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Pilarcitos Lagoon Habitat Enhancement Feasibility Study: Final Report

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1 Introduction

“Pilarcitos Lagoon” is the name popularly given to the lower Pilarcitos Creek system within Half Moon Bay State Beach in Half Moon Bay, California (Figure 1). A map of the creek and its environs is provided in Figure 2. The lower creek and its associated habitats support a population of federally threatened steelhead (*Oncorhynchus mykiss*) as well as a number of other special-status species such as Western snowy plover (*Charadrius alexandrinus nivosus*) and California red-legged frog (*Rana draytonii*). The morphology of the lower creek, which is primarily a mile-long, shallow, braided channel on the beach adjacent to the toe of a late Pleistocene marine terrace, makes fish passage between the Pacific Ocean and the creek difficult under most flow conditions. As a result, the Pilarcitos Creek Integrated Watershed Management Plan (PWA et al. 2008) placed a high priority on identifying opportunities to enhance fish passage and populations of other species of concern within the lower creek. In response, the San Mateo Resource Conservation District (RCD) requested proposals from qualified consultants to implement the Pilarcitos Lagoon Habitat Enhancement Feasibility Study (the “Project”). In early 2009, SMCRCD chose our team comprised of Wetlands and Water Resources (WWR, San Rafael, CA), Balance Hydrologics (Berkeley, CA), Peter Baye, PhD, and DW Alley and Associates (Brookdale, CA) to implement the Project. The Project team was comprised of the following individuals:

- Don Alley, DW Alley and Associates
- Peter Baye, PhD, independent botanist/coastal ecologist
- Brian Hastings, PG, Balance Hydrologics
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- Jonathan Owens, Balance Hydrologics
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- Christina Toms, Wetlands and Water Resources

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- Dan Gillenwater, Wetlands and Water Resources
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The purpose of this report is to (1) describe and synthesize the research done as part of the Project, (2) provide detailed descriptions of potential habitat enhancement options for the lower Pilarcitos Creek system, and (3) evaluate the feasibility of each option. This report contains the following sections:

1. **Introduction** – An introduction to the Project and its team, goals and objectives, process, and terminology
2. **Summary of Conceptual Model** – A concise summary of the extensive conceptual model presented in Appendix A, which provides the scientific framework for the Project
3. **Evaluation Criteria** – Descriptions of the criteria used to evaluate the feasibility of potential preliminary enhancement options
4. **Enhancement Options** – Illustrated descriptions of the preliminary enhancement options for the lower creek system, including evaluations of their feasibility using the criteria established in Section 3
5. **Conclusions and Next Steps** – A brief summary of conclusions and next steps to consider for Project feasibility analysis and implementation

1.1 Goals and Objectives

The primary goal of the Project is to identify what, if any, lagoon fish passage and habitat enhancement approaches have the potential to provide significant ecological benefits for fish (i.e. steelhead) and/or other species of concern. Project objectives include the following:

- Develop a conceptual model that synthesizes historic and contemporary evidence on the natural range of site-specific geomorphic variability inherent in the stream mouth/beach system, with an emphasis on primary physical and ecological controls, to guide the formulation of enhancement options
- Assess the degree to which the system has been or continues to be altered or constrained by contemporary anthropogenic conditions;
- Identify hydrological and ecological functions (e.g. special-status species habitats) associated with specific alternate states of the stream mouth that occur within its natural or artificially modified range of variability;
- Identify feasible options for modifications within and beyond the lagoon to improve ecological functions for multiple target species with contrasting habitat requirements
- Solicit and incorporate feedback from the Project Technical Advisory Committee (TAC) on all aspects of conceptual model and enhancement option development and feasibility evaluation

1.2 Project Process

For the first step of the Project, the Project Team reviewed existing information (historic materials and a literature review) and collected new field data to support conceptual model development. Our review of historic materials included:

- 21 historic aerial photographs of the creek mouth and surrounding area from 1928-2006, scanned from the UC-Santa Cruz Map Library (Figure 3)
- 1861 (preliminary) and 1863 (final) US Coast Survey maps of Half Moon Bay obtained from the UC-Berkeley Earth Sciences Library and NOAA (Figure 4)
- Engineering drawings for the SAM wastewater treatment plant upgrades of the late 1970s – early 1980s

Our literature review included:

- Multiple US Geological Survey publications on topics such as: coastal geology, geomorphology, and evolution; marine terrace morphology, fault dynamics, and more
- Scientific papers describing wave refraction, longshore sediment transport, beach sand grain size, and beach slope in Half Moon Bay (Bascom 1951 and 1954)
- Previous work done within the Pilarcitos watershed, including the 2008 Pilarcitos IWMP, supporting technical documents, and work done by Balance Hydrologics on basin sediment supply/dynamics and hydrology
- Publications by Gary Griggs and others at UC-Santa Cruz describing coastal geology and sediment dynamics
- Draft maps of seafloor geology, sediment, faulting, and more from the California Coastal Mapping Project (joint project between USGS, CA Coastal Conservancy, CSU Monterey Bay, California Geological Survey, California Ocean Protection Council, and Fugro)

Field data collection activities were comprised of:

- New ground-based topographic surveys of the lower creek, floodplain, dunes, and beach and conversion of these data into a Digital Elevation Model of the lower creek (Figure 5)
- Installation and monitoring of a flow gage at the pedestrian bridge
- Water quality and fish community monitoring at Pilarcitos and two other creek/lagoon systems, Gazos and San Gregorio Creeks
- Soil core sampling along the creek mouth and floodplain

- Multiple field visits to characterize vegetation communities, wildlife use, local geology, fluvial and beach sediment, and creek mouth morphodynamics

With input from the TAC, we synthesized historic and contemporary evidence (including topography, shore morphology, water quality, streamflow, sediment cores, vegetation, fish habitat conditions) describing the range of variability in ecological, hydrological, and geomorphic conditions and processes at the Pilarcitos Creek mouth to provide a working conceptual model of its lagoon form and dynamics. This model is summarized below in Section 2 and presented in whole in Appendix A. We applied the conceptual model to interpret recent conditions and develop a rough first cut of feasible modifications of hydrologic and ecological functions to special-status species habitats associated with specific alternate states of the system. Further consultation with the Project TAC and other stakeholders resulted in the detailed enhancement options and evaluation Criterion described in Sections 3 and 4 below.

Appendix B contains a list of the vascular plant species encountered during reconnaissance-level field surveys performed by Dr. Peter Baye over the course of the project. This information is presented to help characterize and describe the ecosystems present at the site's environs.

1.3 Terminology

Lower Pilarcitos Creek is a geomorphically complex system, and accurately describing the creek's environments often requires the use of a specific vocabulary. For reference purposes, the lower creek's features are defined below; many are labeled in Figure 2.

Lagoon. Cooper (1997) most likely puts it best when describing the challenges of defining a coastal lagoon:

> *Precise definition of a coastal lagoon is problematic, and many definitions have been proposed. Considerable overlap between lagoons and estuaries has been identified. As morphodynamic systems, lagoons have been defined as "coastal water bodies which are physically separated, to a greater or lesser extent, from the ocean by a strip of land" (Ward and Ashley, 1989). The imprecise definition of coastal lagoons is probably the main problem in the lack of co-ordinated research, as many features variously termed estuaries, blind estuaries, embayments, coastal bonds, coastal lakes, bays and sounds may alternatively be regarded as lagoons.*

Within California's Central Coast, the term "lagoon" is typically used to describe the matrix of open water, marsh, and floodplain habitats that is formed when waters from a coastal creek are impounded by the beach (Clifton et al. 1972). These systems are typically open to the ocean during winter-spring (when storm flows breach the beach dam) and disconnected from the ocean during the summer-fall months (when flows gradually impound behind the beach dam).

Since this is not the type of system that exists within lower Pilarcitos Creek, we typically will not refer to the system as a "lagoon." Additional information about the lower creek's morphology and the nuances of lagoon definitions can be found in Appendix A, the conceptual model.

Foredune. Dunes formed by sand-trapping vegetation directly behind (landward of) the beach. Foredunes may occur as discrete scattered mounds, broad and low terraces, or discontinuous or continuous ridges.

Foredune ridge. Continuous, consolidated foredunes.

Berm. A seasonal or persistent swash bar (wave-deposited sand bar) emergent above high tide or ordinary high water levels.

Beach ridge. A single or compound (multiple berm) beach landform composed of active and relict berms, with or without dune deposits.

Foreshore. The intertidal zone of the beach.

Backshore. The supratidal zone of the beach and foredune.

Stream mouth. Where the creek exits its confined channel within the marine terrace, near the SAM wastewater treatment plant.[1] To be contrasted with "beach outlet" (defined below), where the creek actually exits the beach.

Beach outlet. Where the creek exits the beach and flows into Half Moon Bay. Often, the Pilarcitos outlet merges with the Frenchman's Creek outlet, and the creeks flow jointly into HMB at an outlet location, usually north of the Frenchman's Creek mouth.

Floodplain. Topographically level areas along the sides of the creek that carry occasional or frequent flood flows.

Mainstem channel. The main channel of the creek that carries most of its flows and where its thalweg (deepest portions) are located.

Backbeach channel/runnel. The channel along the toe of the marine terrace bluff where lower Pilarcitos Creek flows after exiting the mouth.

Backwater slough. Floodplain depression to the east of the mainstem Pilarcitos channel; was formerly an active stream channel but is now for the most part hydraulically disconnected from the mainstem of Pilarcitos Creek.

[1] While our use of "stream mouth" within the context of Pilarcitos Creek and its environs is consistent with its usage in technical literature (see Clifton, Hunter and Phillips 1973); it is atypical of popular and legal usage of the term, which is often used to describe the beach outlet.

2 Summary of Conceptual Model

<u>Note:</u> For detailed descriptions of key observations and inferences about the lower Pilarcitos system, and a rigorous discussion of physical and ecological controls on habitat dynamics, please see the complete conceptual model in Appendix A. What follows is a brief summary of this model meant to inform the reader of the general thought process that went into development of the enhancement options described in Section 4.

The Pilarcitos Creek mouth is distinctive among other lagoon systems along the Central Coast in its historic and modern lack of geomorphic space for a large-scale lagoon. The creek bed at the mouth does not appear to incise to intertidal elevations (Graphic 1 below). Intermittent lagoon formation by the creek appears to have been confined to the channels and depressions in the beach. Without creek channel incision to intertidal elevation ranges, there is minimal potential to form a beach-dammed lagoon with fresh to brackish gradients suitable for smolt osmotic regulation and other habitat functions.

The Pilarcitos stream mouth and adjacent floodplain (the potential lagoon positions) are extensively vegetated and aggraded with sand and silt to elevations well above the tidal range. The mouth forms a deltaic channel behind a coarse-grained, permeable beach ridge with high potential for subsurface discharge (seepage) losses. The creek floodplain (willow woodland) is aggraded to the elevation range of the beach backslope.

The creek and floodplain at the mouth are strongly depositional sedimentary environments. Our team estimated a mean annual sediment yield of almost 5,000 m^3 per year to the local beach sand budget. Water surface elevations in the deltaic channel reach crossing the backbeach are likely limited by high beach seepage rates. The beach outlet of the creek channel often drifts far to the north of the mouth, extending the length and channel bed area along the back of the coarse-grained, permeable beach. The estimated seepage potential through the beach is proportional with the length of the beach outlet channel. The creek outlet position was historically variable, but tended to drift northward towards Frenchman's Creek. In recent decades, the northward deflection and attenuation of the channel outlet appears to have become the prevalent condition. Direct breaching of the beach at the mouth has become increasingly restricted by stabilized woody riparian vegetation and a substantial foredune ridge established in recent decades.

Sediment cores at the Pilarcitos Creek mouth beach and floodplain revealed no fine-grained lagoon deposits, peats, or restrictive layers (sandy clay) within the upper 6 ft that may inhibit seepage losses of stream discharge through the beach. In contrast, restrictive clay layers were encountered at 3 ft depth below the beach at Frenchman's Creek, which regularly forms a small lagoon.

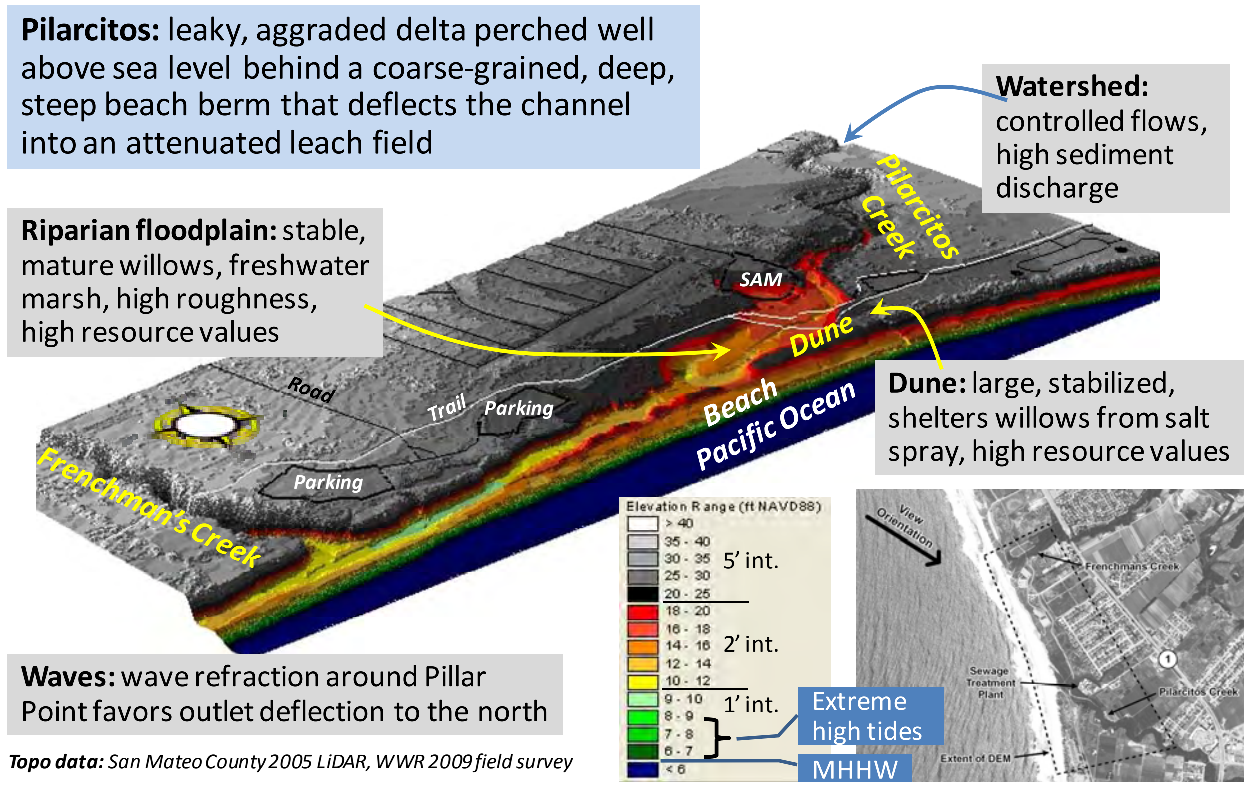
Maximum lagoon water surface elevations in the creek are ephemeral and associated with brief extreme high tides, overwash, or fluvial flood peaks during open beach outlet conditions in the winter/early spring. Maximum *sustained* lagoon WSEs during beach-dammed/choked outlet conditions in the summer are below the floodplain surface elevations.

The lower creek and "lagoon" have a predominantly freshwater salinity regime; there little or no evidence of a persistent, residual brackish influence in vegetation composition or structure. The mouth and potential lagoon area of Lower Pilarcitos Creek supports predominantly salt-sensitive freshwater marsh and riparian scrub vegetation throughout. Water in the lower creek has a chemical "fingerprint" similar to that of water above Stone Dam.

The ecological trajectory of the creek mouth shifted from an unstable, sparsely vegetated state evident in 1861 U.S. Coast Survey maps up until the 1970s, when extensive riparian vegetation began to establish, persist, and spread. The El Nino storm disturbances of the early 1980s temporarily reversed vegetation trends, but riparian woodland, freshwater marsh, and coastal foredune vegetation established a trend of increasing vegetative stabilization of the mouth by the 1990s.

The conceptual model implies that substantial inherent limitations may exist for "enhancing" lagoon conditions identified with other coastal stream mouths that are not geomorphically supported by this system. Steelhead habitat improvements compatible with the system as it currently exists may include placement of scour objects (e.g. large woody debris) to increase the depth and area of channel pools. Establishing fresh to brackish salinity gradients in the creek mouth to benefit smoltification of juvenile steelhead may be infeasible due to the channel's location well above the tides. Improvement of steelhead passage conditions may potentially be improved by restricting the northward drift of the stream outlet along the beach, with an objective of prolonging critical outflows for smolts. Increased outflows during spring and fall months may also improve fish passage. Future opportunities for engineering better steelhead habitat may arise following natural catastrophic storm disturbance to the mouth.

