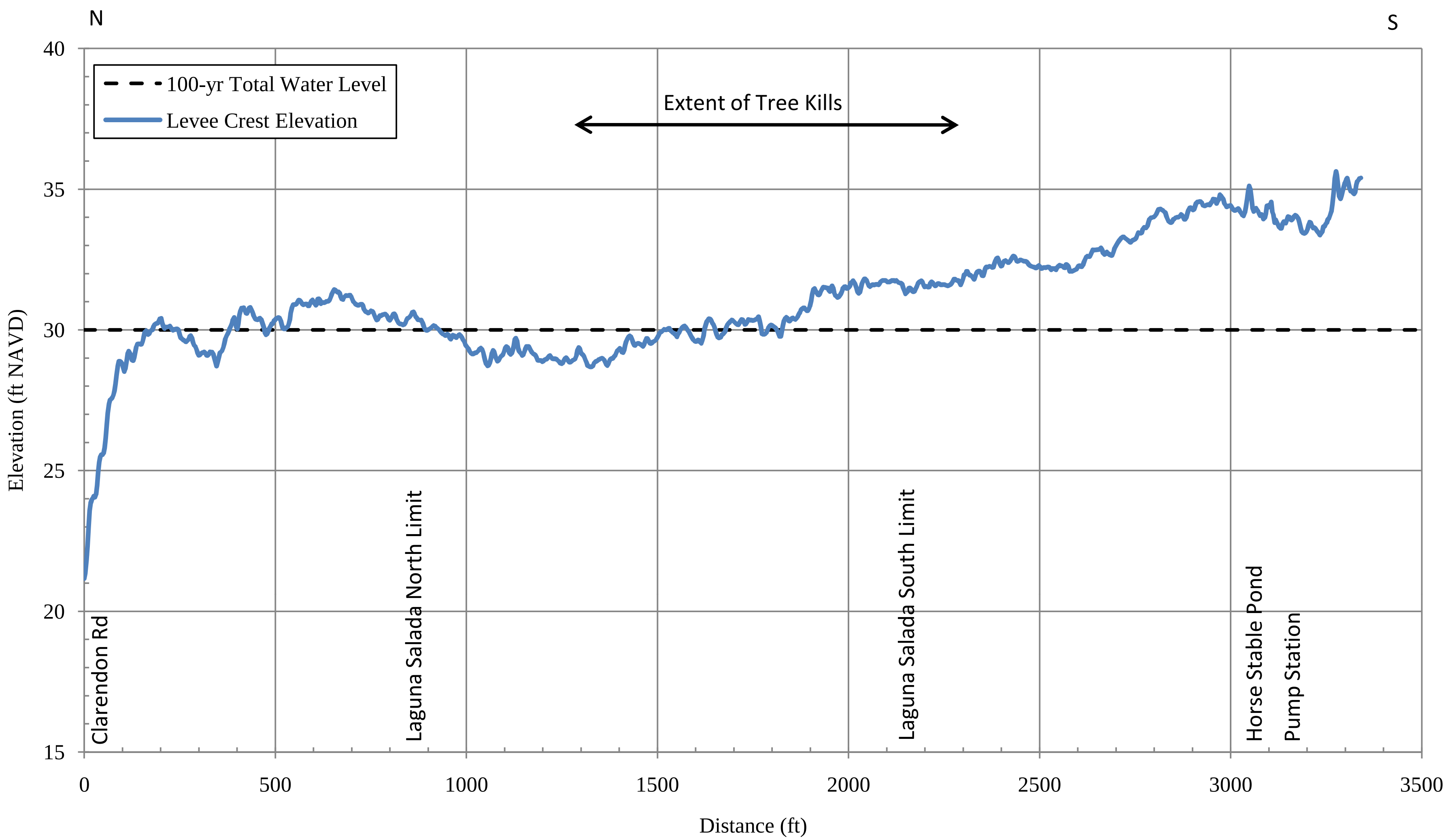

Notes: Laguna Salada North and Laguna Salada South labels indicate approximate northern and southern limits of lagoon, based on 2009 NAIP aerial image. Approximate 100-yr total water level of 29 ft NAVD shown for reference.

Source: NOAA Fall 1997 and Spring 1998 Lidar Topography. Topography shown is average of two surveys, smoothed using 3-point moving average.

figure ***6***

Laguna Salada Ecosystem Rehabilitation Feasibility Study

Sharp Park Levee Elevation Profile

PWA Ref #: 2028

PWA

APPENDIX C. LAGUNA SALADA ECOLOGICAL ASSESSMENT

APPENDIX C.

LAGUNA SALADA ECOLOGICAL ASSESSMENT

1.0. BACKGROUND

In this Appendix, we review previous assessments of endangered species San Francisco garter snake (SFGS) (*Thamnophis sirtalis tetrataenia*) and the California red-legged frog (CRLF) (*Rana draytonii*), habitat quality at Sharp Park (Tetra Tech et al. 2009, PWA 1992, McGinnis 1986) in the broader context of the lagoon's physical processes, historic ecology, and the relevant current scientific literature on amphibian and snake ecology. In addition, the PWA team conducted multiple site visits to Laguna Salada in 2009 and 2010 to collect supplemental data and independent observations on habitat, hydrology, water quality, wildlife, and vegetation.

The scope of our assessment of Laguna Salada's ecological status and trends covers both short-term and long-term conservation and management issues, and does not depend on any assumptions of future land uses or land use conflicts within Sharp Park itself. This re-assessment provides the basis for our short-term (interim) and long-term restoration and management recommendations.

1.1. San Francisco Garter Snake

1.1.1. Review of San Francisco Garter Snake Life History Information.

The San Francisco Garter Snake (SFGS) is both fully protected by the State of California and is federally protected under Endangered Species Act implemented by U.S. Fish and Wildlife Service (USFWS). The range of this snake is extremely limited, with approximately only 6 areas identified in the snake's Recovery Plan (USFWS 1980) as worthy for management and restoration; Sharp Park is one of them. The entire range for SFGS occurs from SF airport out to the coast at Sharp Park and down the coastal range of San Mateo County to the northern boarder of Santa Cruz County. This snake primarily eats the tadpoles of native amphibians (tree frogs, California red-legged frogs). Tree frogs are important prey items of juvenile SFGS and are also consumed by adults. The federally protected California Red-legged Frog, however, is one the most important and heavily used prey items of adult SFGS. Therefore, recovery and enhancement of multiple and robust CRLF populations is one of the essential habitat enhancement requirements for the SFGS. The other essential habitat requirement for the SFGS is suitable non-aquatic or upland habitat within nearby locations of aquatic areas. A description of upland and basking habitat is presented below.

Habitat requirements of the SFGS vary throughout the year, and include aquatic foraging habitat, basking habitat (both aquatic and terrestrial), and upland areas close to aquatic sites. “Upland” habitats in the context of SFGS life-history include all well-drained terrestrial vegetation types adjacent to the primary freshwater perennial and seasonal wetland (marsh, riparian) habitats of SFGS. Upland SFGS habitats include seasonally dry coastal grassland and scrub habitats of hillslopes, as well as mesic riparian habitats in valley lowlands that are free from flooding and saturation year-round. Upland areas are used by SFGS as refuge when primary marsh and shaded riparian wetland habitats ares too cold for movement; they are therefore important habitat for the snake especially during the winter and with cold weather in the spring and fall. Upland areas contain small underground mammal burrows and soil crevices with dry warm shelter for the snake: this is typically located in adjacent coastal grassland and shrub community. SFGS also require basking habitat in both aquatic and upland areas. Suitable SFGS basking habitat contain open sunlit areas, with immediate escape cover from predatory birds and mammals. Basking habitat can be in the form of small break in aquatic vegetation (of marshes, lagoons, ponds and creeks), matted rush canopies, debris mats, woody debris, or as dense floating algae mats (USFWS 1985) or pondweed patches (Reis personal observation) that reach the surface but have deeper water for escape cover below, and gaps in terrestrial grassland or coastal scrub vegetation. These snakes use cover of dense vegetation (tules, cattails, grasses) to travel under, and are therefore often hard to find.

SFGS adults forage primarily on native CRLF frogs and tadpoles but will also eat Paciftc treefrog tadpoles (*Pseudacris regilla*), immature California newts (*Taricha torosa*), recently metamorohosed western toads (*Bufo boreas*), threespined stickleback (*Gasterosteus aculeatus*) and non-native mosquito fish (*Gambusia affinis*) (USFWS 1985). Mating occurs either in the spring or fall, but is especially concentrated in the first few warm days of March but has also been observed in late October and early November. Mating aggregations has been observed on open grassy sunny slopes on warm mornings (USFWS 1985).

1.1.2. SFGS distribution and potential habitat at Laguna Salada and vicinity.

SFGS were known to historically occur at Laguna Salada, as documented in 1951 by W.L Fox. The populations were though to have declined by 1978 when only 37 snakes were observed in the aquatic areas adjacent to Horses Stable Pond and 46 were observed at Mori Point (Barry 1978). In 1986, McGinnis did not find any SFGS after 2,000 hours of trapping efforts.SFGS were found by CDFG trapping efforts in 2004 in the wetlands around Laguna Salada (SFRPD 2006).

The existing population of SFGS at Sharp Park is thought to be small and not very robust, which is concerning. SFGS were were detected at Horse Stable Pond as recently as 2008, but have not been detected during the most recent (2009) surveys at this location (Swaim 2009). Detection probability of SFGS in variable widths and densities of cattail/tule marsh vegetation have not been assessed. SFGS are known to occur in the North Pond, on the hill-slope a few hundred feet to the east of the Horse Stable Pond by GGNRA Staff Biologist and at the nearby Mori Point Ponds (Swaim 2008). SFGS are also known to occupy the SFPUC watershed land to he east at the San Andreas Reservoir below Sweeney Ridge (Swaim 2008). The status of SFGS at Arrowhead Lake, Sanchez Creek, or the lagoon or should not be assumed as absent as these areas have not been thoroughly assessed during the last 5 years. The existing potential SFGS habitats at Sharp Park's Arrowhead Lake, Sanchez Creek, the Lagoon and Horses Stable Pond need well timed and focused SFGS surveys that include sex ratios so that the population and potential for future viablity at Sharp Park can be better understood.

Historically SFGS must have existed at Laguna Salada before it was developed as a golf course because there were no other potential significant freshwater or fresh-brackish pond and marsh habitats represented within the Laguna Salada watershed, as shown in the detailed 1869 U.S. Coast Survey map of the San Francisco Peninsula (Appendix A). SFGS were document to occur at Laguna Salada in 1951 by W.L Fox. However, SFGS habitat conditions of the wetland and adjacent uplands are currently far less favorable (and largely displaced) than in the past. The SFGS population at Sharp Park has likely been affected by the following:

a) loss of foraging sources due to extreme salinity pulses in topographically depressed drained Laguna Salada marshes (interaction between artificial marsh drainage on marsh elevations, and overwash) causing brief intensive mortality events of frogs and tadpoles by wave overwash into the depressed remnant lagoon areas and into Horse Stable Pond;
b) possible predation by fish in the lagoon (Swaim 2008);
c) golf course use and maintenance practices (past and ongoing mowing, past and ongoing fertilizer application, past pesticide application, past and ongoing vehicle operation,past and ongoing lagoon pumping,drainage);
d) possible collecting and competition with other garter snake species found present at the site (McGinnis 1976);
e) decline in habitat quality and structure, including water quality, upland cover, mammal burrow refuges, basking habitat, and prey base;
f) Highway and urban developments act as a barrier for snake movement into and out of the park.