The Mouths of Pilarcitos and Frenchman's Creeks: A Morphological View of Key Controls



3 Evaluation Criteria

This section describes the criteria used to evaluate the enhancement options described in Section 4. These criteria provide a means for qualitatively evaluating the feasibility of different enhancement options. These criteria are:

- Criterion 1: Benefits to Target Species
- Criterion 2: Implementation Costs
- Criterion 3: Regulatory Requirements
- Criterion 4: Probability of Securing Funding for Implementation
- Criterion 5: Life Expectancy without Operations and Maintenance
- Criterion 6: Intensity and Cost of Operations and Maintenance
- Criterion 7: Interactions with Other Habitat Enhancement Efforts
- Criterion 8: Level of Community/Stakeholder Project Support
- Criterion 9: Potential Unintended Consequences
- Criterion 10: Cost and Benefits Relative to Actions Above Highway 1

- Criterion 11: Extent Option “Works with Nature”

3.1 Criterion 1: Benefits to Target Species

The most critical criterion is the likelihood to which each enhancement option would provide “significant benefits for fish or other species of concern” – the primary project goal as defined by the project purpose statement. Given the various distinct life histories of steelhead in Pilarcitos Creek, and the current constraints on steelhead habitat within the system (discussed at length in the conceptual model, Appendix A), this general goal can be refined into the following evaluation criteria. These criteria are inherently *subjective* as their application is based on conceptual models which always reflect uncertainty in our knowledge. It may not be possible for any one enhancement option or group of options to rate well under all of these criteria; thus, decisions can be made through an understanding of the tradeoffs that may have to be made.

Sub-Criterion 1A: Adult steelhead migration. Increased movement of in-migrating, spawning adults from the ocean, through the lower creek, and into the spawning reaches.

Sub-Criterion 1B: Juvenile steelhead migration. Increased movement of out-migrating smolts and kelts out of the watershed, through the lower creek, and into the ocean.

Sub-Criterion 1C: Increased steelhead lower creek survival. Increased steelhead survival in the lower creek during periods that the outlet is closed (for both in-migrating adults and out-migrating smolts/kelts) – i.e., improving the lower creek’s “holding capacity” by creating rearing and refuge habitat.

Sub-Criterion 1D: Maintain habitats for other species of concern. Maintenance of existing foraging/breeding/roosting/etc. habitat for other species of concern, such as California red-legged frog, Western snowy plover, and others.

Sub-Criterion 1E: Increase habitat amounts for other species of concern. Increased amounts of existing foraging/breeding/roosting/etc. habitat for the species of concern.

3.2 Criterion 2: Implementation Costs

This criterion allows for direct comparison of costs of different enhancement options, including planning, design, permitting (discussed more in detail in Criterion 3 below), and construction. Operations and maintenances costs are compared in Criterion 6 below. This criterion is fairly *objective*. The significance of budget constraints in California including the bond freeze makes this criterion of high importance.

3.3 Criterion 3: Regulatory Requirements

Enhancement options will require permits and consultations from a variety of agencies, including the California Coastal Commission, California Department of Fish and Game, US Fish and Wildlife Service, and the National Marine Fisheries Service. Enhancement options will also require varying levels of analysis under the California Environmental Quality Act. The lower the regulatory burden for an option, the lower its associated costs, and the more likely it is to be permitted. This criterion is somewhat *subjective*, but early and frequent consultations with the applicable agencies can reduce the uncertainty associated with the regulatory process and improve the criterion's objectivity.

3.4 Criterion 4: Probability of Securing Funding for Implementation

This criterion addresses in relative terms the likelihood that different enhancement options will be able to obtain grant or other funding for implementation. Options that are more likely to be funded are preferable to those that are less likely. This criterion is *subjective* due to the fact that various state and federal funding sources are constantly in flux and assessing/predicting their availability is very difficult.

3.5 Criterion 5: Life Expectancy without Operations and Maintenance

This criterion allows for evaluation of how long a particular enhancement option might achieve the objectives described in Criterion 1 without long-term operations and maintenance (O&M). For example, a hard-engineered deflection structure would have a longer life expectancy without O&M than a channel dredged in between the mainstem of Pilarcitos Creek and the backwater channel. This criterion is generally *objective*.

3.6 Criterion 6: Intensity and Cost of Operations and Maintenance

This criterion allows for direct comparison of the long-term operations and maintenance efforts and costs. O&M includes activities such as monitoring and reporting, vegetation management, structural inspection, and the like. Criteria 5 and 6 are especially important in light of the limited O&M budgets generally available to California Department of Parks and Recreation projects. This criterion is generally *objective*.

3.7 Criterion 7: Interactions with Other Habitat Enhancement Efforts

It is important that any actions to enhance habitat in the lower creek do not negate other parallel efforts to enhance habitat elsewhere within the Pilarcitos watershed or along Half Moon Bay State Beach. Similarly, enhancement options that would act in concert with other habitat enhancement efforts (i.e., "value-added" projects) would be preferable to those that do not. For example, managing for pulse flows within the creek would likely be beneficial only if the outlet is manipulated so that the pulse flows have an improved likelihood of reaching the outlet. This criterion is *subjective* in that it would be informed greatly by additional information about planned and hoped-for watershed activities (such as other efforts described in the Pilarcitos Creek IWMP).

3.8 Criterion 8: Level of Community/Stakeholder Project Support

Many of this project's TAC members are already on the Pilarcitos Watershed Working Group, a broad group of stakeholders invested in developing community-informed support for watershed improvement measures. Much of the area of potential habitat enhancement considered in this Evaluation is located within Half Moon Bay State Beach (HMBSB), a very popular beach with heavy visitor usage especially during the summer and early fall months. Native American artifacts have been found along the creek and the beach. In addition, the Coastal Trail through HMBSB and over Pilarcitos Creek receives heavy daily usage from local dog walkers, walkers, runners, cyclists, birdwatchers, and other user groups. As such, any actions implemented within the lower creek are likely to receive heavy scrutiny from the Working Group, local residents, and external interested parties and these entities will all have comment opportunities during permitting and CEQA review. This level of scrutiny is especially true of any option that will significantly change how the creek outlet will look and behave. Enhancement options receiving higher levels of stakeholder and overall community support will be easier to implement. This criterion is *subjective*, as the level of community support for a particular enhancement option can often be influenced by the nature of public education and outreach offered by project proponents.

3.9 Criterion 9: Potential Unintended Consequences

This criterion allows for consideration of unintended impacts to habitat, public access opportunities and the like that could result from implementing an enhancement option, including evaluating effects of a catastrophic failure of the enhancement. Some of the enhancement options – such as installation of large woody debris to create scour pools – have been implemented and monitored in other locations along the Central Coast, so their consequences are fairly well-known and understood. Other enhancement options – such as installation of a creek deflection structure on the beach – have few if any local examples along the Central Coast in recent decades[2] to guide evaluation of their consequences. This criterion is highly *subjective*.

[2] Here defined as the period since the 1960s and 1970s that environmental conservation laws such as the Clean Water Act, CEQA, state and federal Endangered Species acts have been in place.

3.10 Criterion 10: Costs and Benefits Relative to Actions above Highway 1

This criterion allows consideration of how enhancement options at Pilarcitos “lagoon” compare to options above Highway 1 (sediment source reduction, vegetation management, etc.) relative to ecological benefits achieved at a given cost. This criterion is highly *subjective* for a number of reasons, the primary one being that enhancements above and below Highway 1 tend to have different targeted ecological outcomes (e.g., steelhead spawning habitat vs. passage/rearing/refugia habitat) and thus are often difficult to compare. The TAC and the Pilarcitos Creek Working Group are valuable resources that will be able to help project proponents perform this analysis.

3.11 Criterion 11: Extent Option “Works with Nature”

The suboptimal conditions for steelhead passage and rearing in lower Pilarcitos Creek exist due to a combination of natural and human-influenced conditions. Enhancement options that “force” the creek to behave in a manner contrary to its known and postulated history and projected future conditions generally work “against” rather than “with” nature and thus may perform poorly and require greater ongoing intervention (i.e., O&M). In the field of restoration science, a general guideline is to “work with nature” which translates into approaches that function effectively within a given landscape context and suite of natural processes. Limited options for addressing effects of human modification in natural landscapes can necessitate approaches less consistent with this general rule. This criterion is fairly *objective.*

4 Enhancement Options

The project team considered five main categories of potential approaches to habitat enhancement in the lower creek:

- Improve the capacity of the existing backwater slough area to provide rearing and refuge habitat for steelhead
- Manage flows within Pilarcitos Creek to improve passage between the creek and the ocean for inmigrating adults and outmigrating smolts and kelts
- Create large, deep scour pools with complex cover in the lower portion of the creek (between Highway 1 and the creek mouth) to provide foraging and refuge habitat for steelhead, particularly outmigrating smolts who need “holding” habitat when they await breach and marine dispersal opportunities

- Limit the northward drift of the outlet to reduce streamflow losses due to beach seepage, improve steelhead passage conditions (increasing scour depth of outlet channel), and potentially increase the windows of time in which steelhead can move between the creek and the ocean
- Alter the equestrian crossing to prevent disturbance to lower creek habitats and create refugia for resident steelhead and outmigrating smolts

A sixth category – erosion control actions above Highway 1 – would likely help to improve steelhead habitat conditions in the lower creek, but actions in the watershed above Highway 1 are outside the present scope of work for this project. However, on-going efforts to reduce watershed sources of excessive sediment (Chartrand et al. 2003) should be continued to improve the potential success of the options presented in this memo.

The outcomes targeted by each enhancement approach are summarized in Table 1 and detailed below. Each section describes an option, how it could be implemented, which stakeholders would partner in implementation, and other details. Each option has its own subsections which describe the associated opportunities and constraints.

Table 1. Summary of Enhancement Options for Lower Pilarcitos Creek

	Potential Outcomes Targeted by Action													
	Outmigrant Steelhead (Smolts and Kelts)							Spawning Steelhead				Nonmigrant Steelhead	
	Habitats		Passage to Ocean		Water Quality			Passage from Ocean				Habitats	
Enhancement Options	Rearing	Refuge	Increased Depths in Channel and/or Outlet	Increased Time Window of Open Outlet	Rearing Habitat	Refuge Habitat	Passage	Refuge Habitat	Increased Depths in Channel and/or Outlet	Increased Time Window of Open Outlet	Water Quality	Rearing[3]	Refuge[3]
Improve Backwater Slough Habitat for Steelhead[1,2]	X	X			X	X		X				X	X
Flow Manipulations in Pilarcitos Creek	X		X	X			X		X	X	X	X	
Create Scour Pools in Lower Channel		X	X					X	X				X
Limit Northward Drift of Beach Outlet	X	X	X	X					X	X		X	X
Improve Equestrian Crossing		X[3]			X	X	X	X			X		X

Notes:
1. Will likely require increased flows within lower channel
2. May require post-catastrophic event engineering in order to obtain requisite permits
3. Only if perennial flow is provided to the creek mouth

4.1 Option 1: Improve Backwater Slough Habitat for Steelhead

4.1.1 Existing Wetland Environment

The backwater slough is a small relict channel within the deltaic stream mouth that is almost completely stabilized by riparian woodland and freshwater marsh vegetation. The mouth of the slough at the back of the beach is currently choked by closed, continuous stands of dense emergent marsh (mostly tule, bulrush, sedge, and bur-reed; *Schoenoplectus californicus, S. pungens, Scirpus microcarpus, Sparganium eurycarpum*). The slough drains a small, ephemeral, and urbanized subwatershed to the north and east of lower Pilarcitos Creek. The slough is parallel and to the east of the mainstem Pilarcitos Creek channel (Figure 2). The upper extent of the slough is part of a historic drainage that had a confluence with the creek near the present-day location of the SAM wastewater treatment plant (Figure 3).

The current backwater slough last supported an active, unstable sand bed in the late 1980s – early 1990s. At various times in its history, this channel (especially its northern limits) has carried flows from the mainstem channel of the creek. The backwater channel's direct connections to mainstem flows were eliminated after significant flooding events in the spring of 1986. These floods, and the subsequent growth of a dense willow thicket on both sides of the channel, have reinforced the more westerly position of the mainstem and prevented subsequent flooding events from markedly altering the channel configuration, as the significant flood event in 1998 did not result in mainstem flow through the backwater slough.

The slough receives runoff from nearby residential, commercial, and agricultural areas, and thus is most likely nutrient-enriched. While we have not directly monitored water quality in the slough, the presence of large amounts of filamentous algae is indicative of a nutrient-enriched, eutrophic environment (Photo 1). Decomposition of abundant filamentous algal biomass in anoxic bottom environments appears to be conducive to high levels of sulfide production in bottom sediments, indicated by the notable sulfidic odors of the disturbed bed.

Photo 1*: Filamentous algae attached to emergent vegetation in the backwater channel, April 2009. Photo: C. Toms.*

4.1.2 Goals and Objectives

The primary goal of backwater slough enhancement is to provide productive lagoon-like off-channel summer rearing freshwater habitat for juvenile steelhead. Secondary goals include providing winter and spring off-channel refuge habitat for spawning steelhead and returning kelts, as well as rearing habitat and refuge for outmigrating steelhead smolts. If this backwater slough becomes stable and perennial, it may provide potential habitat for the introduction of tidewater goby (potentially from sites such as San Gregorio Creek Lagoon). Since lower Pilarcitos Creek does not provide steelhead-supporting lagoon habitats like those found in other Central Coast systems (such as a Waddell, Scott, Laguna, Wilder, and other creeks), this option is intended to provide a kind of "surrogate" lagoon. "Surrogate" lagoon habitats such as those found in San Vicente Pond along San Vicente Creek in Santa Cruz County[3] can support summer rearing and winter refugia, but only if certain habitat objectives are met. In order to provide suitable habitat for steelhead, enhancement of the Pilarcitos backwater channel must:

- Maintain tolerable water temperatures for steelhead (preferably a daily maximum of 22°C but tolerable as high as 26°C for short periods of 1-2 hours) and dissolved oxygen

[3] It is important to note that San Vicente Pond has a very different environmental setting (coarse, permeable cobble and gravel alluvium, high summer baseflows) than that of the Pilarcitos backwater channel, and as such is only a partial ecological analogue.

(preferably above 5 mg/L but tolerable above 2 mg/L for short periods of 1-4 hours at dawn or during foggy periods). Below 2 mg/l, steelhead survival is problematic but has been documented in the 1-2 mg/l range for 1-2 hour periods in San Simeon Lagoon (Alley 1995; 2006)

- Facilitate year-round access between the backwater channel and mainstem habitats with suitable water quality so that salmon foraging in the backwater channel have access to cooler, more oxygenated waters[4]
- Not expose steelhead to excessive predation or stranding risk

It is important to note that perennial flow to the creek mouth – sufficient to maintain a connection between the slough and the main channel – is required to allow nonmigrant, juvenile steelhead survival through the summer and fall.

4.1.3 Approach Options

There are three possible approaches considered here to expand perennial backwater pool habitat that is connected year-round to the mainstem suitable for rearing juvenile steelhead and supporting smolts:

(1A) Hydraulic reconnection of upstream end of slough to main channel. Option 1A directly reconnects the slough with the mainstem by excavating a new channel between the mainstem and the head of the backwater slough. The connector channel would be excavated along approximately 200 feet from the head of the slough heading due west across the willow thicket/floodplain to the mainstem (Figures 2 and 5).

(1B) Hydraulic reconnection of downstream end of slough to main channel. This option directly reconnects the northern, downstream end of the slough with the mainstem by excavating a short connector channel between the two.

(1C) Expand open water shallow backwater pond habitat. Option 1C would include a channel reconnection as in 1A and adds conversion of freshwater marsh to shallow open water and submerged aquatic vegetation (SAV; sago and dwarf pondweed, *Stuckenia pectinata, Potamogeton pusillus*) habitat. This conversion would be done by excavating freshwater marsh that has infilled the slough margins and deepening the slough bed during summer. The excavated backwater pond would be actively revegetated with submerged aquatic vegetation (SAV).

[4] The work of Bond 2006 and Hayes et al. 2008 hypothesizes that the high productivity of coastal lagoons relative to in-stream environments may help juvenile steelhead survive in lagoons - environments which otherwise would be metabolically unsuitable due to generally higher temperatures and lower DO levels.

4.1.4 Opportunities and Constraints

There are substantial uncertainties about the stability and likely ecological outcomes (habitat functions) of the backwater slough modification options. In all options, the backwater slough would be reconnected to the main channel to provide fish access. Channelized reconnection of the slough would also necessarily affect its sedimentation regime.

Sedimentation: Option 1A/1C. Hydraulic reconnection with the main channel at its upstream end (for approaches 1A and 1C) and the attendant sediment bedload during high flows would likely cause increased deposition of sand and silt in the excavated channel. These deposits would be concentrated at locations where inflow velocities rapidly decrease – either in the connector channel itself (where overbank flows occur), or in an internal delta at the mouth of the connector channel where it joins the open water slough habitat.

The increased deposition of sand and silt at the upper end of the backwater slough following channel reconnection would likely be followed by the rapid spread of dominant clonal (rhizomatous) freshwater marsh vegetation following flood events. Abundant sediment and nutrient availability in the slough would likely support the rapid spread of freshwater marsh from the edge of the slough, which would encroach into open-water (SAV and steelhead) habitat. Clonal spread of tule, bulrush, bur-reed, and similar emergent marsh vegetation may be expected to occur at rates approaching or exceeding 0.3 m per year across shallow (0.3 – 0.5 m summer water depth), gently sloping bedforms such as bars and deltas.

Connections between channels and open water habitat subject to rapid sedimentation and marsh encroachment would likely require artificial maintenance by excavation. Excavation for open water habitat maintenance would require periodic re-entry into the floodplain wetlands with amphibious excavation equipment and rehandling of excavated sediment (i.e., dredge spoil management). The frequency and magnitude of maintenance would likely depend on the return interval of peak flood events and their sediment loads. It is difficult to predict marsh growth based on the fluvial sedimentation impacts of future storms' frequencies and intensities. However, based on a qualitative examination of the spread of wetland vegetation in the creek mouth's aggraded delta in the 1980s and 1990s (evident in aerial photographs), we offer a preliminary, subjective estimate that a reasonable maintenance interval could range from 5 to 10 years, or up to 15 years if Pilarcitos Creek sediment loads decrease significantly below 1990s levels. We caution, however, that the seaward position of the backwater slough in the mouth makes it vulnerable to catastrophic overwash deposition if an extreme El Nino storm event occurs in conjunction with spring high tides.

Sedimentation: Option 1B. Option 1B would require relatively less excavation than Options 1A and 1C and would avoid potential sedimentation of the slough that may occur with reconnection at the upper end. However, the invert (bottom) elevation of the excavation must be high enough to prevent draining the slough, and low enough to allow for adequate hydraulic exchange between the slough and the mainstem. If perennial flow is not provided to the creek mouth, it is unlikely that this option will provide steelhead habitat into the summer and fall. Also, vegetative encroachment at the slough outlet will be problematic, as with Options 1A and 1C, and would likely require annual maintenance to limit this encroachment and maintain a proper outlet elevation in relation to the main channel.

Sediment disposal and management during construction and maintenance of reconnected channels or expanded backwater pool habitats would also present environmental and engineering constraints. The excavation of sulfide-bearing sediments, which are toxic to aquatic organisms, would likely induce careful scrutiny by regulatory agencies and would need to be timed to avoid impacts to sensitive resident species such as California red-legged frog and potentially San Francisco garter snake (though the latter has not been observed at the project site in recent years). Dredged sediments would have to be placed in ruderal (weedy) upland disposal sites that would not be adversely impacted by the oxidation of sulfides into acid sulfates. Off-site spoil disposal would likely require stockpiling and double-handing of spoils, temporary staging area impacts within the floodplain, and construction impacts (e.g., noise, odors) during the summer-early fall season when adjacent campgrounds are occupied.

The stability of newly excavated open-water habitats in disturbed, nutrient-rich conditions is uncertain. Even if native SAV species are actively introduced into these habitats, high dissolved nutrient concentrations (especially nitrate) may result in the excessive growth of epiphytic (attached) filamentous algae on SAV. Reduction of freshwater marsh vegetation, which sequesters nutrients and shades the water surface, is likely to result in relatively higher available nutrient pools and increased productivity of filamentous green algae. Excessive filamentous algal production would increase the risk of critically low dissolved oxygen periods (times of high biological oxygen demand) during the summer steelhead rearing/refuge period, contrary to this option's primary ecological objectives. This risk would require further evaluation in future design feasibility steps.

Finally, **diversion of flows** from the mainstem of Pilarcitos Creek into the backwater slough may reduce the volume of flows available to excavate/maintain scour pools in the bed of the mainstem channel downstream of the connector channel (see Section 4.3 below). This flow diversion creates a potential conflict between simultaneous implementation of these separate enhancement options.

4.1.5 Feasibility Evaluation

Criterion #1: Benefits to Target Species. The backwater slough enhancement option would potentially provide productive summer rearing habitat (increased growth and survival of juvenile steelhead) in off-channel slough open water habitats that would be similar to small, shallow lagoons. Such habitats may enable juveniles to reach larger size-classes with higher rates of survivorship and reproductive success rates. The benefits of a functional backwater slough for summer rearing of juvenile steelhead under optimal conditions would likely be comparable with those of the off-channel pond at San Vicente Creek for juvenile coho. This option does create the potential for excessive mortality due to the temporary drawdown of slough water levels due to fluctuations of groundwater elevations or outflows (related to groundwater withdrawals/pumping, stream diversion, or insufficient dam releases) during the low-flow season. Therefore, the design and maintenance of such a feature must be carefully considered and rigorously analyzed in the conceptual design phase. Resource agencies may decide that the costs and risks of maintaining such a feature may not be worth the potential benefits to steelhead.

Criterion #2: Implementation Costs. Implementation costs of the backwater slough alternative may be substantial for both construction and particularly for long-term maintenance, due to complexity of excavation work in sensitive wetland habitats. Implementation costs would include design work, grading plans, permit approval and environmental impact costs, potential mitigation costs for water quality and sensitive species impacts of construction, mobilization and staging of excavation equipment, temporary stockpiling and double-handling of excavated spoils, off-site spoil disposal costs (transport, possible tipping fees), non-native vegetation management during post-excavation recovery, and periodic maintenance (re-excavation of accreted sediment and infilling by creeping freshwater marsh vegetation).

Criterion #3: Regulatory Requirements. Permitting requirements for excavation and fill in coastal wetlands regulated by the U.S. Army Corps of Engineers (USACE) and the California Coastal Commission (CCC) would include Corps permits (either Nationwide Permit 27 or standard individual permit process, at the discretion of the Corps), Coastal Development Permits from either the Coastal Commission or the City of Half Moon Bay (the latter, if the site is within the HMB Local Coastal Plan), California Dept. Fish and Game (CDFG) 1601 stream alteration agreement, Section 401 water quality certification from the Regional Water Quality Control Board (RWQCB), and CEQA evaluation (presumably Mitigated Negative Declaration).

This option would likely affect California red-legged frogs and steelhead, providing long-term benefits to both species, but potential short-term (construction) and long-term (maintenance) adverse impacts to California red-legged frogs. The federal permit process would require at least informal consultation with USFWS (Biological Assessment and request for "not likely to adversely impact federally listed species" letter), but may require formal Section 7 consultation for Incidental Take Statement (ITS) including Section 10 authorization for incidental take of California red-legged frogs (and potentially San Francisco garter snake, if they are deemed to be potentially present) under the Endangered Species Act. The backwater slough is located landward of the beach, and would be unlikely to adversely affect the other principal federally listed species in the project area, the western snowy plover, which is restricted to open sand habitats.

Criterion #4. Probability of Securing Funding for Implementation. Because this option would potentially have long-term benefits for two federally listed species, Central coast steelhead and California red-legged frogs, it may be eligible for recovery grant funding and coastal wetland grants from USFWS and the National Marine Fisheries Service (NMFS). The relatively high construction and maintenance costs of this option, however, may make full project funding challenging.

Criterion #5. Life Expectancy Without Operations and Maintenance (O&M). This option would likely have a relatively short effective life without long-term maintenance. Highly productive tall emergent clonal freshwater marsh vegetation in and surrounding the project site indicates a high probability that fringing marsh would expand and infill the shallow open water (submerged aquatic vegetation) habitats, causing a significant reduction in open water/SAV habitat within 5-10 years in the absence of a major fluvial flood depositional event or oceanic overwash. Extreme coastal storm or fluvial flooding events would increase the risk of premature substantial maintenance or reconstruction needs.

Criterion #6. Intensity and Cost of Operations and Maintenance. The type and intensity of maintenance activities, and their costs, would be similar to those of construction: they would require excavation of accreted sediment, organic matter, and vegetation in the slough, temporary stockpiling or double-handling, and off-site disposal. The frequency and timing of maintenance or rehabilitation of the enhanced backwater slough would depend on the return intervals of extreme coastal storm or fluvial flooding events. These may be expected to occur roughly within one to several decades. Progressive vegetative infilling (succession) would likely occur in less than a decade, regardless of storm return intervals.

Criterion #7. Interactions with Other Habitat Enhancement Efforts. The backwater slough habitat functions would likely be enhanced by interaction with increased flows due to seasonally timed dam releases (Option 2) or other flow enhancement efforts (e.g., use of recycled water, improved irrigation efficiency throughout the watershed, etc.). The backwater slough habitat functions may also benefit from restriction of stream outlet deflection (Option 4) if it forces the outlet to form and close at a location with relatively high berm crest elevations, and corresponding higher potential for high maximum lagoon water surface elevations at or above floodplain elevations.

Criterion #8: Level of Community/Stakeholder Project Support. It is uncertain whether California State Parks or local neighbors would be supportive of short-term construction impacts, recurrent maintenance, and the impacts of this maintenance to the floodplain in an area of high visitor use (pedestrian, equestrian, bicycle trail, beachgoers, campers).

Criterion #9: Potential Unintended Consequences. Potential unintended consequences of excavation could include a temporary decline of backwater slough water quality (hypoxia, toxic levels of dissolved sulfides, low pH) due to exposure to mobilized anoxic organic sediments from the slough benthos. Other potential unintended consequences could involve excessive steelhead mortality due to the factors described under Criterion #1 or nuisance mosquito production from the slough. The San Mateo County Mosquito and Vector Control District should be consulted if this option is moved forward into conceptual design.

Criterion #10: Costs and Benefits Relative to Actions Above Highway One. Backwater open-water habitats with native submerged aquatic vegetation and fringing freshwater emergent marsh could potentially be developed in off-channel impoundments or excavated ponds in upstream reaches of Pilarcitos Creek. The relative costs and availability of sites with suitable topography for creation of analogous backwater slough habitats upstream of the stream mouth floodplain are unknown and not part of this feasibility study.

Criterion #11: Extent Option "Works With Nature." The backwater slough habitat emulates a natural backwater slough habitat structure, based on enhancement and expansion of an existing spontaneous geomorphic feature. The long-term successional trend of this feature, however, is likely to be a reduction of open water habitat, an increase in freshwater marsh, and sediment accretion. Maintenance of the enhanced backwater slough system would require an engineered reversal of natural successional trends. The natural formation or expansion of backwater sloughs is possible under some infrequent extreme fluvial flood events that cause erosion of meander scars or secondary channels, followed by abandonment of channels.

4.2 Option 2: Flow Manipulations in Pilarcitos Creek

Note: *The option of managing in-stream flows in Pilarcitos Creek may be enhanced if used in conjunction with Option 4: Limit Northward Drift of Beach Outlet. The rates and volumes of flows that could be managed for key life stages of steelhead could be more productive if both the hydrologic and biological constraints of the lower reach are managed in tandem. Hydrologically, an outlet deflection structure would minimize beach infiltration losses in the* *channel's current configuration, thus maximizing the hydraulic ability of the channel to maintain fish passage between the ocean and the creek. The combination of Options 2 and 4 will be more likely to support at least a small summer lagoon, including a connection to the backwater slough, provided that perennial flow to the beach is maintained. Biologically, this structure would also help to reduce predation and possible stranding of juveniles within the backbeach runnel. With this understanding, we discuss this option in detail below.*

Summary. Small flow pulses released from one or multiple sources upstream that reach the creek mouth could facilitate passage habitat for out-migrating smolts (creek to ocean) during years when a lagoon mouth closes before mid-May. Under existing conditions, many out-migrating smolts become stranded in the backbeach runnel or channel, as flows become insufficient to maintain opening to the ocean. This shallow backbeach runnel provides limited to no cover and water quality conditions degrade in the absence of sufficient inflows. Smolts trapped in the backbeach runnel appear to perish from predation before it re-opens in early winter or have low ocean survival due to the poor conditions (Bond, 2006; cited in PWA, 2008, Alley, D., pers. comm.). The unique physiography of the lower Pilarcitos Creek system – with its small volume, ephemeral nature, and an elevation well above the vertical reach of the tides – makes a flow management alternative more feasible for Pilarcitos Creek than other coastal systems. The physiography facilitates the use of pulse releases to re-open or keep open the outlet between the lagoon and the ocean, though significantly smaller release rates could be needed if additional measures to encourage outlet opening are adopted.

4.2.1 Setting

The Pilarcitos Creek watershed is a coastal drainage with an approximately 28 square mile drainage area. The upper watershed of Pilarcitos Creek is managed by two reservoirs – Pilarcitos Lake and Stone Dam – reducing the effective watershed of the lower channel to 21.8 square miles. Pilarcitos Lake is used to store water for the San Francisco Public Utilities Commission (SFPUC). Stone Dam (also managed by the SFPUC) is used to divert water to Coastside County Water District (CCWD) and Lower Crystal Springs Reservoir (owned by SFPUC). Historically, all water influent to Lake Pilarcitos or Stone Dam was stored or diverted east to these reservoirs with no flows released downstream, except for precipitation-runoff exceeding capacity and the small volume seeping around the dam[5]. Since October 2006, the dams have been operated such that most baseflows entering Pilarcitos Reservoir are bypassed to downstream environs (Apperson, S., pers. comm., 2009).

[5] Balance Hydrologics (1997) suggests that historical operations of the dams reduced low flows in the creek by approximately 50 to 90 percent varying with the type and time of year.

Research conducted on Waddell Creek (a similar-sized coastal watershed located approximately 25 miles south of Pilarcitos Creek but with an extensive lagoon and freshwater marsh) from 1934 to 1941 (Shapovalov and Taft 1954) and analyzed by Kelley and Dettman (1981) demonstrated that smolt production in Waddell Creek increased linearly as minimum streamflow during the summer increased. More recent studies have recognized that aquatic resource restoration and enhancement in Pilarcitos Creek is contingent on securing appropriate instream flows of sufficient quantity, quality, and duration to allow viable populations of aquatic resources to persist as a healthy community (Feeney et al. 1997, revised 2002). These studies proposed flow augmentation using modifications to CCWD's diversions at Stone Dam and re-capture at the CCWD well field approximately 2 miles downstream from the dam (upstream from California Highway 1). "Experimental" releases from Stone Dam, beginning in 2007, appear to be at least partially responsible for the anecdotal presence of flows at the pedestrian bridge relatively later than in previous years (Kerbavaz, J., pers. comm., 2009) or measured at the USGS gage at HWY 1 (PWA 2008; Hastings, unpublished data).

The Pilarcitos Lagoon Enhancement Technical Advisory Committee (TAC) and this team have identified the importance of addressing both (1) fish passage at Pilarcitos Lagoon outlet and (2) the quality and quantity of upstream spawning and rearing habitat. Flow modifications must address flow quality, quantity, and duration through the lower reach (Hwy 1 to the Pacific Ocean) in order to benefit fish passage. We designed the flow modification alternatives described here to address these needs.

<u>How do we know flows released from Stone Dam are conveyed to the lower reach of Pilarcitos Creek</u>? As discussed above, since October 2006 the SFPUC has been experimenting with releasing flows of between 1 cfs and 2 cfs from Stone Dam. We evaluated mean daily flows at the USGS gage at Half Moon Bay[6] (referenced in this memo as "Pilarcitos Creek at HWY 1") over the last three years and compared them to the long-term average daily flows. We found that even in dry years[7] such as water years[8] 2007, 2008, and 2009, the experimental releases may have led to higher mean daily flows at the Pilarcitos Creek at HWY 1 when compared to the long-term average (45-year period of record). Similarly, when flows at Stone Dam diminished

[6] USGS gaging station #11162630: Pilarcitos Creek at Half Moon Bay

[7] Annual and long-term average precipitation evaluated from Balance rain gages along Coastal San Mateo County and mean-annual precipitation maps (Nahn and Saah, 1988)

[8] A water year is measured beginning on October 1 of the previous year and ending on September 30 of the stated year. For example, WY2009 began on October 1, 2008 and ended September 30, 2009.

from 1.1 cfs on August 27, 2009 to 0.4 cfs on August 28, 2009, flows at HWY-1 dropped from 1.7 cfs to 0.3 cfs[9] on the corresponding dates.

If flows at Stone Dam are so closely linked to those near the mouth during a summer heat spell when losses throughout the watershed are at their maximum, releases from the dam are likely to propagate downstream even more efficiently during spring months, when there are fewer intervening losses. And managed releases from this (or other) facilities during the spring months could potentially improve outmigration conditions for smolts by (1) increasing the window of time in which the outlet is open to the ocean and (2) providing additional water depth in the lower channel so that smolts can reach the open outlet. These are briefly explored under Opportunities below.

4.2.2 Goals and Objectives

The goals of flow management or "pulse flows" would be (1) to improve steelhead passage at Pilarcitos Creek mouth, specifically for smolt outmigration, and possibly adult spawning migration and (2) to improve rearing habitat functions. Therefore, objectives to achieve this goal include:

Objective #1: Extend the window of time the lagoon is open in the late spring to the ocean at times critical to the life stages of steelhead, and;

Objective #2: Provide sufficient water quality conditions for the various life-stages of steelhead.