Deficient SFGS prey base and deficient suitable upland refuge habitat (where the golf greens now occur) during the winter are likely **limiting factors** in ensuring the persistence of the SFGS at Sharp Park. Laguna Salada, Horse Stable Pond, Arrowhead Lake and other water bodies at Sharp Park need to be net sampled for the presence of predatory fish, including mosquito fish that prey on treefrog tadpoles, so that the suitability of these water bodies for CRLF/SFGS can be better assessed and appropriate actions, such as the eliminating fish can be taken if needed.

With no action, the future of SFGS at Sharp Park is, at best, uncertain. The restoration and or creation of the following mix of SFGS habitat types is needs to occur in balance: the absence of one of these habitat sites at the Park could limit the viability of SFGS at Sharp Park. These different snake habitats include:

a) viable breeding ponds/lagoon for native frogs (food source for SFGS);
b) suitable aquatic and terrestrial basking sites;
c) upland non-flooded refuge habitat for non-active snakes during cold periods in fall, winter and spring;
d) vegetated movement corridors and linkages to Mori Point and into and out of the park.

1.2. California Red-legged Frog

1.2.1. CRLF Life History Information.

CRLF are known to occupy and reproduce in marshy habitats, springs, ponds (both natural and artificial), backwater pools of rivers and streams (Stebbins 1985, Reis 1999a, Reis 1999b, Reis 2001, Reis 2002). CRLF are also known to occur and breed in tidally influenced, seasonally nontidal coastal backbarrier lagoon marshes formed by beach (“sandbar”) impoundment of fresh or fresh-brackish (oligohaline) water during the late spring and summer (Smith and Reis 1997, Reis 1999b).

Habitat characterizations are different for each CRLF life history stage (egg, tadpole, juvenile, and adult) (Reis 1999b). CRLF eggs are laid near the surface of the water. Adult CRLF need aquatic areas with emergent vegetation to attach their egg-masses. In a coastal marsh, adult CRLF select warm and shallow water sites for laying eggs, while tadpoles utilize waters of shallow to medium depth (Reis 1999b). CRLF are also known to attaché eggs masses to cattails and tules in deep water (Reis 2001 and 2002). For successful reproduction to occur, surface water must last long enough for tadpoles to complete metamorphosis, at a minimum to late June (Reis 1999b) but depending on the locality, may require surface water through October (Reis 2002).. Tadpoles use both vegetation and mud for escape cover from predators (Jennings and Hayes 1988). It is speculated that CRLF tadpoles are mainly algae grazers (Reis personal observation).

Juvenile and young-of-the-year (y-o-y) CRLF mostly occur in sites with shallow water and limited shoreline or emergent vegetation (Jennings and Hayes 1988). It may also be important for juvenile CRLF and y-o-y to have small (1-meter) openings (gaps) in the vegetation or clearings in the dense riparian cover to warm themselves in the sun and forage, but still have vegetation close for escape from predators (Jennings and Hayes 1988). Population studies of CRLF conducted by Smith (pers. com. 1999) along Waddell Creek and Waddell Creek lagoon, where the reproductive habitat is limited to a small ephemeral marsh and permanent pond near the mouth of the lagoon, have indicated that juvenile frogs remain farther upstream in the creek environment during the reproduction season. Data from other locations where the reproductive habitat is more extensive have shown that juvenile frogs will use both non-reproductive habitat and reproductive habitat throughout the year (Reis 1999a). Juvenile CRLF will eat both aquatic and terrestrial insects.

Radio-tracking studies of CRLF in Waddell Creek indicate that during the reproductive season, adult frogs remain close to reproductive ponds (Smith, pers. com. 1999). During the non-reproductive season, adults are likely to be found in deep (greater than 0.5 m), as opposed to shallow water reproductive areas (Reis 1999b). Deep water areas provide adult CRLF with escape cover from mammalian and avian predators. If the surface water becomes scarce or either air or water temperatures are too warm, the CRLF will seek cool, moist locations in non-aquatic habitats. Adult CRLF die from heat exposure above 95 F (Jennings, Hayes and Holland 1993).

The upland (non-aquatic) and riparian areas adjacent to occupied aquatic areas are essential to juvenile and adult frogs for maintaining prey bases and as foraging area. Adult CRLF will eat mice, aquatic and terrestrial insects, and treefrog tadpoles and adults. Adult CRLF using the upland areas will spend over 22 consecutive days using upland areas to rest and feed in the vegetation, even when surface water is available (G. Rathbun pers. com 2000, USFWS 2001). The maximum amount of time an adult CRLF has been observed inhabiting an upland area without taking refuge in water is 77 days (J. Bulger et al. pers. com 2000).

A radio-tracking study of adult CRLF, conducted in at coastal year round stock ponds in Santa Cruz County, by the National Biological Service (now USGS), found that most adults stay resident and within a few feet of surface water areas during the spring and summer months (Bulger and Seymour 1998, Bulger pers. com. 1997). However, a subset of the CRLF adults was found using upland areas within 60 m (200 ft) of the water. Examples of micro-habitats in upland areas that contain cool and moist climates suitable for adult and juvenile CRLF include small mammal burrows, moist leaf litter, and moist woody debris (USFWS 2000).

During this same radio-tracking study, a few adult CRLF move long distances 3.6 km (2.2 miles) during rainy weather for migrations between ponds (Bulger and Seymour 1998, Bulger pers. com. 1997). During these migrations, CRLF adults moved in straight-lines from non-breeding to breeding habitats and left creek and riparian corridors to crossed upland habitats, including agricultural fields, redwood forest and chaparral (Bulger and Seymour 1998, Bulger pers. com. 1997). Potential barriers to adult movement and dispersal include busy road, roads and highways without culvers or underpasses, heavily urbanized areas, water bodies over 20 ha (50 acres) and saline habitats over 9 ppt. See Table 1 for summary of limiting factors by CRLF life history stage.

Table 1. Potential for California red-legged frogs (*Rana draytonii*) to occur in aquatic areas depending on life-stage.

Life History Stage	Limiting Factor
Eggs	
Water Temp °C	Above freezing and under 24.0° C. *Ideal temperatures are between 14 and 20° C.*
Water Salinity (ppt)	Less than 4.0 ppt (Jennings and Hayes1990) 3.8 ppt (Reis 1999) *when eggs are laid and for 2 to 6 weeks after* until the embryos develops in to free swimming larva/tadpoles. *Ideal water salinities are less than 1 ppt*
Sand Bar (lagoon beach outlet) Closed	Not applicable-sand bar can be open or closed as eggs are laid in backwater or overflow areas when fresh water input is great enough to create a freshwater barrier to tidal action.
Water flow and longevity	Still water with no high water flows which would scour out an egg mass **after** eggs are laid. CRLF eggs in central and northern CA are laid between the end November (USFWS 2002) to mid-May (Reis personal observations).
Water Depth (m)	Shallow water (less than 0.5) is not a liming factor but it is a indicator of potential egg mass presence (Reis 1999). Water depth near eggs should be long enough to complete development of eggs and connected to deeper water that will allow development of tadpoles.
Other	Emergent vegetation (dead or alive) is needed for egg-mass attachment
Tadpoles	
Water Temp °C	Above freezing and below 25.0 °C (between 7.0 and 24.9 Reis 1999) ***until tadpoles have completed development***. *Ideal growing water temperatures are 14-18.* °C
Water Salinity (ppt)	Less than 5 ppt (McGinnis 1986) Less than 7.5 ppt (Jennings and Hayes1990) or less than 6.5 ppt (Reis 1999) ***until tadpoles have completed development***. Unless areas are protected from tidal action, the sand bar needs to remain closed until tadpoles have completed development. *Ideal water salinities are less than 2 ppt*
Water longevity	Surface water though July preferablely through late September (development rates vary from site to site) *Ideal water longevity would be year round, but only if predatory fish and bullfrogs are absent*
Water Depth (m)	Not applicable as long as there surface water and structural cover from predators (shallow water under 0.5 meter is a better predictor)
Other	Presence of Cattails and Potagometon sp. are good predictors for CRLF tadpoles.
Resident Adults	
Water Temp °C	Less than 29.0 °C

Life History Stage	Limiting Factor
	Ideal temperatures are between 14 and 20 ºC .
Water Salinity (ppt)	Less than 9 ppt (McGinnis 1986 and Jennings and Hayes1990) ***all year***. *Ideal water salinities would be fresh, less than 2 ppt*
Water Longevity	Not applicable as adults can live up to 77 days away from water if there is moist ground or leaf litter *Ideal water longevity would be year round, but only if predatory fish and bullfrogs are absent*
Water Depth (m)	Residential adults need deep water (0.64 m or more) to use as refuge from mammalian, and avian predators
Other	
Transient Adults	
Water Temp ºC	Less than 29.0 ºC, Ideal temperatures are between 14 & 20 . ºC
Water Salinity (ppt)	Less than 9.0 ppt (Jennings and Hayes1990) *while moving* (not needed all year) Ideal water salinities would be fresh, less than 2 ppt
Water Longevity and Depth	Water depth does not limit, availability of water is needed for hydration *while* moving

In summary, the discrete age classes (eggs, tadpoles, juveniles and adults) use different microhabitats within the same general area. Further, juveniles and adults may disperse to entirely different habitat types and depend in part on upland areas for prey sources and foraging if the aquatic environment is overcrowded or limited. Dispersal patterns and habitat use of juvenile and adult CRLF varies, and is likely dependent on year-to-year variations in climate and habitat suitability, and on the varying requirements of each life stage.

1.2.2. CRLF distribution and potential habitat within Laguna Salada and vicinity.
Swaim 2008 found CRLF egg masses in Laguna Salada, at Horse Stable Pond, and in the cannel connecting these two remnants of the historic lagoon. CRLF eggs were also found in Lake Arrowhead, east of HWY1 (Swaim 2008). During the PWA Team site vsit in May of 2010, large CRLF tadpoles (TL approximately 7.5 cm, ten adult CRLF and two subadult CRLF were readily observed in a small 4 x 4 meter segment of Sanchez Creek at the base of the walking path to the park on the ocean side of Fairway Drive. CRLF are also know to occur at the nearby Mori Point ponds (Tetra Techet al,. 2009). Laguna Salada was the only potential CRLF breeding habitat in the watershed prior to historic agricultural and urban modification of the landscape, as indicated in detailed U.S. Coast Survey 1869 topographic map of the San Francisco Peninsula (Appendix A). Potentially suitable breeding habitat (cattail, tule, bulrush marsh, pondweed beds, and adjacent open lagoon water) was evident at Laguna Salada during agricultural land use periods prior to golf development, as late as the 1920s (Appendix A).