Along the Central Coast including San Mateo and Santa Cruz Counties, the adult steelhead spawning run extends from December through April (Shapovalov and Taft 1954), while smolt outmigration typically occurs in late April into May and later if sufficient flow and conditions provide access to the sea (D. Alley, pers. comm., 2009). Adult run timing is highly dependent on available flows and typically coincides with storm events that result in high stream discharge and allows fish access to the creek from the Pacific Ocean. Most smolts (except for some of the very largest ones that may emigrate earlier during larger storm events) typically migrate seaward during the descending hydrograph in late March through May, when storms are unlikely. Steelhead are iteroparous; not all adult spawners die after reproducing. Iteroparous individuals (called "kelts") generally emigrate back to the ocean from March through July, provided sufficient streamflow for migration and passage to the ocean is available. However, spent kelts returning to the sea and juvenile fish emigrating from the stream may find it difficult or impossible to exit Pilarcitos Creek if they do not do so during the

[9] The larger drop in flow at the HWY-1 gage could be associated with the potential error in the USGS rating curve at these low flows—rated as poor to fair at low flows.

early part of the descending hydrograph (see Photo 2); this migration impediment typically begins in April and May when insufficient flows and coastal dynamics result in the closure/attenuation of the outlet.

Photo 2: *Stranded steelhead smolt in the backbeach runnel, 2008. Photo: K. Mangold.*

4.2.3 Approach

The approach to this option involves four elements:

1. Determine what flows are needed to keep the lower creek open to the ocean
2. Identify potential water sources that may be available for late-spring pulse releases
3. Identify the optimal time period to implement late-spring pulse flows
4. Develop detailed frequencies, durations, and rates of managed pulse flows

Following a description of these four elements, we identify two key outcomes:

1. How might a hypothetical pulse release affect flows at or near the mouth?
2. How much water does the hypothetical pulse release require?

Approach, Part 1: Determine flows needed to keep the lower creek open to the ocean. Before a flow prescription can be described for this enhancement option, it is important to describe existing hydrologic conditions under various water year categories (i.e., dry, average, wet). Table 2 presents data from water years 2003 through 2009 describing annual precipitation, water year type, the first date of observed outlet closure (BeachWatch 2009), and the mean daily flow conditions at Pilarcitos Creek at HWY 1 associated with these dates/period of closure.

Table 2. Pilarcitos Creek Lagoon Closures with Precipitation and Flow Conditions, WY2003-WY2009, Pilarcitos Creek, Half Moon Bay, California

Water Year[1]	Rainfall[2]	Year Type[3]	Last Date Lagoon Observed Open[4]	Flow[5]	First Date Lagoon Observed Closed[4]	Flow[5]
WY	*(inches)*	*(precip)*	*(D-M-Y)*	*(cfs)*	*(D-M-Y)*	*(cfs)*
WY2003	30.08	Average	Early June, 2003	6.1	22-Jun-2003	5.0
WY2004	23.86	Below Average	Early April, 2004	5.6	22-May-2004	3.0
WY2005	37.29	Wet	24-Apr-2005	15	16-Jul-2005	2.6
WY2006	35.38	Wet	Late June, 2006	7.2	15-Jul-2006	4.0
WY2007	18.78	Dry	Late April, 2007	5	2-Jun-2007	4.2
WY2008	20.41	Dry	Late April, 2008	4.4	3-May-2008	3.0
WY2009	21.08	Dry	21-Apr-2009; 21-May-2009	4.2; 5.6	22-April-2009; 21-May-2009	4.2; 5.6
			average	6.6	average:	4.0

Notes

1) A water year is typically used to classify water resource issues and begins on October 1 fo the previous year and ends on September 30th of the stated year. For example, WY2003 began on October 1, 2002 and ended on September 30, 2003.
2) Annual rainfall reported for water year, NCDC #3714, Half Moon Bay, Elevation 37 feet; CA dept. of Parks and Rec.
3) Year Type refers to the annual rainfall reported for the given water year relative to the long-term annual average (28.99 inches), based on 50 yr period of record (NCDC #3714)
4) Dates identifying Pilarcitos Creek open or closed to open; BeachWatch Data, Half Moon Bay State Beach. Mulitple closures/openings are common WY2009 included these as a result of more frequent monitoring by BeachWatch and this team.
5) Mean Daily Flow as reported by USGS gaging station #11162630: Pilarcitos Creek at Half Moon Bay (HWY 1), approximately 1.0 mile upstream of beach. Years when no specific date was given--MDF data is average over a 15-day period surrounding observations as described by BeachWatch.

Under existing conditions, it appear that flows of greater than 5 to 7 cfs, measured at the USGS gage in Half Moon Bay, are sufficient to sustain open flow from the lagoon to the ocean, at least under some wave and tide conditions. It may be reasonable to assume that smolt will be able to move from the lagoon to the ocean whenever the lagoon is open[10]. It is uncertain how much more flow may be needed to allow kelts to move from the lagoon to the ocean.

Other flow-planning criteria not yet known are:

1. How much flows may diminish between the Half Moon Bay gage site and the lagoon due to local diversions, out-of-basin diversions at the Balboa wellfield, and evapotranspiration (c.f., observations made during this study and those made by our staff in 2005: Parke and Hecht 2010),
2. How much flow releases will attenuate from the point of release to the Half Moon Bay gage site, and
3. How much flow accretion from tributaries and groundwater may augment the releases.

[10] The "open" condition in the beach with respect to steelhead passage refers to the continuous minimum water depth from the mouth to the ocean of approximately 0.2 ft for smolts, and 0.4-0.6 ft for adults. The outlet may be hydraulically "open" to flow too shallow to allow fish passage during declining flows.

4. The effects of the outlet's shoreline position (i.e., position within the wave energy gradient within HMB) on the threshold streamflow required to maintain an open outlet sufficient for fish passage[11]
5. Outcomes for the Pilarcitos Creek Operational Flexibility Project and Water Budget Development Project associated with operations at Stone Dam and maintained by SFPUC.

Approach, Part 2: Identify potential water sources that may be available for late-spring pulse releases. Potential sources for late-spring pulse releases include:

1. Stone Dam or another SFPUC water source (evaluated upon completion of the Pilarcitos Creek Operational Flexibility Project),
2. Releases from storage on private property elsewhere in the watershed, such as at Pilarcitos Quarry as part of its proposed expansion (6 to 10 years from now, if approved),
3. Short-term augmentation from groundwater pumpage, and
4. Short-term augmentation from treated wastewaters via the Sewer Authority Mid-Coastside (SAM)[12]

A combination of sources may prove most beneficial, allowing smolts to move from upstream sources in a manner imitating natural freshets, while also providing the temperature and water quality needed to enable not only smolt migration but also to protect late-season incubating eggs in upstream locations. Treated wastewaters, at least those from the SAM facility, are of particular value because they may be able to be released on request to help breach the creek closure (bar) at times when 5 or 6 cfs may not prove sufficient.

Approach, Part 3: Identify the optimal time period to implement late-spring pulse flows. Based on the limited data in Table 2, mean daily flows in Pilarcitos Creek at HWY 1 sufficient to maintain an open outlet range are roughly between 5.0 cfs and 7.0 cfs, depending on year type[13]. Flows in Pilarcitos Creek at HWY 1 reach this critical threshold as early as April (2004, 2007, 2008 and 2009) and as late as June (2003 and 2006). Thus, late-spring pulses should be released from April to June, a critical period associated with smolt outmigration that overlaps

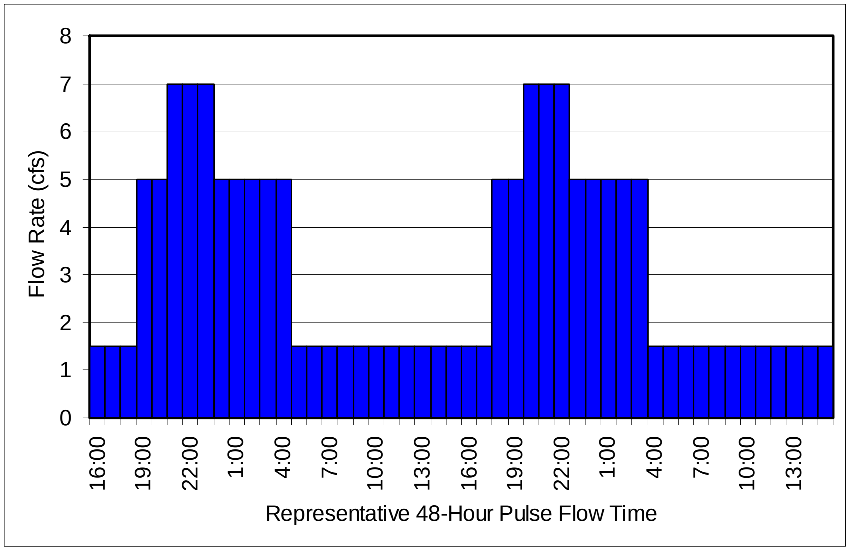
[11] Outlet closure is a function of stream power (scour potential) vs. wave power (beach accretion potential); wave energy decreases northward in HMB (see discussion of Bascom 1954 in WWR 2009).
[12] This project is still in the conceptual phase.
[13] This team acknowledges that additional data are required to better evaluate the range and conditions of flow during lagoon closure.

with a smaller window of time for kelt outmigration. Managed pulse flow releases should be executed during this period and in coordination with observed flows in Pilarcitos Creek at HWY 1.

Approach, Part 4: Develop detailed frequencies, durations, and rates of managed pulse flows. Based on trap studies conducted in Waddell Creek, steelhead smolts utilized a spring rain which generated increased flows and facilitated outmigration. After the storm, a period of a week passed before smolts were observed again in outlet traps (Smith, J., pers. comm., 2009). A 1987-1988 steelhead and coho smolt trapping study in the San Lorenzo River indicated that during spring storms, a very short time (4-7 days) elapsed before large numbers of outmigrating smolt could be observed (Alley, D., pers. comm., 2009). These studies suggest that pulse flows should focus on extending the receding limb of spring storms to ensure an open lagoon up to a week after a storm. Two days (48 hours) of pulse flows may be sufficient to maintain adequate flows to provide ample time to extend existing post-storm out-migration periods (Alley, D., pers. comm., 2009). These releases should mimic a natural hydrograph by quickly ramping up to a peak flow during the evening/early morning hours to minimize water losses (e.g., evapotranspiration, diversion). This strategy also targets species needs, as steelhead prefer to migrate during the night to avoid predation. Another release would ensue the following evening to complete the 48-hour pulse.

Graphic 1 illustrates a representative 48 hour release at Stone Dam, as described above. The current Stone Dam releases of 1.5 cfs would be increased to 5 cfs in the mid-evening hours after sunset. After a couple hours flows would again be increased to 7 cfs, but only for two to three hours to emulate a pulse and return to 5 cfs into the early morning hours. At or near daylight, releases would return to 1.5 cfs and repeated in the following evening.

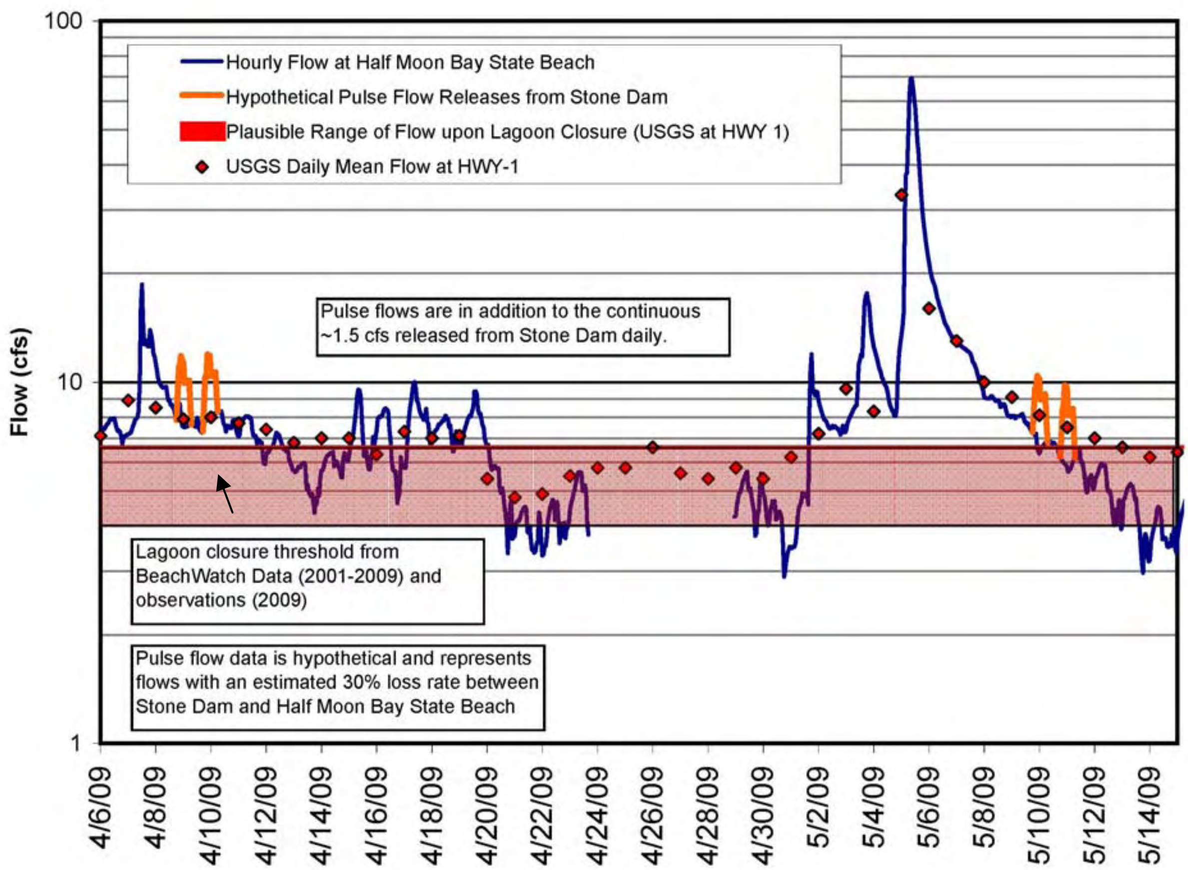
The release in Graphic 1 appears mechanical and may not mimic the characteristics of a storm; however, due to the distance the release has to travel from Stone Dam to the mouth, the transition to higher or lower discharge would likely be attenuated by channel roughness and some bed and overbank infiltration or storage. Conditions at the mouth would likely experience a slower rising and falling limb of this simulated event.



Graphic 1. *Representative hourly flow rates and equivalent volumes for a 48-hour release at Stone Dam*

<u>Outcome #1: How might a hypothetical pulse release affect flows at or near the mouth?</u> In Graphic 2, we illustrate how representative 48-hour period of a pulse-flow release might have been used in 2009 to extend receding storm flows near the mouth after a storm. The graph represents hourly flow data between April 6 and May 15, 2009 for Pilarcitos Creek at Half Moon Bay State Beach[14] (Hastings, B., unpublished data). Flow records from a USGS gage below Stone Dam suggests SFPUC was continuously releasing approximately 1.5 cfs during this period. The two periods of pulse flows shown represent releases in addition to the 1.5 cfs to emulate nighttime peaks on the receding limbs of two identified storm peaks. When flows at Pilarcitos Creek at HWY 1 recede below a threshold (8 cfs in this case), a release (here, assumed solely from Stone Dam) can be coordinated to elevate flows to extend an open outlet.

[14] Balance Hydrologics' temporary gaging station; located on east bank under the pedestrian bridge, period of record: partial water year 2009 (April 2 through September 2, 2009) Data is preliminary and subject to change.



Graphic 2. *Hourly flow at Half Moon Bay State Beach during the outmigrant period April 6 – May 15, 2009. Two hypothetical pulse flows (48-hour releases) are shown and assume a 30% loss between Stone Dam and HMB State Beach. The shaded zone shows the approximate range of flows recorded at the USGS gage at HWY-1 when lagoon closure occurs. Mean daily flows for the USGS gage at HWY-1 are provided for reference.*

<u>How much water does the hypothetical pulse release require?</u> In the example above (Graphic 2), two, 48-hour release would require less than 20 acre-feet (ac-ft) of water in addition to the continuous release (current operation) of 1.5 cfs or 119 ac-ft over the same time period represented in Graphic 2.

The methods, observations, and analysis described above suggest the following conclusions:

Once flows recorded in Pilarcitos Creek at HWY 1 recede below about 8 cfs, flow augmentation could benefit conditions in the lower reach by extending the duration for which the outlet is open, thus providing a longer window for passage;

If water is available, managed pulse flows increase released water volumes by a small amount and might support steelhead passage at the mouth;

A pulse release management plan will require both on-line monitoring and verification of its effectiveness at the lagoon. Points of measurement will likely vary with the sources of water. It should be assumed that the USGS gage site at Pilarcitos Creek at HWY 1 will be the minimum essential measuring point.

4.2.4 Opportunities and Constraints

Although this analysis was limited and additional research and coordination with water users and water resource management agencies is necessary, there are some easily identified opportunities that favor and constraints that do not favor this enhancement option. A preliminary list of opportunities and constraints is described below; it will likely be expanded upon further discussion with the TAC.