2.0 PRINCIPAL CONSTRAINTS ON ECOLOGICAL FUNCTIONS AND SUSTAINABILITY OF LAGUNA SALADA WETLAND HABITATS.

The principal constraints on ecological functions at the Laguna Salada wetland complex can be classified in terms of ongoing golf operations and maintenance, hydrologic management of the lagoon and its associated infrastructure (levee, pumps), and legacy impacts of past natural and artificial events (coastal storms, lagoon and floodplain filling, past conversion of natural vegetation to agriculture and later turfgrass). These primary classes of environmental modifications of the lagoon wetland complex are associated with complex secondary (indirect) significant impacts to ecological functions, and long-term sustainability of the ecosystem.

We distinguish current and future environmental constraints associated with current land uses at Laguna Salada from the legacies of past land use impacts that reshaped Laguna Salada's physical structure, vegetation, and wildlife. These legacies pose significant residual, ongoing influence on modern habitats and wildlife populations. Conversion of natural floodplain riparian wetlands and uplands to crop agriculture, floodplain drainage, floodplain and lagoon filling (conversion to uplands) in the late 19th and early 20th century preceded historic filling of the floodplain, artificial drainage regime (pump and levee system), and artificial stabilization of the barrier beach, are pre-golf environmental legacies that have been retained, expanded, or intensified by modern golf land uses. Our analysis of habitat and ecosystem-level constraints within Laguna Salada focuses on two main modern influences: golf course maintenance and operation activities, and the engineered hydrologic management that permanently drains Laguna Salada's floodplain and maintains artificially low and stable year-round lagoon levels.

2.1 Ongoing golf course maintenance and operation.

Ongoing golf course maintenance includes mowing and fertilizing golf greens adjacent to Laguna Salada wetlands, and these maintenance activities also appear to encroach directly into the wetlands themselves. Fertilizer contamination of amphibian habitat waters (particularly nitrogen fertilizers) are known to adversely affect survival and development of frog larvae (tadpoles), including California red-legged frogs (CRLF) and tree frogs, even at concentrations lower than standards for drinking water quality. Laguna Salada has limited water quality sampling for nitrogenous nutrients (nitrate, nitrite, ammonium), but elevated levels within the effects range for frog tadpoles has been detected. Mowing of the golf course extends into the marsh itself, eliminating cover, potential upland habitat transition, potential woody debris, and reducing functional marsh habitat area and edge. These constraints on the abundance, distribution, and quality of wetlands and their terrestrial habitats at Laguna Salada are due to discretionary active, chronic, or recurrent maintenance. They are analyzed below.

No data are available on cumulative pesticide loads in Laguna Salada wetlands from past or recent golf course operations, runoff from adjacent residential areas, or agricultural legacy pesticides. Pesticides (including herbicides, insecticides, fungicides) are related to regional amphibian declines (Davidson *et al*. 2004).

2.2. Nitrogen and phosphorus fertilizers and amphibian ecotoxicity of nitrate, nitrite, and ammonia.

Nitrate discharges from anthropogenic (human-made) sources may result in a serious ecological risk for amphibians, including frogs (Camargo et al. 2005, Hecnar 1995). Nitrogen is generally the limiting nutrient regulating growth in turfgrasses (Goss 1972). Turfgrass (sports turf) maintenance requires regular and relatively heavy applications of commercial nitrogen fertilizers (low rates = 1-2 lbs/1000 square feet; up to 7 lbs/1000 square feet). Nitrates enter wetlands in runoff and groundwater discharges from agriculture and turfgrass fertilizer applications.

CRLF abundance is negatively associated with elevated aqueous concentrations of phosphate , nitrate, and ammonium derived from fertilizers (D'Amore *et al*. 2010). Nitrates, and related nitrites and ammonium (produced by microbial reduction in hypoxic wetland soils), have significant acute and chronic ecotoxic effects on California California red-legged frog tadpoles and treefrog tadpoles, as well as larval stages of many other amphibian species (Marco and Quilchano 1999, Nebeker and Schuytema 2000, Greulich and Pflugmacher 2003). Acute sublethal effects of nitrate and nitrite in frogs include reduced feeding and swimming activity, disequilibrium and paralysis, abnormalities and edemas (California red-legged frogs and treefrogs; Marco et al. 1999) and reduced response to predator cues in other ranid frogs (Burgett et al. 2007). Significant lethal effects of nitrite in California red-legged frog and treefrog tadpoles (high mortality response) were evident even at the recommended limits of nitrite concentration for drinking water (1 mg NO2-/L) established by the U.S. Environmental Protection Agency. Recommended limits of nitrite for warm-water fishes (5 mg NO2-/L) were associated with significant frog mortality (Marco et al. 1999). Current drinking water quality standards for nitrate (10 mg/L) are not protective of some amphibian species (Hecnar 1995).

Swaim (2009) observed California red-legged frog egg masses in both Laguna Salada and Horse Stable pond, but observed tadpoles only in Horse Stable Pond (Swaim 2009, p. 50), and observed fewer egg masses in Laguna Salada despite its greater area (Swaim 2009, p. 18). Swaim (2009) did not account for the anomalous lack of transition between tadpoles and adults at Laguna Salada. Despite the very different potential nitrate source potential of Laguna Salada (bordering fertilized golf greens) and Horse Stable Pond (discharge from Sanchez Creek through dense riparian and freshwater marsh vegetation), recent habitat assessments did not assess whether fertilizer runoff from golf greens may be a limiting factor for California red-legged frog adults, eggs, or tadpoles (Swaim 2009, p. 24). Eliminating nitrogen fertilizer impacts on habitat quality from habitat assessments is not indicated by current federal conservation biology guidance for the California red-legged frog: nitrogen fertilizer contaminants in runoff are recognized by the U.S. Fish and Wildlife Service as potential factors influencing recovery of the California red-legged frog (USFWS 2002, pp. 28-29).

Past water quality monitoring data from Laguna Salada (PWA 1992, Curtis & Thompson Laboratories 2009) indicate that nitrate, nitrite, and ammonia concentrations at some times and locations occur in the reported effects range for sublethal or lethal effects on California red-legged frogs and treefrogs: nitrite concentrations of 2.6-2.7 mg/L and ammonia concentrations between 4.0-5.0 mg/L were detected at some locations in February 2009 (Curtis and Thompson Laboratories 2009). Nitrate concentrations of up to 1.4 mg/L were reported in 1992, and the pattern of nitrate concentration and sampling location in proximity to golf greens or riparian and marsh buffers (1.4 mg/L northwest LS, 0.23 mg/L southeast LS, 0.14 mg/L Horse Stable Pond) consistent with fertilizer contamination of adjacent Laguna Salada. No sampling strategies to quantify seasonal or spatial variability in aquaeous nitrate, nitrite, or ammonia concentrations at Laguna Salada have been implemented.

The extensive eastern border of Laguna Salada marsh and golf greens contains no buffer areas of unmown perennial grassland, sedge meadow, or continuous strips of riparian scrub to act as buffers to nitrogen runoff or nutrient sinks. The mowing of marsh vegetation to the same level as adjacent turfgrass (see 3.4.1.2.) further facilitates surface and shallow subsurface transport of soluble nitrogen fertilizers into Laguna Salada marsh sediments (during spring/summer drawdown) or open waters (winter high water stands).

A potential secondary effect of eutrophication (excessive nutrient loading) due to fertilizer runoff and leachate (percolated groundwater discharge) is facilitation of toxic cyanobacterial blooms. Extensive use of high phosphorus in fertilizers, and phosphorous from various types of manure are know to cause cyanobacteria blooms (Kuffner and Paul 2001, Lehtimaki et al 1997). In fact, fertilizers for golf greens are know to create overloads of phosphorus which can result in both terrestrial and aquatic cyanobacteria blooms (Colbaugh 2002). Although some species of frog tadpoles graze on cyanobacteria, substantial and recurrent blooms of toxic forms of cyanobacteria taxa such as *Microcystis*, which has formed ecotoxic blooms in fresh to brackish lakes, reservoirs, and estuaries with high nutrient loads in California (Miller *et al*. 2010, Moisander *et al*. 2009). Microcystis and other cyanobacterial toxins bioaccumulate are known to cause embryo malformations and significantly alter the development of amphibian embryos (Dvorakova et al. 2002). Visual evidence of cyanobacterial blooms include high turbidity and green, blue-green, or yellow hues during warm weather and shallow water conditions. No monitoring of cyanobacterial species composition or abundance is currently available for Laguna Salada, but environmental conditions favoring blooms (shallow, warm, slightly saline water, nutrient loading sources) and visual appearance of the lagoon in summer indicate the potential for indirect cyanobacterialmediated ecotoxic impacts of eutrophication.

The recovery plan for the San Francisco Garter Snake recommended monitoring of fertilizer use at Sharp Park to ensure no adverse impacts (USFWS 1985 p. 43, recovery task 253). Tetra Tech (2009, pp. 2,) identified "eutrophication" (excessive nutrient loading) as a problem for Laguna Salada only in the context of biomass production of emergent marsh vegetation, and they attributed it only to the secondary source of nutrient release from "decaying vegetation" rather than the primary source of high-nitrogen fertilizers routinely applied to sports turf (golf greens). Neither Tetra Tech et al. (2009) nor Swaim (2009) addressed the potential adverse impact of fertilizers on San Francisco Garter Snakes or need to assess it.

Our review of limited local water quality data at Laguna Salada, and the relevant scientific literature on nitrogen fertilizer contaminant impacts on amphibians in general, and California red-legged frogs in particular, supports a conclusion that chronic or pulsed aquaeous nitrate, nitrite, and ammonia loads from fertilizer applications on adjacent golf greens may be limiting factors for California red-legged frog larval survivorship and adult recruitment, at least near golf green nutrient sources. The potential reduction in abundance of adult frogs, eggs, and tadpoles in the lagoon, may be limiting prey availability and trophic support of the San Francisco Garter Snake population.

2.3. Marsh and terrestrial habitat mowing

The mowing of the golf greens extensively encroaches into the core habitats of the California red-legged frog and San Francisco Garter Snake. Routine summer turf mowing in 2010 reached 3 to over 5 meters into fresh-brackish bulrush-dominated marsh along the northern and eastern edges of Laguna Salada, reducing marsh vegetation to stubble and turf with essentially no canopy cover (Figures 7-8 of this appendix). Marsh mowing occurs in summer when pumping artificially lowers the lagoon level enough to allow mowing of the marsh edge (Figures 7-8).

The marsh edge mowing was described ambiguously in the recent habitat assessments of Laguna Salada: "Regular golf course maintenance appears to be controlling the growth of wetland habitat in some areas adjacent to the lagoon, as remnants of some hydrophytic plant communities were observed in lower elevation mowed areas (Tetra Tech et al 2009, p. 25, citing Tetra Tech 2008), and also "lack of secured upland habitat" (Swaim 2009, p. 18), "vegetation structure" as a "primary limiting factor" , "lack of suitable upland habitat", (Tetra Tech et al. 2009). These oblique descriptions applied (at least in part) to turfgrass mowing encroaching up to approximately 5 meters into bulrush marsh during lagoon drawdowns appear to be euphemistic understatements of the severity of the impact on wetland habitat amount, distribution, quality, and upland habitat buffering.

The edges of Laguna Salada wetlands were identified as the most likely travel routes of the San Francisco Garter Snake (Tetra Tech et al. 2009 p. 30) and were sites of California red-legged frog egg mass observations (Swaim 2009). The San Francisco Garter snake depends on the availability of “secure basking sites”, “upland cover”, and is threatened by “wetland loss”, “removal of riparian vegetation” (USFWS 1986), and relies on adequate amounts and distribution of “dense cover” of vegetation within and near its primary aquatic and wetland foraging habitats (Jennings 2000).

The direct reduction of core marsh habitats, and the complete elimination of any potential marsh-upland buffers along the landward edge of Laguna Salada, are likely to be significant limiting factors for viable populations of both the California red-legged frog, and particularly the San Francisco Garter Snake. Converting marsh into golf greens by chronic mowing eliminates essential habitat structure in the high marsh that would develop several habitat types on which the San Francisco Garter Snake depends: primary foraging and escape marsh habitat in preferred “dense cover” of bulrush, cattail and rush marsh (USFWS 1985, Jennings 2000); basking habitat (on matted bulrush and rush leaf litter canopies and algal mats; USFWS 1985), and movement corridors (Tetra Tech et al. 2009, Swaim 2009).

Mowing of the transition zone (partially drained soils) above the marsh also eliminates potential grassland, sedge-rush meadow, and riparian scrub habitats that are required as buffer zones and upland transition zones that are minimally required for viable populations of pond-breeding amphibians (minimum 30 m wide; Harper et al. 2008; Semlitsch & Bodie 2003). Mowing across potential buffer zones and into core habitats and dispersal/travel corridor space exposes San Francisco Garter Snakes and California red-legged frogs to elevated mortality risks due to predation, mechanical injury, loss of core marsh foraging habitat and prey base, loss of seasonal foraging habitat and prey base, loss of flood escape habitat (snake), and facilitation of nitrogen fertilizer contamination of frog winter-spring breeding habitat.

2.4. Stabilization of low lagoon levels and depth fluctuation by pump operation.
The single most influential environmental factor affecting wetland habitat extent, quality, sustainability (stability), structure, and vegetation composition under existing conditions is the artificially stabilized, low-level fluctuation of the lagoon water surface elevation near intertidal (still water) elevation ranges. The lagoon is maintained in a condition of permanent drawdown, eliminating the seasonal high stands of natural coastal lagoons above tidal elevations due to impoundment of freshwater runoff and streamflow. The pumps are set to maintain water surface elevations below 7.5 ft NGVD, and eliminate seasonal hydrologic peaks (high lagoon stands) that would naturally inundate the lagoon floodplain, maintain wide seasonal wetlands and riparian transition zones, submerge upper marsh vegetation zones, and limit encroachment of low marsh vegetation by water depth.

Natural lagoon high stand elevations in seasonal or nontidal lagoons in the region range between approximately +11 to +13 ft NAVD. These lagoon water surface elevations are maintained above tidal elevation ranges, and result in seepage outflows through the barrier beach. The high seasonal fluctuation of natural nontidal/seasonal lagoon levels, in contrast, results in gradual spring-summer drawdown from initial high spring lagoon levels (deep lagoon conditions) and maintains wide, variable, dynamics wetland ecotones and upland edges.

The direct effects of maintaining artificially low permanent lagoon levels with minimal seasonal fluctuation include:

- **Reduced flooded area of open water/potential submerged aquatic vegetation habitat.** Potential sago pondweed tadpole habitat of the California red-legged frog (Reis 1999); foraging habitat of Western Pond Turtle;
- **Reduced flooded area and perimeter (edge) of fringing emergent cattail-tule-bulrush marsh.** Known dense marsh cover of San Francisco Garter Snake habitat (USFWS 1985; Jennings 2000)
- **Reduced seasonally flooded area and perimeter length of seasonal wetlands in the floodplain.** Foraging habitat of California red-legged frog and San Francisco Garter Snake.
- **Reduced seasonally flooded area and perimeter length of seasonal wetland/upland edge habitat.** Transition zone: driftwood, rush litter mat basking sites and mammal burrow foraging habitats of San Francisco Garter Snakes (USFWS 1985)

The indirect effects of maintaining artificially low permanent lagoon levels with minimal seasonal fluctuation include:

- **Depression of freshwater marsh elevations in relation to sea level and high tides.** Upper limits of marsh elevations within Laguna Salada are determined by the maximum persistent high water levels established by pumps set to activate when water levels range between +6.9 and +7.5 ft NAVD. These upper marsh elevation ranges correspond to upper intertidal ranges of the adjacent ocean (still water elevations, in the absence of wave-induced elevations). Perennial freshwater marsh in the lagoon cannot establish at elevations significantly higher than the maximum lagoon high water level. The maximum lagoon and marsh zone elevations of Laguna Salada are significantly *lower* than corresponding marsh zones and maximum sustained water levels of natural seasonal or non-tidal reference lagoons of the Central Coast (such as Rodeo Lagoon and Laguna Creek Lagoon), which are ordinarily *supratidal* (above tidal elevation ranges), exceeding +10 ft NAVD (+11-+13 ft NAVD) due to impoundment of freshwater discharge at elevations above tidal range. Natural lagoon levels are ordinarily sustained *above* tidal elevation due to freshwater impoundment in dynamic equilibrium with beach seepage discharge (seaward) rates, stream inflows, and beach crest elevations (also above tidal elevations). Natural lagoon fringing marshes, unlike tidal marshes in which marsh zones are adapted to daily mean tidal elevation ranges, thus generally lie mostly *above* the tidal range, and are thus very infrequently flooded by extreme tides, storm surges, and overwash. When lagoons are tidally breached, they drain, stranding most of the marsh zone above the high tide line except during extreme high tides or storms that flood them very briefly.

In contrast, the artificially low maximum lagoon elevations of Laguna Salada maintain their fringing marshes (and endangered species habitat) at a vulnerable low elevations in relation to tides and storm surges. As sea level rises, the lagoon maximum water level and marsh elevation ranges must fall farther below mean and extreme high tidal elevations, and extreme storm wave runup and overwash elevations. When inevitable storm overwash occurs with or without seawall breaching or overtopping (*i.e.*, direct overwash flooding from the seawall gap at Clarendon Avenue) the entire Laguna Salada marsh elevation range is susceptible to flooding by marine salinity with for prolonged periods of the tide and storm cycle. This risk increases as sea level rise accelerates. Natural lagoon marsh zones at higher, supratidal elevations in equilibrium with higher maximum lagoon water elevations are susceptible to relatively brief peak extreme tide or storm overwash. Natural lagoon levels and beach crest elevations rise in adjustment to rising sea level. Artificially stabilized Laguna Salada marsh zones, like subsided diked baylands of San Francisco Bay or levee-bound Delta islands, falls relatively farther below high tides and extreme high tides as sea level rises. This indicates increasing vulnerability to marine overwash over time. This is potentially one of the greatest inherent threats to long-term sustainability of Laguna Salada.

- **Increased vulnerability to saltwater seepage (beach groundwater salinity intrusion).**
  As sea level rises, high tide wave runup elevations on the beach increase relative to the maximum water surface elevations of Laguna Salada, set by pumps at +7.5 ft NAVD. This appears to result in landward salt seepage through the barrier beach during perigean high tides and high swell even in existing conditions, and is likely to result in landward gradients in brackish to saline beach groundwater as sea level rises (Appendix). Pumping the lagoon down to permanent low water elevations in relation to wave runup is likely to promote significant salinity intrusion from the beach to the lagoon over decades of sea level rise. Natural seasonal or nontidal lagoons, in contrast, maintain fresh-brackish impoundments behind barrier beach at elevations that rise in dynamic equilibrium with sea level.

- **Increased vulnerability to storm overwash impacts; increased capacity for storage of undiluted seawater**. The permanently low freshwater storage and water surface elevation of the managed modern lagoon increases the long-term potential landward penetration of storm overwash surges, and increases the capacity of the lagoon to store undiluted seawater. Marine overwash occurring during high lagoon stands (water surface elevations above tidal frame, near wave runup elevations) is subject to turbulent mixing, dilution, and rapid drainage through high volume surface discharge through breach outlets in natural backbarrier lagoons (see Appendix A). Marine overwash occurring in existing conditions, with low lagoon stands and no breach outlet (armored barrier), has low potential for dilution and high capacity for seawater storage, with discharge rates limited by electrical pump capacity and unimpaired pump operation. The current lagoon structure and hydrologic management is prone to artificially increased spatial extent and intensity of salinity pulses during extreme storm events, compared with natural hydrologic and geomorphic conditions. The relative increase in vulnerability of the artificially stabilized lagoon to extreme storm event salinity impacts will increase as sea level rises (see Appendix B).

- **Increased encroachment of the lagoon bed by cattail and tule marsh vegetation due to pumping.** Shallow water less than 1 m deep during the growing season facilitates clonal expansion rates of tall emergent fresh-brackish marsh vegetation (tules, cattails, bulrushes). Early rapid spring and summer drawdown of the lagoon levels expose more lagoon bed to the submergence depth range over which tules, cattails and bulrushes may spread over an extended low-water growing season. This shallow water facilitation of tule-cattailbulrush spread process is independent of sedimentation, but may be exacerbated by nutrient loading (eutrophication), autochthonous sedimentation (local organic sediment production, or allochthonous sedimentation (runoff transport of watershed-derived sediment). Permanent drawdown of the lagoon maximizes the proportion of lagoon area with shallow gradients subject to cattail and tule colonization. Shallow water depths were identified as a significant contributing cause of cattail/tule spread in 1992 (PWA et al. 1992), and rapid expansion of cattail-tule marsh in shallows of Laguna Salada is consistent with that assessment even in the absence of sedimentation.

- **Increased exposure of anoxic and hypoxic organic sulfidic sediments and oxidized acid sulfates.** Acid sulfates can cause extremely low pH (high acidity) of wetland soils, and are a worldwide environmental problem in artificially diked or drained coastal wetland soils. High sulfide production is naturally associated with strongly hypoxic or anoxic organic sediments in brackish or intermittently seawater-influenced coastal wetlands. High concentrations of sulfides are typically not associated with higher fringing marsh elevations that are subject to only relatively brief seasonal flooding, but occur primarily in bottom organic sediments. (refs) Bottom sediments are usually exposed to shallow water edges or air only during extreme low water levels associated with droughts in natural lagoon conditions. Conspicuous exposures of black, sulfuric organic muck sediments are evident in shallow edges of Laguna Salada during summer drawdowns (Fig. 10), and rust-colored surface films of iron oxide, indicative of acid sulfate production due to oxidation of sulfides, is widespread in surface muds of the northeastern lagoon in summer drawdowns. Sulfide and sulfate concentrations were not measured in water quality past studies, and no quantitative sediment sampling of sulfate or sulfide has been performed at Laguna Salada. Sulfides and acid sulfates are potentially toxic to amphibian larvae and eggs.. In summary, the unhealthy presence of high sulfides and acid sulfate are likely to be in unavoidable impact due to the artificial on-going drawdown of the lagoon.