Opportunities:

1) Other viable sources of water for short-term releases exist or are in the proposal/planning stages (Pilarcitos Quarry, etc.). A combination of sources may prove optimal to increase flows above critical closure thresholds (which appear to be 5 to 7 cfs measured in Pilarcitos Creek at Highway 1, see Graphic 2);
2) Pulse-flow releases during suitable weeks of April and May can substantially improve passage of smolts and kelts into the ocean; this can be most effective if releases are used to extend high flows during the falling limb of a storm;
3) In successive dry years, when no water from reservoirs may be available for release, alternative water sources may be available. These may include using diversions from private holdings, short-term use of groundwater, releases of tertiary-treated effluent from the SAM facility, and voluntary “diversion-and-pumping holidays” irrigation patterns that would allow enough water to flow through the lower creek so that the outlet remains open and;
4) This approach would likely have even greater effectiveness when implemented in conjunction with limiting the northward drift of the beach outlet (Enhancement Option 4)

Constraints:

1) As noted by all previous investigators examining fish habitat conditions in Pilarcitos Creek, sedimentation in the stream channel is a pervasive problem that is a major limiting factor to steelhead production in the watershed. Any reduction in bed sedimentation will increase the effectiveness of a pulse release program, not only by facilitating increased rates of reproduction, but also by (a) providing improved passage

habitat as the smolts move downstream, (b) offering better cover, minimizing predation losses during outmigration, and (c) increasing the amount of above-surface flow in the stream, perhaps by 1 to 2 cfs or more, by eliminating the need to sustain as much hyporheic (shallow sub-surface) flow before surface flow can be sustained.

2) The USGS gage located at Pilarcitos Creek at HWY 1 (#11162630) has limited funding and is currently scheduled for removal in March 2010. This gage can serve a critical role in effectively managing pulse flows for the benefit of steelhead.

3) We have not quantified the magnitude of infiltration losses in the backbeach runnel during April and May, or the tradeoff in increased duration of open flow between the creek and the ocean that could be realized by deflecting the outlet farther to the south (Option 2.4 below). Additional observations will help identify the premium that may be placed on such deflection.

4) Re-evaluation and adjustment of releases from Stone Dam (SFPUC) may require completion of the Pilarcitos Creek Operational Flexibility Project and Water Budget Development Project.

5) Other major sources of water in the upper watershed for release are currently in planning stages and realization of those sources may be 6 years or more away.

6) Further inquiry or information may be needed to verify assumptions made above, among them (a) that water is available for release at temperatures that will not adversely affect other aquatic biota, (b) the threshold for surface connection of the lagoon and ocean will remain at about 5 to 7 cfs (measured at the customary location at Highway 1), (c) alternate sources for flow pulses are all of quality suitable for conveyance in the stream, and (d) existing losses of flow between Highway 1 and the outlet during April and May do not increase.

4.2.5 Feasibility Evaluation

Criterion #1: Benefits to Target Species (Steelhead). This option would provide benefits to steelhead by enhancing the single-most limiting factor to viable aquatic populations — water. Flow management for augmentation of flows provides both spatial and temporal habitat benefits and for varying life histories of the target species. On a spatial scale, increased flows increase the weighted usable area (WUA) or capacity of a stream reach to support steelhead and various life stages for steelhead. On a temporal scale, increased flows managed during important life stages (e.g., steelhead smolt outmigration) extend the length of time the mouth is open for passage, the primary goal of this Enhancement Option. Given that flow has been identified as a limiting factor for habitat enhancement, flow augmentation or release would benefit most aquatic target species if timing, magnitude, water quality, and conveyance are all evaluated and considered in its implementation. This option may not provide direct benefits for snowy plover, another target species considered in this study; however, increased water may enhance the lower riparian zone for other birdlife such as passerines.

Criterion #2: Implementation Costs. This Enhancement Option could require several components: (a) infrastructure modifications; (b) stream gaging; (c) an analysis of the potential water supply and cost impacts to CCWD and SFPUC; and (d) stream monitoring data from SFPUC. This option was developed with limited information about existing conditions in the upper watershed and potential future scenarios for water used in the watershed. Initially, implementation of Option 2 should consider the costs of developing a water budget and/or hydrologic model to understand the conditions necessary to support the target species and passage needs. A Water Budget Development Project is currently in progress, and should be evaluated before further assessing the role that water released from storage may provide in supplementing existing conditions to support different life stages of steelhead in Pilarcitos Creek.

Implementation costs for the ‘pulse-flow’ option will depend on: (a) completion of the Water Budget Development Project; (b) SFPUC’s implementation of the Pilarcitos Creek Operational Flexibility Project; and (c) whether or not the existing funder continues to support operation of the USGS gage at Half Moon Bay. Modification to the Stone Dam operations may require an automated release valve and flow meter to better control the timing and magnitudes of releases. Since the flows are more beneficial to the target species during the evening and early morning hours, a system that can be programmed or controlled remotely would avoid the need for SFPUC personnel on-site, which will likely be a more cost-effective approach in the long-term.

Criterion #3: Regulatory Requirements. The SFPUC is currently providing flow releases on an experimental basis, an effort that is supported by NOAA Fisheries. A flow release for the benefit of a federally-listed species may not have any downstream adverse impacts; however, appropriate studies may be required to identify potential impacts or evaluate landowner concerns. An initial study under CEQA may be necessary. If a management plan requires infrastructure modifications or augmentation of reservoir volumes, these actions may involve work within the streambed or sediment removal and may require early consultation to identify sensitive resources and/or permits from USACE, CDFG, NMFS, and USFWS. Subsequent consultation or applications may be required with RWQCB to evaluate effects on water quality.

Criterion #4. Probability of Securing Funding for Implementation. At this time, both the costs and probabilities of securing funding for the several components that comprise this option are uncertain. SFPUC will require an internal study to evaluate the costs and feasibility of modifications. USACE is currently funding operation of the USGS gage at Half Moon Bay through March 13, 2010; at this time no additional funding has been identified to continue operation past this date.

Criterion #5. Life Expectancy Without Operations and Maintenance (O&M). This option is inherently a water operations action executed each spring. The "life" of each pulse is brief. The "life" of the operational approach equates to the long-term actions committed to by the implementing entities. Ultimately, the life expectancy for this option will depend on funding and water availability. In years of drought and/or recession, this Option would likely not be implemented until conditions become suitable or funding becomes available again. Identification of an alternative water source (e.g., Pilarcitos Quarry, groundwater, treated/recycled wastewater flows) could provide continued operation of this option in times of drought.

Separately, the stream monitor (SFPUC) would be critical in the proper management of flows to support steelhead and life stages the option is designed to benefit. If this role is vacated or funding expires to support such a role, this Option would become less effective.

Criterion #6. Intensity and Cost of Operations and Maintenance. Flow management for enhancement of fish passage would be limited to outmigration, a critical life stage for steelhead. Pulse flow releases would occur between March and June and, more specifically, during storm events. Costs associated with the operations of this option would vary depending on the storm history.

Annual costs or costs for operation, maintenance and coordination would be limited to: (a) continued operation and maintenance of the stream gaging station; (b) salary or hourly wage/benefits for the watershed coordinator; and (c) adaptive management and concurrent evaluation of this option's effectiveness.

Criterion #7: Interactions With Other Habitat Enhancement Efforts. As previously mentioned, this Option can be implemented independent of other efforts within the watershed, though the benefits may be greater if combined with implementation of Option 4: Limit Northward Drift of Beach Outlet. A structure that imposed a shorter length of channel along the backbeach (under Option 4) would: (a) decrease the likely losses to bed infiltration currently observed when Pilarcitos Creek extends north to Frenchman's Lagoon, (b) concentrate the increased flows to favor maintaining an open mouth; and (c) minimize steelhead stranding and the predation rates observed in the longer, shallow channel.

Implementation of the flow management option does not impair or jeopardize any other Options considered as part of this assessment. In fact, increased flows may benefit components of the other Options. For example, increased flows will likely enhance or maintain a scour pool at a large woody debris structure (Option 3) and enhance flow circulation through an improved backwater slough (Option 1).

Criterion #8: Level of Community/Stakeholder Project Support. State Parks does not have objections to this option based on their current understanding of potential impacts to State Parks resources. State Parks manages habitat, an important resource, and seeks a sustainable solution for steelhead recovery. Resource agencies such as NMFS, CDFG, and the RWQCB are also highly likely to support options that reduce disturbance to the channel bed and banks while improving steelhead habitat. It has yet to be determined if the community of Half Moon Bay and residents and landowners in the upper watershed are supportive of flow management; however, this option does not impose limits to existing water users or streamside residents. Reduced groundwater pumping or diversions are only introduced as concepts or voluntary actions to support higher base flows during times of drought or low flow. Additional outreach and studies into the effects of groundwater pumping and diversions on flows at Pilarcitos lagoon may be required.

Criterion #9: Potential Unintended Consequences. Option 2 is unlikely to have significant unintended consequences because the volume, magnitude and frequency of flows under consideration are not hazardous or flood-inducing. Alternatively, increased flows may lead to unintended opportunities for downstream and groundwater users. However, given the timing (evening hours) and short duration of pulse flow release, it is unlikely to be significant.

Criterion #10: Costs and Benefits Relative to Actions Above Highway One. Managed flow releases from the upper watershed primarily address the issue of fish passage at the mouth and secondarily support greater wetted usable area in the entire reach below Stone Dam. Actions above Highway One would tend to be actions aimed at improving (1) passage at features such as culverts, plunge pools, and other hydraulic barriers, and (2) reducing excessive erosion from upland sources. It seems imperative that actions in the upper watershed identified to improve habitat should continue or be implemented; however, the conceptual model developed as part of this analysis identified fish passage at the mouth as a key limiting factor to restoring viable populations of steelhead throughout the entire Pilarcitos Creek system.

Criterion #11: Extent Option "Works With Nature". Currently, runoff from the upper 6.2 square miles of the watershed is currently captured in the two reservoirs—effectively muting the natural frequency and magnitude of peak flows downstream relative to pre-reservoir conditions. A flow release at Stone Dam during the receding limb of a storm hydrograph would restore some of the natural hydrology. Although the "pulse" may not mimic the natural watershed response, it addresses steelhead needs based on the best available science, the limitations of current water management, and with little to no disturbance of existing natural resources.

4.3 Option 3: Create Scour Pools in Lower Channel

The Pilarcitos Integrated Watershed Management Plan (PWA 2008) has ranked the lower reach of Pilarcitos Creek (Highway 1 to the ocean) as providing "poor" rearing conditions due to high sedimentation/transport, modified flow regime, existing land uses, and other factors which influence geomorphic processes. The reach exhibits excessive sedimentation of coarse sands (Photo 3); the abundance and texture of this sand promote the infiltration of low flows, decreasing support for surface flow volume and continuity. As regulated flows decline during the spring through early fall period, the surface area and depth (wetted usable area) of the creek decline. In some years, much of the lower reach dries up completely, potentially stranding fish in isolated pools which results in their vulnerability to heavy predation. Prior to the 1997 flood, pools in the lower reach were described as frequent though shallow (PWA et al. 2008). A recent examination of the reach revealed that the number of pools has declined significantly due to sedimentation. Presently, pools continue to be few and shallow, ranging between 0.5 and 1.5 feet deep during baseflow (dry season) conditions (Smith, J. and Alley, D. in PWA 2008). Sand generally covers and buries a substrate rich in large willow and alder roots, which can provide much better cover and substratum for periphyton and invertebrates (Parke and Hecht 2010). Deeper, more articulated pools can be an important advantage in this reach for improving the number and sizes of outmigrating smolts, and can reduce predation in the lower mile of the creek. With less filling by sand, the roots and woody debris can also provide more winter shelter and refuge niches under high-water conditions.

Photo 3: *The aggraded, sandy bed of lower Pilarcitos Creek near the pedestrian bridge, April 2009. Photo: C. Toms.*

4.3.1 Goals and Objectives

The goals of this Option are to improve refuge habitat primarily and limited rearing habitat secondarily for down-migrant smolts on their way to the ocean. Pool habitat was nonexistent in the five reaches (4,300 ft) of lower Pilarcitos Creek that Alley observed adjacent to the wastewater plant down to the creek mouth in April and May 2009. Objectives of this Option include (1) developing deeper in-channel pools under both winter and summer conditions in multiple locations within the lower reach that fit within the geomorphic context of the system, and (2) identifying near-channel or side-channel high-water refuge pools.

4.3.2 Approach

There are two primary approaches under this Enhancement Option that would develop new refuge and/or rearing habitat. The first is to place large woody debris (LWD) structures within the reach at various intervals and in locations consistent with the channel's geomorphic context. For example, structures could be placed at sufficient intervals consistent with existing pool-riffle spacing, and placed near existing pools while avoiding riffles. The second approach is to excavate near-channel backwater habitat. Current land uses limit the ability of the creek to re-occupy floodplain habitat outside the active channel. Several areas within the lower reach may provide opportunities for enhancing such features. These features could be small (less than 100 cubic yards of material removed) and have direct hydrologic connectivity with the active channel.

4.3.3 Opportunities and Constraints

The opportunities and constraints for this option are as follows:

<u>Opportunities:</u>

LWD structures can be constructed out of wood obtained locally. One logical approach to LWD enrichment is to collect and place eucalyptus trunks and snags acquired from the upper watershed or other nearby areas. This approach addresses both the desire to use local, natural materials and the need to reduce non-native species in the upper watershed as outlined in the Pilarcitos Integrated Watershed Management Plan (PWA 2008). The use of redwood, Douglas fir, or cypress snags and rootwads is also consistent with the Integrated Watershed Management Plan and our understanding of conditions in the creek corridor upstream of the lagoon.

Most San Mateo and Santa Cruz County coastal streams present limitations for implementing LWD structures due to the threat of flooding if such structures move downstream to existing constrictions at crossings. California Highway 1 crosses Pilarcitos Creek much further inland at

Half Moon Bay. The lower reach is absent of such constrictions with the exception of a pedestrian bridge at Half Moon Bay State Beach.

Much of the sediment within the bed of Pilarcitos Creek in this reach is sand-sized and non-cohesive. Even though the pools are currently overwhelmed by sediment, the size and nature of the sediment is favorable for being scoured by the turbulence created by log structures. If log structures were placed along the banks or in the channel of the creek, hydraulic turbulence created by the logs could deepen existing pool habitat or create new pool habitat, depending on the placement of the wood structures.

Increasing alder growth along lower Pilarcitos Creek may eventually replace the need for imported wood. Significant new alder growth has been established near SAM over the past decade, largely as a result of planned Caltrans mitigation efforts; growth rates indicate that a future supply of large wood from this source is likely.

<u>Constraints:</u>

Construction of LWD structures typically requires the ability to transport the materials to the creekside. Much of the land adjacent to Pilarcitos Creek in the lower reach is privately owned, which can limit the locations where these structures can be placed unless their cooperation is secured. LWD structures are far more cost effective if materials are located materials from local sources. Costs associated with LWD structures typically increase rapidly with the greater distances materials need to be transported. These structures will also require the necessary permits for working within the wetted perimeter of the channel.

Similar constraints exist for backwater enhancement opportunities. These projects typically require multiple land-owner access and agreements but could be facilitated by an entity such as the county RCD.

It is important to note that rock weirs, which have been used on other Pilarcitos Creek tributaries (Clearwater Hydrology 1998), may not be suitable or appropriate for lower Pilarcitos Creek given its location within the watershed. Rock weirs encourage step-pool features which are typically found in reaches with slopes of 0.03 to 0.065 ft/ft (Montgomery and Buffington 1997, Chartrand 2000) and inducing that morphology on a reach that exhibits a slope of 0.002 ft/ft (WWR, unpublished data) would likely result in unintended consequences. The gentle slope within lower Pilarcitos Creek therefore necessitates the use of LWD instead of rock weirs.

LWD could potentially induce erosion along channel banks if it is incorrectly placed or migrates to a suboptimal location within the creek. This may create liability concerns for State Parks, the SAM plant, and other resource agencies.

4.3.4 Feasibility Evaluation

Criterion #1: Benefits to Target Species. This Option is specifically providing benefits for steelhead by enhancing refuge and possibly some limited rearing habitat. Existing rearing habitat in lower Pilarcitos Creek is poor to non-existent. This Option would facilitate scour processes by re-introducing additional structure to the lower channel, which has abundant, coarse-grained sediment. Any direct or indirect benefits to other target species considered in this study have not been evaluated.

Criterion #2: Implementation Costs. Option 3 could be implemented on a limited and experimental basis with moderate cost. The option could utilize non-native eucalyptus trees in the upper watershed which also addresses the need to remove such species — a priority listed in the Pilarcitos Integrated Watershed Management Plan. Costs include, but are not limited to: (a) an evaluation of structure locations and access; (b) development of plans to assess impacts for implementation, staging, cut/fill volumes, erosion control, and revegetation; (c) regulatory compliance and permit applications; (d) tree removal and hauling to the site; (e) off-haul of any excavated sediment; and (f) revegetation.

Criterion #3: Regulatory Requirements. The placement of structures in the active channel will require consultation with USACE, CDFG, NMFS, and USFWS to identify sensitive resources. Subsequent consultation or applications may be required with the RWQCB and possibly the City of Half Moon Bay for a grading permit and Coastal Development Permit (CDP). Some federal (NMFS) and state (CDFG) agencies have currently adopted and are promoting artificial introduction of large wood into streams for enhancement of steelhead and coho habitat. If an LWD enrichment project at Pilarcitos Creek provided a geomorphic/biological-based, experimental approach to LWD structures installations, agency review would likely be streamlined with these agencies including CEQA review (categorical exemption, class 7 or 8) and USACE if the project qualifies for a Nationwide Permit (NWP 27: Stream and Wetland Restoration Activities).

Criterion #4. Probability of Securing Funding for Implementation. Given the current status of the California state budget, the likelihood of acquiring funding for this option is uncertain. Federal funding through American Recovery and Reinvestment Act (ARRA) may be appropriate since the option is addressing habitat enhancement for a federally-listed threatened species; however, this funding is only for permit-ready projects with completed designs and so could only fund implementation, not design.

Criterion #5. Life Expectancy Without Operations and Maintenance (O&M). The life expectancy of placing LWD in a stream is primarily dependent on the species and quality of wood, effective placement and location geomorphically, and the occurrence of episodic events (e.g., major floods or wildfires). Eucalyptus are typically more resistant to rot when compared to other species (e.g., redwood, oak, juniper), so they might last longer than these other species in a fluvial environment. Separately, if a wildfire were to occur within the watershed, excess sediment could bury LWD structures in the lower reach. Similarly, a major flood could move or relocate structures causing them to have less habitat function depending on their adjusted positions. Structures should be designed to move and adjust to a dynamic channel in a way that minimizes the potential for erosion along private property and the SAM property.

Criterion #6. Intensity and Cost of Operations and Maintenance. If Option 3 is implemented on a limited and experimental basis, O&M costs (in addition to implementation costs) should reflect the desire of the stakeholders and the extent or number of structures necessary to meet project goals. Each time additional structures are requested, costs can escalate due to the repeated requirements needed for agency consultation, permit applications, plan development, tree removal and revegetation. Once a LWD structure is constructed, no additional costs are anticipated unless some maintenance or monitoring for flood control is warranted by special permit conditions.

Criterion #7. Interactions With Other Habitat Enhancement Efforts. Option 3 focuses on addressing in-stream habitat and does not address passage at the mouth — a constraint identified in the conceptual model. However, if other options that address passage are considered in combination with this option, their interactions could enhance habitats both spatially (reach wide) and temporally (winter refuge, summer rearing) for several life stages (rearing, outmigration) of steelhead. However, careful consideration of LWD scour-pool structure locations should be evaluated. For example, implementation of a beach deflection structure (Option 4) may limit the location of LWD structures due to potential backwatering effects of a deflection structure. Implementation of Option 2 would likely enhance the efficacy of LWD placement by providing additional flows to scour deeper or more varied pools. Finally, removal of non-native eucalyptus is identified in the IWMP as a watershed enhancement measure; the use of this material for LWD placement would add value to both projects.

Criterion #8: Level of Community/Stakeholder Project Support. Option 3 would necessitate support from creekside residents or land owners for either access, staging, or implementation of LWD structures. Given that these structures should require little if any maintenance, State Parks would likely support implementation of Option 3 within the boundary of HMBSB if appropriate locations are identified.

Criterion #9: Potential Unintended Consequences. The concept of introducing LWD into a stream has many intended and well documented benefits for habitat. However, these structures commonly accumulate other wood and debris moving downstream. The structure then imposes larger roughness and deflective forces on flow. The result may be: (a) more frequent overbank flows at that location of the structure or (b) scour and/or property loss due to erosion. Similarly, an accumulating structure may also generate greater depositional processes immediately downstream—thus, changing the channel's cross-sectional area and flood capacity. Engineering design of LWD placement should consider such consequences.

Criterion #10: Costs and Benefits Relative to Actions Above Highway One. The lower reach of Pilarcitos Creek has been identified as providing poor spawning and limited rearing habitat relative to reaches upstream of Highway One (PWA et al. 2008). Any enhancement effort in the lower reach will be an improvement over what currently exists. However, sedimentation is a watershed-wide issue and excessive sources of erosion/sediment in the upper watershed should continue to be identified and reduced. The RCD has been conducting assessments of rural roads throughout the watershed and is working with landowners to reduce sediment delivery from those and other sources.

Criterion #11: Extent Option "Works With Nature". As mentioned before, many of the resource/regulatory agencies have identified 'large wood' as a limited resource in our coastal streams and support efforts to restore it. Pilarcitos Creek exhibits limited recruitment opportunities for large wood in the lower reach due to current land uses and a reduced riparian zone. Re-introduction of wood would restore more natural structures and functions to the creek.

4.4 Option 4: Limit Northward Drift of Beach Outlet

4.4.1 Existing Berm and Backbeach Channel Environment

Geologic controls and antecedent beach topography (see Figure 3 and the Conceptual Model in Appendix A) favors the northward drift of the beach outlet: berm crest elevations decrease northward, and the backbeach channel bed slopes north to Frenchman's Creek, following the wave refraction gradient south of Pillar Point. The foredune ridge (accreted wind-transported sand) that runs almost entirely across the creek mouth inhibits breaching of the beach outlet at the mouth and deflects the channel to the north-northwest. The back of the foredune is stabilized by dense willow thicket and sedge marsh that strongly inhibit streambank erosion. Breaching of the beach outlet channel occurs naturally where creek outflow can readily overtop low points along the berm crest and initiate rapid incision of a channel through the swash slope. There are no resistant rock outcrops or embedded structures in the Pilarcitos-Frenchman's beach to locally increase water surface elevations or promote turbulent flow that may trigger outlet breaching. When the outlet is located at a stable northern position, streamflow losses to beach seepage (subsurface infiltration through coarse beach sand of channel bed) are high, resulting in a loss of adequate depth for fish passage upstream of the outlet.

4.4.2 Goals and Objectives

The goal of restricting the natural northward deflection of the beach outlet is to improve steelhead passage conditions. Improvement objectives include:

1. Shortening and deepening the outlet channel and fish dispersal distance between the fluvial and marine environments,
2. Reducing beach seepage (infiltration) losses of streamflow to maintain adequate depths for migrating steelhead, and
3. Increasing the duration of open outlet conditions during critical seasonal windows for steelhead migration (generally speaking, Jan-March for inmigrating adults, April-May for outmigrating smolts).

Of these objectives, the duration of open beach outlet conditions during declining streamflows may be the most difficult to reconcile with the primary aims of shortening and deepening the passage route between the stream mouth and the beach outlet. The challenge arises from forcing the beach outlet to form where wave heights and berm crest elevations are higher than at its current location, as this forcing will subject the outlet to greater potential instability due to swash processes such as swash slope accretion and longshore drift. Based on consensus between our fishery consultant and fishery biologists on the TAC, we assume that the benefits of a shorter, deeper outlet override the potential disadvantages of greater outlet instability (i.e., a higher probability of outlet closure at a given streamflow) due to a forced shoreline location where higher wave energy prevails.

4.4.3 Approach and Design Options

The overall approach of beach outlet position management is to impose some structural control on the outlet so that it forms near or within the stream mouth, restricting longshore drift of the outlet northward. This Option is a pilot (experimental) project design without precedent in the Central Coast region, so a “soft” engineering structure (defined in more detail below) is preferable for initial implementation. Two options are proposed: one with a stand-alone deflection structure placed across the beach berm at the north end of the stream mouth (Option 4A), and one with a deflection structure embedded within a large naturalistic artificial landform to provide both compatible habitat and additional topographic control (Option 4B).

The basic engineering design of this Option restricts stream outflow north through the backbeach channel and forces impounded outflows to overtop the adjacent berm crest and incise an outlet closer to the mouth of Pilarcitos Creek. Achieving this outcome will require a structure that can impound a temporary backbeach lagoon with sufficiently high water surface elevation to spill over the adjacent beach crest, and deflect stream outflows to the foreshore, bypassing the backshore channel trough at the toe of the bluff. The design height of the structure is therefore tied to spill elevations of either natural or lowered adjacent berm crests. Because the berm crest elevations adjacent to the mouth are the highest in the study area (Figure 5), and because some floodplain areas landward of the mouth occur at elevations below the berm crest, this design approach includes combined management of the beach (annual pre-breach maintenance excavation of berm gaps to lower spill elevations during high streamflow breach events) and an artificial deflection structure to force the outlet to form near the mouth.

The design function of the deflector structure is ***not*** that of a beach groin, which is designed to trap longshore drift of sand in the backshore and upper foreshore of the beach profile. Groin function is contrary to the purpose of the outlet deflector, as choking the outlet with trapped longshore drifted sand would impede fish passage. In contrast, the outlet deflector must avoid trapping longshore drift in the swash zone, which would promote closure of the outlet. The deflector structure therefore must be designed to act as a partial, temporary pre-breach impoundment structure within the backbeach channel, and a guide to the orientation of streamflow across the beach profile.

The location requirements for a deflection structure are: (1) a location next to a bluff (marine terrace) elevation equal to or exceeding the adjacent beach berm elevation range, to prevent the backflooding of impounded streamflow into the floodplain, and (2) the seaward end of the deflector must extend into the berm profile, but not the swash zone (where there is maximum wave energy and erosion potential); the seaward edge of the deflector must extend partly into the berm profile, or the channel will flow around the deflector tip and re-occupy the backbeach channel. Along the beach in between the mouths of Pilarcitos and Frenchman's Creeks, our preliminary analysis indicated that the most appropriate location for a deflection structure may be a small beachward protrusion in the marine terrace approximately one tenth of a mile north of where Pilarcitos Creek exits its willow thicket (Figures 6 and 7). Our initial thoughts about this location were that this protrusion would help guide storm flows along a deflection structure and out towards Half Moon Bay. This hunch was confirmed in January 2010 when an approximately 2.5-year flood scoured through the beach berm at this exact location, forming scarps over 10 feet deep in the beach profile (Photo 4). This beach outlet location persisted into February 2010 even though swash-deposited sand subsequently filled much of the outlet channel (Photo 5).

Photo 4. *The Pilarcitos Creek outlet on January 20, 2010, after a major storm scoured a new outlet to the south of the original merged Pilarcitos-Frenchman's outlet. The bluffs along the beach can be seen in the upper-right corner of the photo; a geomorphologist is standing at the new outlet to provide a sense of scale to the extreme scour through the beach berm that occurred during this storm event. Photo: B. Hastings.*

Photo 5. *The outlet on January 29, 2010, after swash-deposited sand filled most of the outlet channel that had incised during the storm of January 18-19. The standing waves within the outlet are the result of interactions between flood tidal surge and creek outflow. Photo: C. Toms*

4.4.3.1 Option 4A: Beach Outlet Deflection Structure

Structure Type: Conceptual design options include a **"soft-engineered" structure** such as geotextile tubes or bags filled with sand, with or without a geoweb or geonet cage, or a **"hard-engineered" structure** (Figure 6). The latter would be a structural equivalent of an engineered revetment, such as a boulder trapezoid with a geotextile fabric base, core stones, and cap stones. Soft-engineered structures would be suitable for adaptive management experimental designs to deal with the relatively high uncertainties of a locally unprecedented coastal engineering design, providing performance data (as part of project implementation) with lower capital costs, duration (see next design criterion), permitting burdens, engineering costs, and impacts. The temporary nature of geotextile structures for beach engineering can be an advantage, in that they can be constructed in experimental forms and later strengthened to provide a more permanent function if the design performs well (Nordstrom 2000). Hard-engineered structures may be more suitable for investment in a long-term structure with a suitably high confidence of engineering efficacy and low environmental impact. The potential level of environmental damage anticipated from installation of a hard- engineered structure must be weighed against the potential environmental benefits before this option is chosen.

Pilot Breach Maintenance (seasonal excavation of berm gap). A practical design option to minimize the fill height, volume, and area of the deflection structure and minimize additional backflooding risk of the adjacent floodplain would be to integrate annual maintenance (i.e., re-excavation) of a **pilot outlet channel** across the berm crest during neap tides of October, at the beginning of the rainy season and the end of the snowy plover nesting season. Pre-breaching the berm would lower the spill elevation relative to the deflection structure crest, facilitating berm breaching with relatively low flows. High waves, however, may induce rapid swash bar accretion (beach dam re-formation) in the pilot channel, which may need to be re-excavated to be ready for "unscheduled" stream outflows. Excavation should occur at the very end of the dry season, right before winter rains arrive, to avoid draining any ponded lagoon habitat at the mouth (see "Constraints" below).

Opportunities and Constraints.

<u>Opportunities.</u> As discussed above, a soft-engineered structure would provide an opportunity to deflect the outlet to benefit in- and out-migrating steelhead within an adaptive management context. Such context is important to consider given the relatively unprecedented nature of passage-focused beach outlet deflection along the California coast.[15]

[15] Multiple California creeks and rivers, such as Aptos Creek near Aptos, CA and the Mad River near Eureka, CA have had their outlets deflected for various anthropocentric reasons; the authors are not aware of any

Constraints. A soft structure would require a stable base set deep in the beach profile. A deflection structure set superficially in the beach would be subject to partial or complete destruction from relatively small storm erosion events. Undermining would probably occur only when wave-cut beach scarps extend to the back of the berm, which could cause undermining and collapse of a structure. The recent landward limit of beach scarp retreat near the mouth appears to be aligned near the seaward edge of the vegetated foredune. The depth of beach sand extends below MLLW, so the deflection structure must be keyed into the deeper restrictive layer well below MLLW.

The timing of the excavation of the pilot outlet channel must balance the need not to flood infrastructure within the Pilarcitos floodplain (e.g., the pedestrian bridge, equestrian crossing, and SAM plant) once storm flows arrive with the need to avoid draining any lagoon habitat that may exist late in the dry season if upstream flow manipulations result in perennial flow to the creek mouth. Premature breaching of such habitats without concurrent stormflow would destroy lagoon habitat and cause steelhead mortality.

Expected Long-Term Outcome. The stand-alone deflection structure would likely persist at least until the next large El Nino storm erosion event. The structure would likely accrete wind-blown sand (ramp-like accretion on the windward north slope, followed by lee slope accretion on south slope) at least seasonally, if not between years. The backbeach channel remnant north of the deflector would likely fill in with washover and wind-blown sand, and could undergo gradual succession to low foredunes if the supply of beach sand remains ample. Initially, the northern end of the trough formed by the cut-off backbeach channel may become an intermittent lagoon extension of Frenchman's Creek. The significant reduction in shallow backbeach runnel habitat under this option may significantly reduce the use of both lower channels by seagulls, which should help to reduce *E. coli* contamination of the beach.

4.4.3.2 Option 4B. Artificial Foredune Terrace With Embedded Deflection Structure

Structure Type. This option combines a smaller deflection structure (a geotextile tube filled with beach sand) with a much larger pilot channel beach cut volume, balanced or exceeded by a substantial beach sand fill of the backshore profile across the former (north-deflected) backbeach channel. This design would form the platform for a native foredune similar to the existing foredune across the Pilarcitos mouth. This artificial landform is designed to be

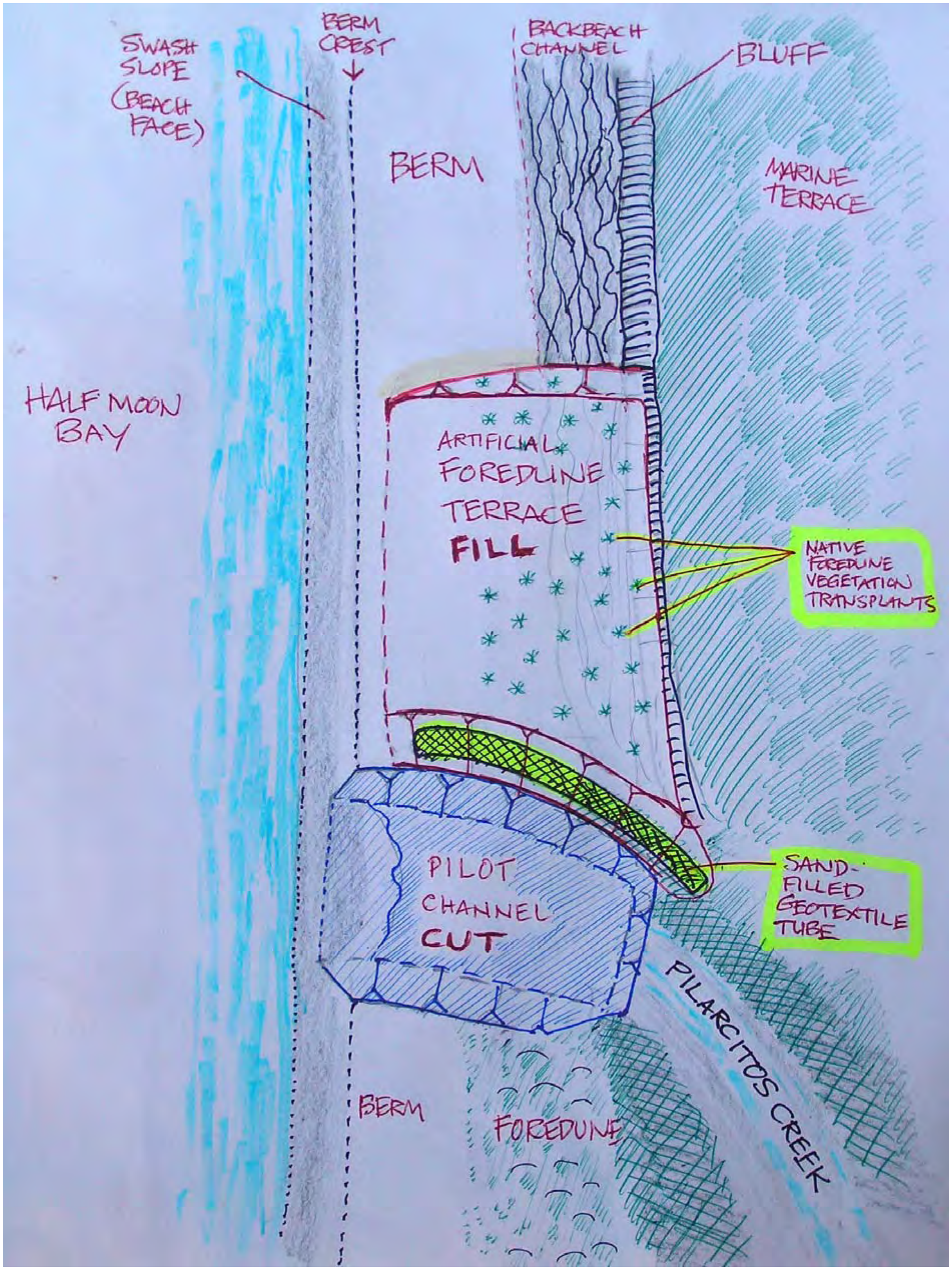
California/West Coast instances of outlets being deflected for habitat reasons. The mouths/outlets of the Russian and Carmel Rivers are currently being manipulated by USACE on an experimental basis to manage local salmonid habitat and flooding concerns.

vegetated with native foredune vegetation and grow into a substantial topographic control of the outlet's position over time – in effect opposing the northward-deflecting effect of the existing foredune on the outlet's orientation. The vegetated foredune terrace would be located north and landward of the pilot channel outlet. This design reduces the deflector to only toe protection of a substantial artificial vegetated foredune terrace fill in a segment of the backbeach channel.