- **Reduced capacity to restrict salinity intrusion from beach groundwater**. The higher lagoon levels stand above sea level, the more the hydraulic head of the lagoon is able to "push back" salt seepage in beach groundwater. Salinity seepage occurs briefly in the short term when high wave runup during high tides occurs on the beach. However, sea level rise poses an increasing long-term risk of salinity intrusion to a lagoon that is maintained at levels below the elevation of beach groundwater that rises with sea level.

- **Concentration of high-nitrogen fertilizer runoff**. Maintaining permanently shallow water levels in the lagoon reduces the capacity of the lagoon to dilute and dissipate fertilizer runoff (through wind-stress current circulation of open water associated with naturally high lagoon stands).

2.5. Elimination of protective dynamic barrier beach functions, sea level rise adaptation, and associated ecological functions.

The barrier beach formerly supported a high beach ridge and low foredunes with dynamic, disturbance-adapted native vegetation until the late agricultural period, when artificial dunebuilding and stabilization plantings with non-native vegetation were developed (see historic ecology, Appendix A). Currently, coarsening beach sand has eliminated onshore wind-transport of dune sand grain size classes (Appendix A), and restricted native pioneer dune vegetation to the toe of the extensive erosional scarp in the earthen "seawall" berm and boulder armor (Figures 13-14). Native foredune vegetation is capable of regenerating both landforms (foredune topography and elevations) and habitats (low, prostrate forb vegetation and gaps; federally listed western snowy plover habitat) following erosion events, and also allows net landward transport of sand across the barrier beach (barrier rollover), which is the essential, primary mechanism of barrier beach profile adjustment to rising sea level (Appendix A).

The artificial fill and boulder armor of the "seawall" (earthen berm or levee) permanently displaces the native foredune community, and prevents constructive washover deposition during storm events. By preventing all washover deposition of sand, the levee arrests the dynamic adjustment response of the barrier beach profile to sea level rise and storm events, and eliminates sand storage in the backbarrier profile where it can buffer the barrier response to sea level rise. The "seawall" reduces the potential beach response to sea level rise to net erosion and profile steepening, and restricts landward sand transport (currently none) to the high threshold of complete levee failure (overwash during erosion of entire levee profile), which would likely result in catastrophic intensity of overwash processes across the sediment-starved backbarrier washover profile. The backbarrier profile retains little or no native disturbance-adapted native vegetation capable of regenerating after natural constructive washover deposition. The artificial levee thus diminishes the resilience of barrier beach system to coastal processes, forces extreme storm events to be exclusively erosional (until the extreme threshold of "seawall" failure), and increases its vulnerability to catastrophic failure and progressive net erosion.

2.6 External constraints on habitats and population viability.

The long-term recovery of special-status amphibian and reptile species at Laguna Salada (western pond turtle, San Francisco Garter Snake, California red-legged frogs) depends not only on population robustness and population viability and habitat quality within the site itself, but also metapopulation structure and community dynamics – including the genetic and demographic interactions among populations in the local watershed and surrounding watersheds, potential non-native species invasions and species interactions (Semlitsch 2002). For example, the proposed CRLF and SFGS mitigations will include the construction of additional ponded areas along the eastern edge of the lagoon and alogn the Sanchez Creek Cooridor so that there are multiple areas that can provide potential reproductive habitat for CRLF. If a catastrophic event happened to one reproductive local there would be other localities to aid in the resiliency of potential reproductive success during that year. Increased population connectivity is also a conservation need for core recovery areas of the California red-legged frog in south San Francisco Bay area (USFWS 2002)

Isolated, small inbreeding populations of San Francisco Garter Snakes are at risk of impaired population viability due to inbreeding depression, and possibly allee effects (inability to find mates at very low population densities) over the long-term, regardless of habitat quality (Semlitsch 2002). Low-level genetic exchange through immigration (infrequent dispersal from relatively isolated but neighboring populations) is needed in the long-term to avoid potential inbreeding depression associated with genetic bottlenecks following declines to very low population sizes.

Bullfrogs (*Rana catesbiana*), are larger non-native competitor and predators of the California red-legged frog, and are widespread in ponds and reservoirs in California and within the Bay Area. Their co-occurrence with smaller frog species, including the California red-legged frog, is often associated with reduced local population viability or population size (Fischer and Schaffer 1996, Kieseker and Blaustein 1998, Lawler et al 1999, USFWS 2002,). Bullfrogs have not been reported from Laguna Salada, but the species can invade even isolated stock ponds in cool coastal core habitats of the California red-legged frog, such as Tomales Bay. Deliberate introduction of bullfrogs in urban ponds from aquaculture or pet sources is a potential pathway of invasion. Perennial water depths at Laguna Salada are suitable for bullfrogs to thrive, but it is not known whether summer peak aquaeous salinity currently exceeds bullfrog tadpole tolerances. . Bullfrogs are limited by seasonal extremes (such as drought/seasonal wetland drawdown) or salinity levels that exceed the tolerance of their tadpoles that require, in cool coastal locations, two years of continuous suitable aquatic habitat to metamorphose into adults. Although bullfrogs are not known to occur at Sharp Park, long term monitoring of amphibian species should include bullfrogs. Optimal survey timing for CRLF and bullfrogs are different.

Non-native predatory fish are also associated with reduced population size or viability of California red-legged frog populations (USFWS 2002, Kieseker and Blaustein 1998, Lawler et al 1999). Non-native mosquitofish are present in Laguna Salada, and larger non-native predators have not been surveyed (Tetra Tech et al. 2009) but are likely to be present, based on the observed frequency of Caspian tern foraging and prey size from open waters of Laguna Salada. All water bodies at Sharp Park, including Arrowhead lake and Horse Stable Pond should be net surveyed for the presence of fish and actions taken if necessary.

2.7. Other habitat degradation factors

Several habitat constraints were identified by Tetra Tech et al. (2009) and Swaim (2009) as outstanding habitat and population threats for conservation of San Francisco Garter Snakes and California red-legged frogs specifically at Laguna Salada. We have reviewed the evidence, analysis, and relevant scientific literature support for these conclusions, but have found insufficient or incompatible evidence for their conclusions regarding the roles of unsuitable “vegetation structure” (excessive cattail/tule shoot density), salinity and oceanic overwash flooding, and upland habitat within marsh as limiting factors. These are explained below.

- **Marsh vegetation shoot density and structure**.
  Tetra Tech et al. (2009) and Swaim (2009) refer to excessively dense marsh vegetation structure as a primary limiting factor for California red-legged frogs:

  > The primary limiting factor for the CRLF in the wetlands complex is a vegetation structure that is inappropriate and not optimal for successful breeding and/or recruitment of larval stages into the adult population. The dense emergent vegetation combined with little remaining open water offers poor habitat for the survival of egg masses or tadpoles. (Tetra Tech *et al*. 2009 p. 29; p. 4)

  No data on shoot density, or shoot density/frog reproductive success relationships, or other analysis of “vegetation structure” were provided to support the conclusion that vegetation structure was a limiting factor, or a “primary” limiting factor, for California red-legged frog habitat. No arguments were presented to suggest that this factor was relatively important compared with other potential limiting factors. The recovery plan for the California red-legged frog (USFWS 2002) does not identify shoot density of marsh vegetation as a limiting factor for habitat quality. The recovery plan for the San Francisco Garter Snake (USFWS 1985) states that dense marsh vegetation cover of tules, cattails, and bulrushes is the preferred core habitat of that species, in agreement with later species accounts (Jennings 2000).

There is extensive open water/marsh edge in Laguna Salada, but low abundance and diversity of seasonally flooded marsh vegetation at the upper, landward perimeter of the fringing wetlands, which is mowed and drained and artificially graded to prevent isolated shallow seasonal ponds from forming. We conclude that artificially homogenized and stabilized topography at the upper edge of the lagoon, combined with excessive artificial drainage and mowing (destruction) of the upper marsh edge vegetation, are the primary vegetation structural and compositional deficiencies affecting the California red-legged frog. The density or extent of cattail and tule vegetation is not likely to be a primary limiting factor for frog habitat.

- **Salinity pulses and chronic salinity.**
  Storm overwash may cause infrequent, intensive, short-term mortality of California red-legged frogs in the seaward reaches of coastal lagoon wetland complexes, such as El Niño events. All coastal lagoons in Central California that are inhabited by California red-legged frogs are subject to long-term infrequent overwash flooding of their seaward wetland reaches during extreme coastal storms. There is no evidence that intermittent, infrequent storm overwash is a primary threat to long-term persistence of California red-legged frog populations in coastal lagoon wetlands, except where connectivity with upland and freshwater refuges in landward marshes and floodplains has been eliminated or impaired by berms and levees. California red-legged frog adults tolerate fresh-brackish salinity regimes of coastal lagoons if not too saline most years (Smith 2007; see Table 1 and Appendix A). Western pond turtles tolerate brief exposure to marine salinity, and can live in mesohaline estuarine salinity regimes, such as Suisun Marsh, where they are locally abundant in the absence of perennial freshwater sources. Salinity pulses in coastal lagoons have low potential to be catastrophic events for California red-legged frogs, San Francisco Garter Snakes, and Western pond turtles populations unless (a) populations are reduced to artificially low and unstable sizes, and (b) populations are occupying marginal habitat without nearby freshwater refuges. Salinity pulses and chronic fresh-brackish salinity *per se* are not threats to persistent populations of these special status wildlife species in coastal lagoon wetland.

- **Upland grassland habitats.** The recovery plan for the San Francisco Garter Snake states that SFGS are most often observed in dense, tall, emergent marsh vegetation including cattails, tules, spike-rush or rush, while upland grasslands are used mostly for basking, seasonal refuge, and movement (USFWS 1985 p. 9). SGFS are not active in cold weather in the winter, nor during cold fall or spring days, and need refuge (dry areas) such as mammal burrows during these times. Jennings (2000) stressed the habitat importance of dense marsh vegetation cover and adequate prey base, with proximate basking sites, along with adjacent upland habitats with small mammal burrows used for foraging on treefrogs. Similarly, the recovery plan for the California red-legged frog identifies upland habitats as movement/dispersal corridors and seasonal foraging areas, as well as refuges (USFWS 2002).

3.0 CONCLUSIONS

The primary limiting factors for habitat quality, sustainability, and population persistence of special-status wildlife species are likely to be consequences of two primary influences: ongoing golf course maintenance and operations and stabilization of artificially low lagoon levels. Golf maintenance impacts result from mowing of marsh and upland edges, exclusion of dense native vegetation cover by wetland and riparian vegetation and large woody debris, and chronic nitrogen loading of the lagoon due to fertilizer application to turfgrass. Stabilization of artificially low lagoon levels with minimal seasonal fluctuation has multiple significant short-term and long-term impacts to the habitat quality and sustainability of the lagoon wetland complex. These impacts include elimination of the lagoon floodplain hydrology and habitat connectivity; increase in the proportion of the lagoon area within depth ranges suitable for rapid spread of cattail and tule vegetation. Artificial stabilization of lagoon wetland elevations within tidal elevation ranges makes them increasingly susceptible to increased marine flooding risks as sea level rises. In addition, pumping the lagoon to fixed, low levels relative to wave runup as sea level rises over decades is likely to induce increasing frequency and rates of salinity intrusion due to reversal of beach groundwater gradients. Salinity intrusion over decades is a more significant threat than intermittent, infrequent overwash in a lagoon that is not artificially drained of its impounded freshwater.

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APPENDIX C

LIST OF FIGURES

APPENDIX C.

EXISTING CONDITIONS - FIGURES

Figure 1. **Artificially low maximum water levels of Laguna Salada**. Central western shore of Laguna Salada at remnant washover fan following winter rains (February 17, 2009), showing transient lagoon surface elevations re-occupying artificially drained floodplains above emergent tule marsh prior to drainage by pumps. Rapid drawdown due to pumping prevents seasonal wetland habitats from establishing in upper flooded areas.

Figure 2. **Artificially low maximum water levels of Laguna Salada**. Central western shore of Laguna Salada at remnant washover fan following winter rains (February 17, 2009), showing temporary lagoon surface elevations partially re-occupying artificially drained floodplains prior to drainage by pumps. Rapid drawdown due to pumping prevents seasonal wetland habitats from establishing in upper flooded areas.

Figure 3. **Artificially low maximum water levels of Laguna Salada**. Horse Stable Pond at pump station, showing transient high lagoon surface elevations partially re-occupying artificially drained floodplains, February 17, 2009. Note partial flooding of fairways in background. Rapid drawdown due to pumping prevents seasonal wetland habitats from establishing in floodplain above tule marsh.

Figure 4. **Artificially low water levels of Laguna Salada and marsh zonation**. Fresh-brackish tule marsh (*Schoenoplectus californicus*) of central west shore Laguna Salada is drained in late spring of dry year (June 15, 2009) nearly to base of tule culms; tule marsh elevations colonized by perennial stands of less flood-tolerant threesquare bulrush (*Schoenoplectus pungens*). Corresponding marsh zones in natural seasonal or nontidal lagoons of the Central Coast are submerged in spring.

Figure 5. **Drainage and discharge of Laguna Salada waters on Salada Beach during the dry season**. The natural filling of Laguna Salada by Sanchez Creek low flows and groundwater discharges in summer is arrested by active pumping even in dry months, maintaining artificial drawdown of the lagoon to low levels all year. Discharge point below the outfall results in scour pools, internal drift-lines delineating high water levels in the pool, and an erosional discharge channel. Photo at left June 11, 2010. Right, August 17, 2010.

Figure 6. **Relict washover flats: drained lagoon floodplain and upland ecotone vegetation invaded by non-native species**. Remnant washover flats landward of "seawall", dominated by non-native terrestrial vegetation. Iceplant (*Carpobrotus edulis* x *chilensis*) occupies the (artificially drained) potential ecotone between seasonal wetland zones of the lagoon (saltgrass-salt rush -bulrush-silverweed) and native dune vegetation. Traces of native dune vegetation are present but scarce.

Figure 7. **Marsh mowing: golf maintenance impacts**. The golf turf mowing encroaching the northeast end of Laguna Salada, extending directly into the marsh and riparian woodland zones. The apparent golf turf is composed of the same fresh-brackish marsh species shown at the left, *Schoenoplectus pungens, Argentina egedii, Agrostis stolonifera,* and *Cotula coronopifolia.* The seasonally flooded outer marsh and its terrestrial ecotone are replaced by turf even with pumped drawdown of the lagoon. The natural floodplain (unimpaired maximum lagoon elevations) would include a much wider floodplain area. All wildlife cover is eliminated, exposing travel corridors of SF Garter snakes and eliminating suitable mammal burrow foraging habitats. All potential buffers for fertilizer impacts are eliminated by encroachment of golf turf into the marsh. Above: June 10, 2010. Below: August 3, 2010.

Figure 8. **Marsh mowing: golf maintenance impacts.** Detail of mown marsh turf composition by fresh-brackish marsh (FACW and OBL wetland indicator species): left, *Argentina egedii* (syn. *Potentilla anserina*) and *Agrostis stolonifera.* right, *Cotula coronopifolia* (succulent leaves, yellow flowerheads) and *Agrostis stolonifera.*

Figure 9. **Marsh mowing: golf maintenance impacts.** Paved path encroachment of fresh-brackish marsh and riparian woodland. Paved paths were constructed in marsh (mown into turf on landward side), and are partially flooded even in the dry season. Earthen fill (golf turf sod wastes) are dumped directly in jurisdictional wetlands (apparently without federal or state authorization) on the landward side of the flooded path at the northeast end of Laguna Salada. August 3, 2010.

Figure 10. **Iron oxide surface films and iron sulfide accumulation of muds exposed by artificial lagoon drawdown**. Iron oxide (orange-brown mineral films indicative of oxidation of iron sulfide and acid sulfates in brackish coastal sediments subject to alternating strong hypoxia and oxidation) are apparent in drawdown-emergent muds at the northeast end of Laguna Salada. Organic-rich sediment immediately below the iron oxide-stained surface sediment film is deep black (lower left), indicative of toxic iron sulfide, formed under strong hypoxic bottom conditions, exposed at the marsh surface by artificial drawdown of the lagoon.

Figure 11. **Absence of submerged aquatic vegetation in modern Laguna Salada contrasting with rapid colonization of adjacent Mori Point perennial ponds**. The wind-rippled surface of the entire Laguna Salada lagoon (above) indicates a lack of submerged aquatic vegetation. The lagoon supported two species of submerged aquatic vegetation (sago pondweed, *Potamogeton pectinata*, syn. *Stuckenia pectinatus*; and wigeongrass, *Ruppia maritima*) in the 20^{th} century and likely before. In contrast, 2 year old ponds constructed by GGNRA adjacent to the lagoon (below) were rapidly colonized by vigorous *Stuckenia pectinatus* in the absence of planting (D. Fong, GGNRA pers. comm. 2010). Sago pondweed is important potential habitat (breeding, foraging) for red-legged frogs, and foraging habitat for waterfowl.

Figure 12 . **Brackish marsh along western shore of Laguna Salada on relict washover fan**. In the absence of overwash in more than 2 decades, brackish and salt marsh plants (pickleweed, saltgrass, jaumea, silverweed; upper left) dominate wetland flats bordering the west shore of the lagoon (upper right), near areas where groundwater salinity has been measured at 15 ppt (nearly half seawater concentration; Kamman 2009). Below, brackish marsh vegetation (saltgrass, jaumea) spreads into ground layer of emergent lagoon bed in summer where hardstem tule dieback has allowed enough sunlight to penetrate.

Figure 13. **Armored and earthen "seawall" profiles**. Erosional scarp in earthen berm "seawall" at south end of boulder armoring. No eolian (wind-deposited) dune sand occurs within or in lee of boulders, or on landward slope of berm. Adjacent beach is coarse sand. Small patches of native dune vegetation (beach-bur, *Ambrosia chamissonis*) occur at the toe of the scarp or boulders.

Figure 14. **Beach armoring (boulder revetment).** The historic location of the lagoon outlet, near the modern pump outfall, is completely armored by an engineered boulder revetment approximately 3 m above the adjacent beach. The seawall and revetment preclude natural lagoon outlet from forming and draining impounded floodwaters in Laguna Salada by gravity following natural breaches.

Figurer 15. **Bluff erosion facilitated by lagoon outfall discharge** (bluff toe erosion and saturation). The high volume discharge of the pump outfall on the beach is deflected along the base of the adjacent Mori Point bluffs, where it forms a channel with an erosional scarp, and extensive areas of persistent saturation. The adjacent bluffs are actively slumping on to the beach despite a lack of direct wave attack behind the wide coarse beach berm. February 17, 2009, except lower right (July 25, 2010). Above: pump outfall pool and berm-deflected outlet channel with erosional scarps. Middle: saturated sheetflow across braided deltaic channel at back of beach, bluff toe. Bottom: large to small rotational slumps occur along the bluff despite a wide beach profile.

APPENDIX D. SUMMARY OF LAGUNA SALADA MIDSUMMER SHORELINE AQUEOUS SALINITY

Summary of Laguna Salada midsummer shoreline aqueous salinity (shallow lagoon edge**),**

Peter Baye

Prepared for Philip Williams and Associates, Laguna Salada Conceptual Restoration Study

Refractometer measurements, 1-2 cm water depth, near maximum seasonal drawdown (emergent lagoon bed). Precision: 1 ppt

Sample date: August 3, 2010

Sample locations:

APPENDIX D – SUMMARY OF LAGUNA SALADA MIDSUMMER SHORELINE AQUEOUS SALINITY

Location	**shoreline vegetation above waterline dominants/subdominants**	**shoreline vegetation below waterline dominants/subdominants**	**Iron sulfide/sulfate indicators**	**Aqueous salinity measurement 1 cm depth**
Pump basin 5 m NW of intake, Horseshoe Pond	Jaumea, threesquare bulrush /silverweed	Broadleaf cattail	Sulfidic black mud at shoreline surface	1.0 1.0
Pump basin 5 m NE of intake, Horseshoe Pond	threesquare bulrush, silverweed	Broadleaf cattail	(steep; not visible)	1.0 1.0
Ditch between S end lagoon and S fairway	Threesquare bulrush, silverweed/Jaumea	Broadleaf cattail California tule	Sulfidic black mud at shoreline surface	2.0 2.0
5 m N of washover fan	Saltgrass, threesquare bulrush	California tule	Sand & muck; sulfidic black below 1 mm	2.0 2.0
Washover fan, NE	Saltgrass, salt rush, pickleweed, silverweed	Hardstem tule	Sand & sulfidic black below 1 mm	2.0 2.0
Washover fan, central E	Saltgrass, threesquare bulrush	Broadleaf cattail (distal leaf necrosis >25%)	Black sulfidic muck/leaf litter	3.0 3.0
Washover fan, central	None (bare sand; trampled)	None (bare sand/filamentous algal detritus)	Black sulfidic sand & muck below 1 mm	2.0 2.0
Washover fan, S	Saltgrass, threesquare bulrush	None (bare sand/filamentous algal detritus)	Black sulfidic sand & muck below 1 mm	2.0 3.0 (depression) 2.0 3.0 (depression)
N end, flooded fairway path	Bare path (asphalt)	Willow, broadleaf cattail, creeping bentgrass	N/A (no sediment)	2.0 2.0
NE end, golf ball impact pit	Bare mud	Broadleaf cattail, silverweed, creeping bentgrass	Rusty brown surface film; black mud below 2 mm	5.0 ppt
MARINE REFERENCE: ocean, Salada Beach	n/a	n/a	n/a	35.0 ppt
FRESHWATER REFERENCE: Fairway Drive ditch (CA red-legged frog occupied)	Small-fruited sedge, watercress, horsetail	Small-fruited sedge, watercress, horsetail	none	0.0 ppt 0.0