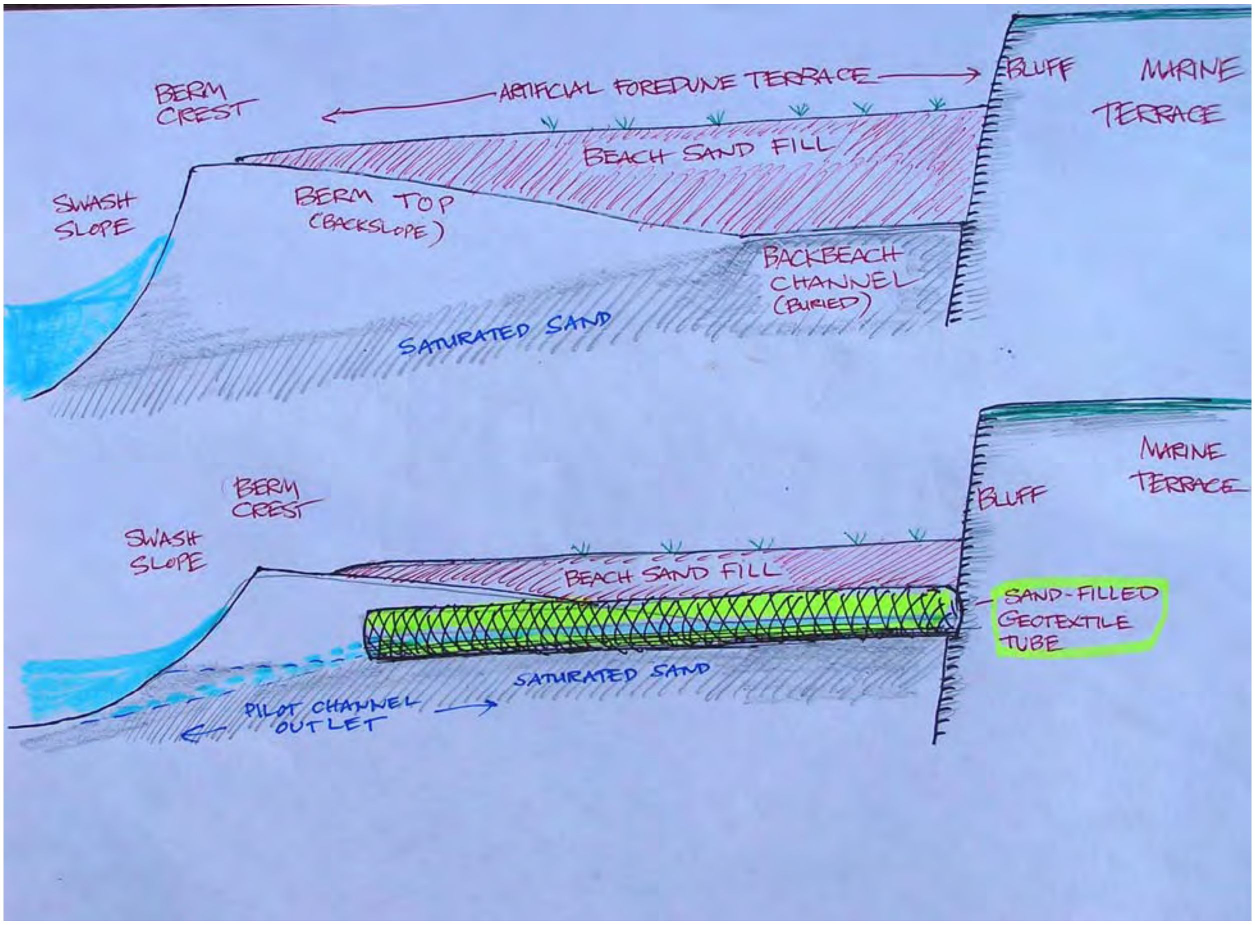
A crude version of this option was implemented in 1984, when a large pile of sand was placed across and perpendicular to the backbeach runnel close to the mouth of the creek (Figure 3). While this effort successfully deflected the creek outlet well to the south, the effect was only temporary as the storms of 1985-1986 wiped out the sand pile and relocated the outlet to the north. The structure described here within this option is meant to be more robust than the 1984 effort, but still be able to be easily removed if so desired.

Pilot Breach Maintenance. The pilot channel would be expanded versus Option 4A to a large berm excavation, used as a borrow source for backbeach channel fill extending from the berm crest to the bluff face, with a design elevation close to the berm crest elevation (Figure 7, Graphic 5). The bottom elevation of the berm excavation area would be slightly lower than the bed of the adjacent backbeach channel. The shoreline length of berm excavation and backbeach channel fill would be approximately 300 to 400 feet. The excavated or scraped beach sand would be placed in the trough of the beach profile north of the deflection structure, backfilling the cut-off backbeach channel and lower berm profile.

Constructed Foredune Terrace. The toe of the constructed foredune terrace facing the outlet would be protected by a single geotextile tube along the toe of the fill bordering the excavated pilot channel bed, approximately 1 to 1.5 m in height above the bed (Graphic 6). This height corresponds roughly with the willow floodplain height above the channel bed in the mouth. The tube would be embedded below the channel bed and would restrict undercutting of the outlet channel bank and northward drift of the outlet. The geotextile tube may be covered with wet sand and stabilized with turf-forming creeping flood-tolerant seasonal wetland plants native to the mouth (salt rush, threesquare bulrush, saltgrass, etc.) for a more natural habitat structure at the channel edge, or it may be left exposed to scour.



Graphic 5. *Conceptual drawing of the cut and fill necessary to excavate the pilot channel and construct the artificial foredune terrace. Graphic by Peter Baye, December 2009.*



Graphic 6. *Conceptual drawing of the post-construction profiles north (top) and south (bottom) of the deflection berm. Graphic by Peter Baye, December 2009.*

The foredune terrace would be vegetated with a mix of native foredune pioneer species which matches the existing foredune (beach pea, *Lathyrus littoralis;* yellow sand-verbena, *Abronia latifolia;* beach-bur*, Ambrosia chamissonis;* beach morning-glory*, Calystegia soldanella*, with optional addition of Pacific dunegrass, *Leymus mollis* to maximize sand trapping and accretion rates). The foredune terrace would be planted with vegetative plugs on irregular 2 meter centers during the wet December-January transplant window.

The foredune planting pattern would concentrate nearly prostrate (laterally-growing) beach morning glory at the seaward end of the planting (approximately the location of the existing berm top) because western snowy plovers readily nest in the prostrate, sparse, but complex cover and flat topography produced by this species. The prostrate morning glory vegetation would allow significant onshore aeolian (wind-driven) sand transport to pass over the morning glory and nourish the mound-building foredune species (i.e., species that respond favorably to high accretion rates of wind-driven sand) planted landward of it. The mound-building foredune species would be concentrated at the back of the foredune zone, at approximately the location of the existing backbeach channel. As the foredune grows in height, topographic resistance to northward drift of the outlet would increase naturally over time, much like at the existing foredune across the stream mouth. The accretion of the foredune would also increase the system's resistance to erosion, reducing the likelihood that the backbeach channel will become reoccupied even during large storms.

Opportunities and Constraints.

Opportunities. This design provides a mechanism for deflecting the creek outlet in a manner that is less intrusive and more easily reversed than a hard-engineered structure (e.g., Option 4A). The design could also be modified so that the dune terrace is constructed gradually over the course of many seasons, replacing an intensive one-time construction effort with seasonal placement of sand excavated from the pilot channel[16]. This design may reduce bluff retreat rates, as well as reinforce the position of the outlet; this potential requires more in-depth analysis by geotechnical and coastal engineers. It may also potentially increase the extent of suitable Western snowy plover (WSP) habitat north of the mouth, though this would need to be confirmed by biologists prior to implementation as the project would also impact nesting habitat that has been used in the past by WSP. This design may possibly represent an approximate "restoration" of an anomalous patch of mapped vegetation along the bluff position in the US Coast Survey T-sheet of 1861 (Figure 4). The vegetation type is not represented elsewhere in the map, but the position of the anomalous vegetation unit mapped is consistent with a local patch of remnant foredune or dune scrub.

Constraints. As with Option 4A, the pilot outlet channel cut through the berm must not drain a pre-existing lagoon or cause a deepening of the notch afterwards by wave action that would drain the lagoon without stormflow. If the pilot outlet channel is not excavated, then flows may be impounded to elevations equal to the adjacent beach berm crest; such backflooding may put upstream infrastructure such as the pedestrian bridge and SAM plant and private properties at risk of flooding.

Expected Long-Term Outcome. The foredune terrace would likely undergo natural aeolian accretion of vegetated foredune mounds and prostrate foredune terrace vegetation, unless extreme El Nino storm erosion events set back succession to the pioneer stages of colonization. In the absence of stream channel erosion, the backshore profile is likely to become depositional, and bluff toe erosion is likely to be reduced between Frenchman's and Pilarcitos

[16] Minor but continual disturbance of the site during phased foredune terrace construction would create its own implementation challenges. An impact analysis of phased vs. one-time construction should be a part of any future conceptual design efforts for this option.

creeks, even north of the artificial foredune terrace. The geotextile tube toe protection of this landform may be re-exposed following extreme flood discharge and erosion events. During calm intervals between erosion events, marsh vegetation is likely to provide partial stabilization of substrate along at least the upstream end of the deflection structure. The mass of the foredune terrace is likely to retard migration of the outlet, even if structural integrity of the geotextile tube is compromised by storm erosion damage. Again, as with Option 4A, the significant reduction in shallow backbeach runnel habitat under this option may significantly reduce the use of both lower channels by seagulls, which should help to reduce *E. coli* contamination of the beach.

4.4.4 Feasibility Evaluation

Criterion #1: Benefits to Target Species. Any deflection structure that persists is likely to cause or substantially contribute to improved passage conditions for steelhead. A deflection structure would significantly shorten the broad, braided deltaic backwater channel with very high infiltration rates, and promote a narrower, deeper stream outlet channel. This change would substantially mitigate an important constraint on steelhead habitat conditions at the mouth of Pilarcitos Creek. A secondary potential benefit of forcing the outlet to form at a position along the shoreline with relatively higher beach crest elevations (compared with downdrift outlet positions) would be increased flooding due to increased probability of impounding lagoon water surface elevations above the adjacent floodplain. Potential benefits/impacts to Western snowy plover require further analysis by biologists.

Criterion #2: Implementation Costs. The implementation costs of deflection structure options may range from a simple geotextile tube (or set of tubes) filled with sand, to a combination of beach grading (foredune terrace foundation) and geotextile tube installation. One-time grading costs (local beach cut/fill) to create the foredune terrace could be substantial, and would require substantial design, permitting, and engineering costs.

Criterion #3: Regulatory Requirements. Permits would be required for excavation and fill in the existing backbeach fluvial channel and the beach below the high tide line by the U.S. Army Corps of Engineers and the California Coastal Commission. This work would not be covered under Nationwide Permit 27, and would presumably require the standard individual permit process. Coastal Commission and Corps permits have been issued for beach grading in the San Francisco Bay Area (e.g., the mouths of the Russian and Carmel Rivers) and also in southern California, where soft engineering of artificial foredunes has many precedents. It is possible for a federal agency to seek a federal consistency determination for their actions on CDPR lands within the Coastal Zone; however, that would not remove the requirement for approval from the Coastal Commission. [NMFS has obtained a federal consistency determination from the

Coastal Commission for an experiment in Pescadero Marsh (also owned by CDPR) that would place a temporary bladder dam in a marsh channel in an attempt to reduce fish kills within the marsh.] A CDFG 1601 stream alteration agreement would also be required for infilling the terminal backbeach reach of Pilarcitos Creek and deflecting its outlet at a southerly position. A Section 401 water quality certification from the RWQCB would be required, as well as CEQA evaluation (presumably at least a Mitigated Negative Declaration).

The project would be likely to affect the Pacific population of the Western snowy plover, a federally listed threatened species. The federal permit process would require formal consultation with USFWS (including Biological Assessment) and an Incidental Take Statement (ITS) including Section 10 authorization for incidental take of Western snowy plovers under the Endangered Species Act. If the final design of this option is anticipated to affect upstream habitats, then it consultation with USFWS might also be required regarding impacts to California red-legged frog and (if deemed potentially present) San Francisco garter snake.

Criterion #4. Probability of Securing Funding for Implementation. Because the proposed project design would potentially have long-term benefits for two federally listed species, Central Coast steelhead and Western snowy plovers (depending on interpretation and discretion of USFWS and NMFS), it may be eligible for recovery grant funding and coastal wetland grants from these agencies. Relatively high engineering, construction and permitting costs of the project, however, may make full project funding challenging.

Criterion #5. Life Expectancy Without Operations and Maintenance (O&M). An isolated geotextile tube deflector structure would be subject to partial or complete undermining during extreme fluvial erosion events or extreme beach erosion events such as 1982-83, 1986, 1998, etc. The life expectancy of a deflector would likely be greater with a vegetated foredune terrace constructed north of it, because foredune vegetation would likely trap and partially stabilize accreted sand, as the existing foredune has done for several decades seaward of the stream mouth.

Criterion #6. Intensity and Cost of Operations and Maintenance. Replacement or repair of sand-filled geotextile structures is relatively low compared with armored, solid structures. Since the geotextile tubes would be filled with native sand, their failure would not release any non-native materials or contaminants onto the beach; beach sand could simply be re-collected and placed into a new geotextile tube. Yearly excavation of the pilot outlet channel would be an ongoing maintenance cost. Details of this maintenance and associated costs would be developed during conceptual design.

Criterion #7. Interactions With Other Habitat Enhancement Efforts. The deflection structure may enhance the function of backwater slough habitat enhancements (Option 1) by forcing of the stream outlet at a location with relatively high berm crest elevations, and corresponding higher potential for high maximum lagoon water surface elevations at or above floodplain elevations.

As discussed above under Option 2, an outlet deflection structure would minimize beach infiltration losses in the channel's current configuration, thus maximizing the hydraulic ability of the channel to maintain fish passage between the ocean and the creek. The combination of Options 2 and 4 will be more likely to support at least a small summer lagoon, including a connection to the backwater slough, provided that perennial flow to the beach is maintained. Biologically, this structure would also help to reduce predation and possible stranding of juveniles within the backbeach runnel.

Implementation of this option may increase the typical creek stage at the equestrian crossing, rendering the crossing impassable for longer periods of time unless a new bridge is built or the existing pedestrian/cyclist bridge is retrofitted to accommodate horses. Equestrian crossing retrofits are discussed below under Option 5.

Criterion #8: Level of Community/Stakeholder Project Support. One of the primary factors controlling this option's feasibility is the ability to obtain agreement between CDPR, natural resource agencies, and the public regarding placing some sort of deflection structure (whether a hard-engineered feature or artificial foredune terrace) on a beach that experiences exceptionally heavy public use and has considerable existing aesthetic and natural resource values[17]. A relatively "soft" and reversible engineered deflector structure is less likely to induce the opposition expected of a groin-like armored structure. The foredune terrace option may make the project more attractive to the public if it contributes to reduction of cliff erosion and expansion of backbeach area suitable for habitat, recreation, and scenic viewing.