APPENDIX D – SUMMARY OF LAGUNA SALADA MIDSUMMER SHORELINE AQUEOUS SALINITY

Summary of findings:

- Salinity range 1-3 ppt in shallow water at vegetated edge of lagoon and ditches; within range of adult CRLF tolerance; fresh-brackish range, not "freshwater"
- Reduced salinity below Sanchez Ck/Horseshoe Pond (1.0) relative to main LS and ditch (2.0-3.0 ppt); freshwater (0.0 ppt) in Sanchez Ck and Fairway Drive ditch.
- Highest aquaeous salinity (3.0 ppt) at edge of relict washover fan (transmissive coarse sediment closest to beach and potential beach groundwater seepage) associated with local salt marsh vegetation and leaf tip necrosis of cattail (despite 25+ yr seawall barrier to overwash and pumping; potential indicator of salt seepage due to pumping)
- Highest salinities measured were in shallow depressions in marsh or mud: brackish marsh depressions (concentration due to evapotranspiration, S end washover fan) and golf ball impact pit in emergent saturated mud at NE (landward) edge of lagoon – 5 ppt (evaporative concentration; soil porewater seepage from residual soil salt)
- Iron sulfide (black mud) widespread present at or below organic (muck) surface of lagoon bed at lagoon shoreline; iron sulfate (oxidized iron sulfide product) widespread in emergent mud at NE end of lagoon
- Caspian terns foraging in Laguna Salada; fish larger than Caspian bill length taken; species not known (fish predators of CRLF?)
- No CRLF observed (no splashes heard, no frogs or tadpoles seen) in LS; CLRF observed abundant at adjacent reference sites at Fairway Drive roadside ditch , Mori Point (constructed) marsh ponds, Sanchez Creek culvert.
- Anomalous lack of both brackish and freshwater submerged aquatic vegetation (pondweed, wigeongrass) in LS

Observed Plant species salinity indicator status (ranked by salinity tolerance):

- **pickleweed (*Sarcocornia pacifica*)**: salt marsh, brackish marsh, fresh-brackish marsh (marsh (0 ppt to > 60 ppt, extreme hypersaline tolerant)
- **saltgrass (*Distichlis spicata*)**: salt marsh, brackish marsh, fresh-brackish marsh (0 ppt to > 40 ppt, low hypersaline tolerant)
- **Jaumea (*Jaumea carnosa*)**: salt marsh, brackish marsh, fresh-brackish marsh (0 ppt to > 40 ppt, low hypersaline tolerant)
- **Salt rush (*Juncus lescurii,* syn*. J. lesueurii*)**: brackish marsh, fresh-brackish marsh (0 ppt to <30 ppt, brackish tolerant)
- **Silverweed (*Argentina egedii*, syn*. Potentilla anserina* ssp. *egedii*)**: brackish marsh, fresh-brackish marsh (0 ppt to <30 ppt, brackish tolerant)
- **Threesquare bulrush (*Schoenoplectus pungens*, syn. *Scirpus pungens*)**: brackish marsh, fresh-brackish marsh (0 ppt to <30 ppt, brackish tolerant)
- **Hardstem tule (*Schoenoplectus acutus*, syn. *Scirpus acutus*)**: brackish marsh, fresh-brackish marsh (0 ppt to <20 ppt, brackish tolerant)

- **California tule (*Schoenoplectus californicus*, syn. *Scirpus californicus*)**: fresh-brackish marsh (0 ppt to <30 ppt, brackish tolerant)
- **Broadleaf cattail (*Typha latifolia*)**: fresh-brackish marsh (0 ppt to <20 ppt, marginal brackish tolerance)
- **Small-fruited sedge (*Scirpus microcarpus*)** (0 ppt to < 5 ppt, freshwater-oligohaline obligate; salt –intolerant)
- **Creeping bentgrass (*Agrostis stolonifera*)** (0 ppt to < 5 ppt, freshwater-oligohaline obligate; salt –intolerant)
- **watercress (*Nasturium officinale*, syn. *Rorripa nasturtium-aquatica*)** (0 ppt to < 5 ppt, freshwater-oligohaline obligate; salt –intolerant)

APPENDIX E. SUMMARY OF OBSERVED SALINITY INTRUSION AT LAGUNA SALADA

1. Salinity intrusion: seasonal saline seeps. Kamman (2009) found no direct evidence of salinity intrusion by landward subsurface flow of beach groundwater in four transects sampled between April 2007 and April 2008. His groundwater analysis revealed shallow groundwater salinity of 15 ppt at a distance of less than 300 feet from the shore of Laguna Salada, which had a salinity of 2 ppt, and a persistent hydraulic gradient of the shallow groundwater outflow from the pond westerly towards the beach, resulting in freshwater hydraulic head pushing back saltwater from the ocean. He noted, however, that under certain conditions, such as rapid drawdown due to pumping or extreme low water during late summer, the hydraulic gradient may reverse and subsurface water of relatively higher salinity may flow into the ponds. (Kamman 2009). Kamman's groundwater sampling stations were clustered at the southern end of Laguna Salada, where most of the backbarrier profile is generally wide and gently sloping (on relict washover fans), with no piezometers located along the steep backbarrier profile at the N end of the beach.

In February and March 2010, the ESA PWA team did detect extensive conspicuous saline seeps emerging in golf turf patches immediately behind the steep levee backslope at the north end of Sharp Park, following extreme winter tides and storm wave runup events (El Nino storm events coinciding with spring tides). The saline seeps were detected as large, irregular patches of rapid golf turf dieback on landward-sloping, sandy loams with positive drainage, unconnected to localized surface saltwater flooding from wave overtopping in the low gap bordering Clarendon Avenue (Figure 1). During rainless weeks of high evapotranspiration in March 2010, the saline seeps developed white efflorescent salt crusts on moist sandy loam and capillary surfaces of leaf litter from salt-killed grass turf and salt-intolerant weed species (Figures 2-4). The sandy loam immediately below the salt-crust/efflorescent film surface remained moist during periods of efflorescence (Figure 3). The salt-crusted barrens were colonized by two salt-tolerant weeds, succulent spurrey species (*Spergularia* sp., vegetative plants only; likely *S. rubra* and *S. bocconii*) and staghorn plantain (*Plantago coronopus*) producing green foliage in the white-crusted barrens. (Figure 4). Subsequent rainfall in April, and summer overhead irrigation dissolved and leached the soil surface salt evaporites, but left barren turf dieback areas and residual salt-tolerant weed patches (Figure 5).

The beach adjacent to the saline seeps also developed winter storm berm crests that matched or exceeded the height of adjacent seawalls near Clarendon Avenue. The correspondence between extreme coarse storm berm crest elevations and saline seep locations is consistent with current empirical models of super-elevated saline beach groundwater in coarse-grained barrier beaches (Carter *et al.* 1984, Nielsen 1990, 1999, Horn and Li 2006, Isla and Bujalesky 2005, Turner et al. 1997).

The abrupt emergence of saline seeps following high spring tides and storm wave runup is consistent with current validated models and field evidence of significant net landward beach groundwater infiltration above mean sea level due to super-elevation of beach groundwater in coarse-grained barrier beaches due to (a) tidal asymmetry of beach groundwater flow and elevation, and (b) "pumping" of saline groundwater by high wave runup events (Nielsen 1990, 1999, Turner et al. 1997). These effects are particularly efficient on permeable coarse-grained barrier beaches less than 1 km wide, like Salada/Sharp Park Beach (Horn and Li 2006, Isla and Bujalensky 2005). The experimental conceptual model of saline backbarrier seepage in coarse-grained barrier beach seepage lagoons (figure 5 of Isla and Bujalensky 2005; Carter *et al.* 1984), which predicts perched salt groundwater and landward subsurface saline flow during high tides and runup events, appears to be applicable to Laguna Salada at least seasonally under existing conditions.

As Kamman (2009) predicted, sea level rise and climate change (increased swell height and storm intensity, frequency; Allan and Komar 2006) may also alter seasonal and long-term ocean levels and wave energy, potentially reversing shallow groundwater gradients between the lagoon and ocean and allowing more salts to migrate into Laguna Salada. We concur, and conclude that landward salinity seepage is currently occurring seasonally during periods of high tides and wave runup. Landward salinity intrusion to Laguna Salada by reversal of groundwater gradients between the permeable, coarse-grained barrier beach is likely to increase and accelerate as sea level rises, and storm wave heights increase in magnitude and frequency in California (Allan and Komar 2006), and as shoreline retreat continues on the San Mateo Coast (Hapke et al. 2009, Hapke et al. 2006). This prediction is significant for assessment of long-term sustainability of fresh-brackish salinity in Laguna Salada at current managed (pumped) water surface elevations that will be increasingly exceeded by rising sea levels and rising saline beach groundwater elevations over time.

2. Salinity intrusion: wave overtopping and flooding at the Clarendon Avenue gap.

We observed localized seawater flooding of depressional uplands and wetlands at the extreme NW corner of Sharp Park, following wave overtopping of the low pedestrian access gap in the seawall between the north end of the Sharp Park levee, and the lower concrete seawall along Clarendon Avenue. Beach sand with current ripples was observed along the roadside below the gap, and the evidence of prolonged saltwater flooding (salt evaporite crusts in dried puddles, salt-film patterned dieback of iceplant, rapid spread of saltgrass) were evident (Figures 6-8). This gap in the shoreline is currently a location of oceanic flooding (overtopping or overwash), and is beyond the boundaries of Sharp Park. It is likely to become increasingly important as a storm flooding pathway (salinity pulses) for Laguna Salada as sea level rises and extreme El Nino storm events recur.

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Figures

Figure F-1. Overview of saline seep patch in golf turf immediately behind levee at NW end of Sharp Park golf links appeared in February 2010 following high spring tides and high swell runup on adjacent beach, but no levee overtopping by waves. No salt spray injury is evident in adjacent turfgrass. Seeps formed white efflorescent salt crystal evaporite films during rainless, dry weeks through March. [Photo: March 27, 2010]

Figure F-2. Conspicuous white salt evaporite film, composed of efflorescent salt crystals deposited by evaporation of capillary soil moisture at soil surface within localized saline seep patches in golf turf immediately behind levee at NW end of Sharp Park golf links. Dead turfgrass litter is covered with efflorescent salt crystal film. Green vegetation within salt-whitened dieback patches is composed of two succulent salt-tolerant weeds *Spergularia* sp. (spurrey) and *Plantago coronopus* (staghorn plantain). No salt spray injury is evident in adjacent green turfgrass; concentrated salt is localized. [Photo: March 27, 2010]

Figure F-3. Surface soil and leaf litter with conspicuous white efflorescent salt evaporite film. Salt crystals deposited by evaporation of capillary soil moisture at soil surface within localized saline seep patches in golf turf immediately behind levee at NW end of Sharp Park golf links. Dead turfgrass and salt-sensitive weed litter is covered with efflorescent salt crystal film. Shallow scrape (right) exposes moist sandy loam (capillary substrate) below white salt crust at surface. [Photo: March 27, 2010]

Figure F-4. Detail of succulent salt-tolerant *Spergularia* sp. (vegetative plant, winter) growing in dead golf turfgrass covered with efflorescent salt film deposited by evaporation of capillary soil moisture at temporary saline seep behind levee, NW Sharp Park. [Photo: March 27, 2010]

Figure F-5. Sharp Park golf turf dieback patches persist at locations of Feb-Mar 2010 saline seep/capillary evaporate locations (NW golf links), despite overhead irrigation (shown above) that facilitates leaching of soil salts. [Photo: August 3, 2010]

Figure F-6. Local marine flooding of NW corner of Sharp Park golf course from wave overtopping and flooding of Clarendon shoreline gap. Salt evaporite (white film bordering darker saline mud), saltgrass, and dieback patches of iceplant demarcate marine flooding pattern. [Photo: March 27, 2010]

Figure F-7. Local marine flooding of NW corner of Sharp Park golf course from wave overtopping through Clarendon shoreline gap. Detail of evaporated saline puddle with white salt crystal evaporite film and saltgrass; no salt-intolerant species surviving. [Photo: March 27, 2010]

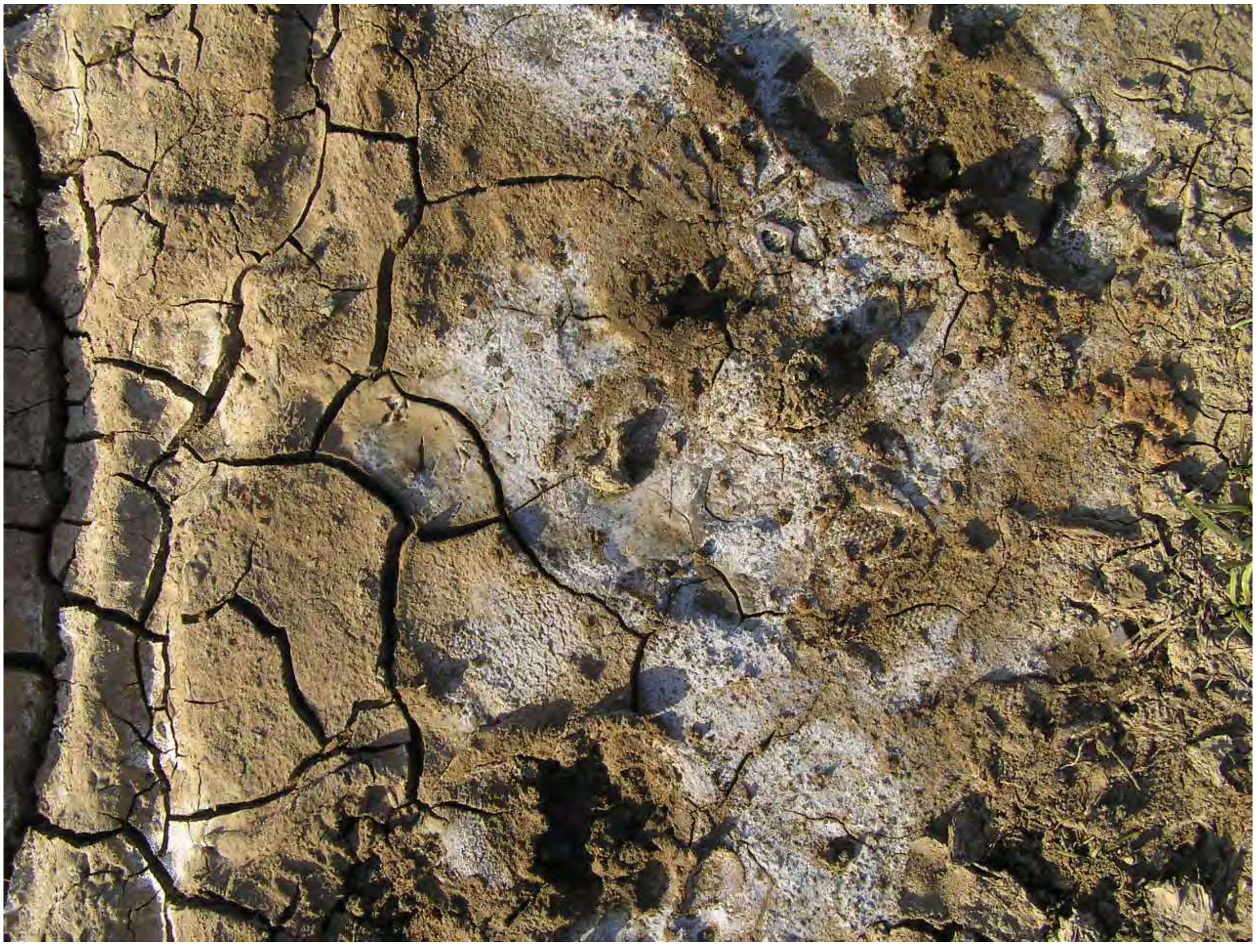

Figure F-8. Local marine flooding of NW corner of Sharp Park golf course from wave overtopping and flooding through Clarendon shoreline gap. Salt evaporite film in dried puddle, polygonal mud cracks, shown in detail. [Photo: March 27, 2010]

APPENDIX F. LAGUNA SALADA PLACE NAME ANALYSIS

APPENDIX F – LAGUNA SALADA PLACE NAME ANALYSIS

The folk place-name “Laguna Salada” (salty lake, lagoon, pond; “Laguna” = Spanish geographical name for small lakes and marshy lakes; diminutive = “lagunita”; Gudde 1969)) has been interpreted at face value to mean that the original historic condition of Laguna Salada was a salt pond (near marine salinity, saline or hypersaline). Yet the historic vegetation evidence from early 20th century agricultural land use era, during which farmers artificially breached the lagoon to drain the farmed floodplain for artichokes, indicates that even with forced openings in the barrier beach and contact with the ocean, the lagoon supported brackish to freshwater vegetation (dilute salinity relative to seawater) and lacked a persistent tidal inlet. This discrepancy indicates a need for critical analysis of the geographic place-name “Laguna Salada” in full historic and geographic context. The term “laguna” contrasts with the term “estero”, which was the historic term applied to “all little lagoons communicating with the sea” (Trowbridge 1854, cited in Engstrom 2006; Gudde 1969).

There is unequivocal historic evidence that true salt ponds (at or above marine salinity) did exist in the Bay Area in early historic times. The largest of these, “Crystal Salt Pond”, from which native Ohlone harvested salt crystals, occurred in the borders of San Francisco Bay near San Lorenzo, now Hayward Shoreline (Ver Planck 1951, 1958). Many smaller true shallow nontidal or intermittently tidal “salt lakes”, also called “salinas” (salt pond or marsh), were mapped in south San Francisco Bay by U.S. Coast Survey topographers in (Goals Project 1999). This raises the question of whether “salada” was a description of relatively salty seasonal lagoon water quality compared with pure freshwater lakes, or a synonym of “salina” indicating a brine-filled waterbody. What folk distinctions were made about salinity in early California history, compared with modern scientific distinctions of salinity gradients?

Hypersaline coastal lagoons are documented from the historic and modern arid southern California coast (Engstrom 2006, Warme 1971), but even there, beach-dammed stream mouths in the early Mission era to the 1870s formed literally “freshwater” backbarrier lagoons (lakes), such as Las Flores Creek lagoon and San Mateo Creek lagoon, distinguished as “tule lagunas” (Engstrom 2006). These were considered “freshwater” (prior to analytic measurements of salinity) in contrast with “saline” lagoons based on their practical potential for agricultural use as crop irrigation or stock watering, such as corn cultivation (Englehart 1921, cited in Engstrom 2006). Any water salinity greater than 1- 2 ppt during the growing season (oligohaline in modern scientific salinity classifications; Cowardin 1979) was too strong for use in agricultural irrigation (due to evaporative concentration) or stock watering in the rainless California summer. Humans also taste brackish water at 1 part per thousand salinity (one tenth of one percent strength, or one thirty-fifth of sea water strength). This human salt taste detection threshold corresponds with the irrigation salinity threshold in dry climates, and also modern regulatory salinity standards for the Sacramento Delta, which set the 2 parts per thousand (two tenths of a percent) salinity standard at the western edge of the Delta bordering Suisun Marsh. Thus, the threshold for “salty” water for drinking or farming corresponded with what ecologists term “oligohaline” (slightly brackish), below 2 ppt.

The term “Salada” was applied to surface waters that had a “strong” saline content, as perceived by settlers and surveyors during the Mission and 19th century agricultural era (Gudde 1969). The threshold for “saline” epithets in folk names for waterbodies in the pre-scientific Mission era did not recognize 20th century distinctions among of multiple salinity classes between freshwater (“sweet water”) and marine salinity (euhaline); “brackish” (dilute seawater) salinity distinction was not even used as a descriptive term applied to marshes by early California naturalists and botanists, who cited localities as “salt marshes” supporting species intolerant of marine salinity (Jepson 1911, Baye et al. 2000). California settlers, ranchers, and surveyors in the early-mid 19th were not naming waterbodies and wetlands according to (later) scientific wetland and aquatic habitat classifications that made fine distinctions among biological salinity tolerance classes.

The aspect of seasonality of salinity is also an important context for lagoons in summer-arid climates, as it is for creeks. Just as the historic epithet “Seco” and “Dry” applied to place-names (Arroyo Seco, Laguna Seco, usually applied to the dry-season condition) indicates important contrast with permanent lakes and streams, and indicated an historic condition of a seasonally or permanently dry creek or lake (Gudde 1969), “salada” does not indicate that a waterbody too “salty” for the contemporary consumptive water uses all year. The epithet “Salada” indicates at least seasonally “strong” salinity relative to land uses and needs, in contrast with a permanently freshwater lake suitable for irrigation, stock watering, or drinking. The term “salada” in the 19th century context would thus apply to all seasonally brackish or fresh-brackish coastal lagoons that were frequently too saline for use.

The perception of “freshwater” and “saltwater” in 19th century coastal place names was relative and influenced by perception contrasts and contemporary practical needs: navigators of mostly oceanic salinity (non-potable) waters named what is now Suisun Bay “Puerto Dulce” (“Sweet Bay” or “Freshwater Bay”) as late as 1842 (Gudde 1969). Suisun Bay is fully tidal and estuarine, fresh-brackish in historic times, with near-zero salinity (potable, < 1 ppt) in sloughs during ebbing tides of the rainy winter-spring runoff period. Stratigraphic data, however, confirm that Suisun Bay has fluctuating oligohaline to mesohaline (fresh-brackish) seasonal salinity variation with brackish marsh and water column biota dominating sediments over two thousand years old (Goman and Wells 2000).

The name “Laguna Salada” is consistent with the early historic condition of a fresh-brackish coastal lagoon with intermittent overwash, as depicted in the earliest scientific map (1869) by the U.S. Coast Survey based on field surveys from the mid-19th century.

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