In general, the artificial redirection of a stream from its historic channel is not an action typically supported by CDPR resource management policies (J. Kerbavaz, pers. comm., 2010). The extent that the backbeach runnel is "historic" (and, by some implication, "natural") is probably up for debate, but it has been a consistent feature of the system for at least 30 years. The project would induce additional operation constraints, such as necessitating the rerouting of existing access for lifeguards and emergency vehicles. The regular maintenance of such a feature (e.g., pilot channel excavation) and the potential for periodic repair/removal of failed

[17] While the artificial foredune terrace option could potentially create additional habitat for Western snowy plover in the long-term, construction of the terrace might involve short-term disturbance to plover habitat.

elements could create considerable costs and liability for CDPR. Environmental review of such a project would be complex, and would require consultation with the many agencies described above under Criterion #2. It is important to note that NMFS and CDPR are working together on a number of lagoon/estuarine habitat enhancement efforts throughout the California coast, such as at the Carmel River, Willow Creek (near the Russian River), MacKerricher State Park, and others.

Analysis of either deflection structure option within the conceptual design phase would need to consider the potential impacts to public use of the beach. For example, children tend to play in the creek outlet and backbeach channel (despite periodic warnings posted by San Mateo County Environmental Health Dept about public health and safety concerns caused by exceedances of coliform bacteria and *E. coli* colony numbers in the backbeach channel), and its deflection might upset some of the public who are used to the creek being in a particular location. Deflection might also make public access to the beach at Frenchman's Creek from Venice Boulevard easier, because it might reduce the amount of time that the concrete apron on the southern side of the creek is underwater.[18] Deflection of the channel/outlet could interrupt access along the beach, and change access routes for lifeguards and emergency vehicles.

Criterion #9: Potential Unintended Consequences. Post-storm failure of a geotextile structure from wave erosion may cause a short-term aesthetically objectionable condition (torn geotextile fabric on the beach or, in a worst-case scenario, washed into the Pacific Ocean), but structural failure could be masked or minimized by post-storm sand accretion depending on the degree of failure (the more of the structure that fails, the less likely the failure could be masked by post-storm accretion). As discussed above, deflection of the outlet further to the south, where it must spill over relatively higher beach berm crest elevations, may impound floodplain water surface elevations to an elevation where they may pose a threat to infrastructure within the floodplain.

Deflection of the Pilarcitos outlet from the merged Pilarcitos-Frenchman's outlet may affect the windows of time that the Frenchman's outlet by itself would be open to the ocean, which could impact the steelhead community within Frenchman's Creek. Predicting these effects is difficult without a thorough understanding of the morphodynamics of the Frenchman's outlet.

If perennial flow is provided to the mouth, unauthorized breaching (potentially by well-meaning but ill-informed visitors to the beach) could prematurely drain the lower creek and potentially

[18] Under current conditions, the backbeach runnel of Pilarcitos Creek inundates the apron before it merges with Frenchman's Creek, blocking access from the Venice Boulevard parking lot to the beach.

cause steelhead mortality. Signage to discourage such activity would help to reduce the likelihood of this activity.

Finally, the effects of beach grading and geotextile tube installation would include short-term construction impacts that could potentially be minimized by seasonal restrictions, but may be unavoidable. Long-term effects of a deflection structure (including grading of a foredune terrace) may include net increase in relatively flat, wide backbeach habitat that may increase the area of suitable breeding, foraging, and roosting habitat of the western snowy plover.

Criterion #10: Costs and Benefits Relative to Actions Above Highway One. As with Option 2, this option primarily addresses fish passage at the Pilarcitos beach outlet, which the conceptual model identifies as a primary constraint on steelhead reproduction within the Pilarcitos system (PWA et al. 2008). If fish cannot move into the creek system at its outlet, they will have no chance of moving upstream of Highway 1 to breed in whatever habitat may be available. Therefore, though this option addresses different habitat functions than enhancement actions above Highway 1 (which typically address spawning habitat and localized barriers to passage), and though it has moderate construction and operational costs associated with it, it will likely have a higher cost-to-benefit ratio relative to enhancement measures above Highway 1. Implementation of such enhancement measures should not be an either-or proposition, as both would likely improve steelhead reproduction within the Pilarcitos Creek system.

Criterion #11: Extent Option "Works With Nature." The deflection structure itself would be an artificial impediment to northerly drift of the stream outlet, but it would reinforce a position of the outlet closer to the range of its historic 20th-century locations. A constructed foredune terrace would provide erosion buffering of the coastal bluff and expand backbeach and foredune habitat, exploiting natural sand accretion and partial stabilization processes mediated by foredune vegetation.

4.5 Option 5: Improve Equestrian Crossing

4.5.1 Existing Conditions

The equestrian path across Pilarcitos Creek is an approximately 1/10th mile long crossing upstream of the pedestrian bridge within Half Moon Bay State Beach (HMBSB). The path was the primary way for pedestrians and horses to cross the creek within HMBSB until the construction in 1993 of the John Hernandez Bridge further to the west. The crossing is now primarily used by equestrians since most cyclists and pedestrians prefer to cross the creek using the bridge. Since the bridge was constructed, the continuing expansion of the willow thicket on the Pilarcitos floodplain and decreased use of the crossing have led to its conversion from an open-canopy crossing to one almost entirely enclosed by willows (see post-1994 photos in Figure 3). The bed and banks of the crossing are trampled and devoid of vegetation (Photo 6), and at times contain small piles of manure (Photo 7) that can potentially enrich the creek with nutrients. Equestrians have been known to ride horses up the creek channel from the crossing (Joanne Kerbavaz, pers. comm.), which causes disturbance of the channel bed. Like the rest of the lower Pilarcitos Creek channel, the channel in the vicinity of the crossing has little to no complex cover for steelhead, despite its location on a bend in the creek where such cover is typically located (Figure 2).

Photos 6 (left) and 7 (right).*The concentrated use of the crossing by horses prevents the establishment of riparian vegetation along the crossing's edges, and manure droppings are often directly deposited on creek banks. Photos by Peter Baye, May 2009.*

Replacement of the existing crossing with a bridge is identified in the Pilarcitos Creek Integrated Watershed Management Plan (IWMP, PWA et al. 2008) as an action to improve watershed and stream health.

4.5.2 Goals and Objectives

The primary goal of improving the equestrian crossing is to enhance the stability and riparian canopy cover of the creek banks while increasing complex cover within the channel bed. Specific objectives of this option include:

1. Reduce the amount of sediment that the eroded, denuded creek banks within the crossing contribute to the creek

2. Restore a robust riparian vegetation community with plants such as willows, sedges, and others along the now-denuded creek banks
3. Facilitate the potential development/installation of complex submerged cover within the creek bend
4. Prevent disturbance of the creek channel by preventing equestrians from moving up and down the mainstem channel from the crossing
5. Provide a safe creek crossing alternative for equestrians that considers their unique safety needs[19]

4.5.3 Approaches, Opportunities and Constraints

Approaches to improve the equestrian crossing, and their corresponding opportunities and constraints, are described below. We have identified six possible approaches, five of which are distinct alternatives and one of which is an added element to combine with other approaches.

Option 5A: Restrict the width of the trail within the existing alignment. One way to reduce (but not remove) impacts to the creek bed and banks by equestrian passage is to use symbolic fencing to reduce the width of the crossing within the creek channel and floodplain. This fencing would likely move during high flow events, and would have to be moved back to its original location once storm flows recede. The areas outside this fence could be actively revegetated with sedges, bulrush, and eventually willows to stabilize the soil surface. Local equestrian organizations could provide input regarding what an acceptable, safe crossing width would be. This option would not completely remove horses from the creek bed and banks, but it could significantly reduce impacts to the channel at a more moderate cost than many other options, even considering the continuous maintenance cost to HMBSB staff to move the fencing after high flow events. Objects such as symbolic fencing may be perceived as a hazard by horses and their riders; such objects would have to be designed to minimize hazards.

Option 5B: Retrofit the existing pedestrian/cyclist bridge to allow for use by equestrians, or construct a new bridge that can accommodate all user groups in the same location as the existing bridge. Eliminating the need for the existing equestrian crossing by accommodating crossing in the location of the existing bridge would remove this source of disturbance to the channel bed and banks, allowing for natural regeneration of a riparian vegetation community

[19] In general, horses require wider berths than pedestrians or cyclists. In addition, more traditional construction materials such as wood or Trex© are unsuitable for equestrian use because (1) they provide little traction under horse hooves, especially when wet, and (2) the metal shoes on many horses can rapidly wear down these materials.

within the crossing (though supplemental planting, maintenance, and monitoring is recommended to help prevent invasive, non-native species from dominating the plant community). Both options (retrofitting the existing bridge vs. constructing a new bridge) are likely to entail considerable costs for design, permitting[20], and construction, especially if the bridge were extended across the entire floodplain and not only the active mainstem channel. Any retrofit/construction work could be coupled with the installation of complex submerged cover such as rootwads at the creek's outer bend. This sub-option has the highest potential environmental benefits but also the highest potential costs compared to other sub-options.

Option 5C: Install a separate equestrian bridge across Pilarcitos Creek (and potentially the entire floodplain) in the location of the existing crossing. This method is similar to method 5B except that it maintains the existing bridge and places a new bridge at the current equestrian crossing. Again, such an effort would entail considerable costs for design, permitting[21], and construction, and would create new monitoring and maintenance requirements for HMBSB personnel. HMBSB would also have to decide if they would limit use of this bridge to equestrians only, or designate it as a multi-use bridge. This effort is likely to be less cost-effective than Option 5B.

Option 5D: Re-route the crossing to an alternate location. Re-routing the crossing to a different location could be potentially very difficult given the environmental setting of the crossing. If the crossing were moved any further upstream out of the riparian floodplain, it would have to cross a steep-sided creek canyon hemmed in by the SAM wastewater treatment plant to the south and private homes along Pilarcitos Avenue to the north. Such a location would likely require CDPR to acquire access easements from these property owners[22] and construct a bridge across the riparian canyon. Another option would be to direct horse traffic onto the beach, where equestrians can then bypass the riparian habitats along Pilarcitos Creek while moving between the Venice Beach and Francis Beach staging areas. This option would be

[20] Installation of a new bridge would likely be self-mitigating for impacts to wetlands, but a Coastal Development Permit or federal consistency determination from the California Coastal Commission would likely be needed along with local permits.

[21] Installation of a new bridge would likely be self-mitigating for impacts to wetlands, but a Coastal Development Permit from the California Coastal Commission would likely be needed along with other appropriate consultations and permits.

[22] Property owners upstream of the SAM plant have expressed interest to State Parks, NMFS, and other agencies about the potential to develop a combined equestrian/farm equipment crossing on their property, which spans both sides of Pilarcitos Creek. Any further analysis of the feasibility of putting a bridge in this location would have to be conducted during the conceptual design phase and involve frequent consultation with the property owners, neighbors, State Parks, and resource protection agencies.

most feasible during the summer months, when Frenchman's and Pilarcitos Creeks do not have an active outlet to the beach that horses would have to cross in order to bypass the Pilarcitos floodplain. However, placing equestrian traffic on the beach would not be consistent with CDPR policies, and could potentially conflict with (1) other natural resource values on the beach, such as Western snowy plover habitat, and (2) recreational use of the beach, which is considerable especially during the summer and early fall months. The presence of large, potentially intimidating animals and horse manure on the beach could pose an especially significant problem for recreational use.

Option 5E: Prohibit instream horse travel up and down the creek from the crossing. Explicitly prohibiting horse travel up and down the creek from the crossing would minimize disturbance to the channel bed and potentially reduce the amount of manure that directly enters the creek. We understand that signage to this effect has not been successful in the past. More active prevention of horse travel, such as the placement of "symbolic fencing" similar to that which is used in delineating Western snowy plover habitat, is another method to discourage (but not prevent) this movement. This sub-option has the same concerns related to perceived hazards and maintenance as sub-option 5A.

Option 5F: Install a more stable structure on the creek banks for horse passage. Installation of a more stable structure within the creek banks at the crossing would decrease bank erosion and improve the safety of the existing crossing. Such a structure could be comprised of "horse steps", broad, low steps (approximately 1 foot rise, 8-foot run, and 10 feet wide) built of timbers and backfilled with a coarse gravel/cobble material. These steps would extend from the edges of the low-flow channel to the top of the bank and give horses a safer, more stable footing for ascending and descending the banks. Similar steps have been implemented in numerous locations favored by equestrians, such as the Old Springs Trail in the Marin Headlands adjacent to the Tennessee Valley stables. The design of such a structure would have to consider that the lower steps would be underwater during high-flow periods, and thus would have to have an engineered backfill that could not be easily washed away under most flow conditions. The design would also have to consider the impacts of the structure on creek hydraulics and patterns of erosion and deposition along the channel bed and banks. Such a structure could induce additional scour along the banks if not designed properly. Another possibility is to stabilize the channel banks using a combination of geotechnical webbing and engineered backfill[23]; such material is already used for erosion control purposes at discrete locations within HMBSB. This material could be installed within the crossing and then planted

[23] Horses would most likely not feel safe walking on webbing that was not completely backfilled, as their hooves would not be level on the ground.

with hardy, fast-growing herbaceous and willow species to encourage biostabilization of the banks. Another alternative within this option is the installation of articulated concrete blocks along the crossing banks; these can be vegetated with woody and herbaceous species to provide further biostabilization and improve crossing aesthetics.

4.5.4 Feasibility Evaluation

Criterion #1: Benefits to Target Species. This option would provide benefits to target species by improving steelhead refuge (and possibly rearing, if creek flows were increased) habitat within the lower creek (Sub-Criterion 1C), especially if some sort of complex cover were installed at the outer bend of the channel. If the existing crossing were narrowed or eliminated, it might improve passage conditions for steelhead through this reach (Sub-Criterions 1A and 1B) by reducing the proportion of the channel that is shallow and braided. By increasing the amount of riparian vegetation, this option could benefit riparian species such as passerines and possibly California red-legged frog (Sub-Criterion 1E), although there isn't currently a dearth of riparian habitat in the lower creek area. Finally, this option may help to improve water quality for target species by limiting or preventing direct discharge of horse manure into the creek, though this would require further analysis in subsequent planning stages.

Criterion #2: Implementation Costs. Implementation costs for this option will vary depending on the sub-option. Sub-options that involve either the construction or retrofitting of bridge structures (5B and 5C) are likely to have considerable costs that could extend into the hundreds of thousands of dollars or more; these costs would stem not only from actual construction but also from likely considerable design and permitting efforts. Other sub-options that would result in fewer disturbances to the site (5A, 5D and 5E) would have less intense design, permitting, and construction costs; 5A and 5E could potentially be partially implemented by volunteers under CDPR supervision. The costs of sub-option 5F will depend on how much excavation/fill is necessary to construct the stabilization design.

Criterion #3: Regulatory Requirements. Sub-options 5B, 5C, and 5F are likely to have considerable regulatory requirements necessitating a Streambed Alteration Agreement with CDFG, consultation with USFWS, NOAA Fisheries, and RWQCB, and potential acquisition of a local/county grading permit. These sub-options would also likely require at the very least development of an Initial Study and Mitigated Negative Declaration under CEQA. Regulatory requirements for Sub-option 5D would vary depending on the location of the new location; any new bridge would have the same regulatory requirements as sub-option 5C. Sub-options 5A and 5E would have minimal regulatory requirements if at all; consultation with resource agencies might be required for installation of symbolic fencing.

Criterion #4. Probability of Securing Funding for Implementation. A funding source would have to be indentified for any significant bridge retrofit/construction (sub-options 5B, 5C, and potentially 5D). Sub-options 5A and 5E have lower implementation costs, and could be implemented partially through the use volunteer labor. CDFG or NOAA Fisheries might also be willing to assist with funding for sub-options 5A, 5E, and 5F.

Criterion #5. Life Expectancy Without Operations and Maintenance (O&M). Life expectancy for this option varies with the different sub-options. Any new or retrofitted bridge structure at the very least should have an expected life span of at least 20 years without O&M. Symbolic fencing, backfill within a stabilized crossing, and similar structures within the active Pilarcitos Creek channel and floodplain would likely persist for less than 2 or 3 years without maintenance since they are highly susceptible to being moved by flood events. The persistence of a re-located crossing (sub-option 5D) would depend entirely on where the new crossing was located; crossing on a beach would likely persist indefinitely while a crossing in a different creek location would be subject to the same flooding forces described above.

Criterion #6. Intensity and Cost of Operations and Maintenance. Any new or retrofitted bridge structure would most likely require some kind of yearly structural monitoring yearly to ensure its safety for use by the public. A new/retrofitted structure would also require periodic (app. every 5 years) maintenance in the form of painting/coating, bridge decking repair, and other associated activities. Installation of complex cover such as logs or rootwads will require yearly monitoring during the rainy season to ensure that the structure is behaving as designed; if the structure is severely compromised or moved during large flood events, it may need to be repaired or replaced. Large or even moderate flood events could move any symbolic fencing, stabilized crossing backfill, or similar structures within the active creek channel/floodplain, necessitating yearly monitoring and likely repair/replacement every few years. New signage will likely require periodic repair or replacement.

Criterion #7. Interactions With Other Habitat Enhancement Efforts. The sub-options described under Option 5 can largely be implemented independent of other efforts within the watershed, though the benefits to steelhead of installing complex cover/scour pool habitat at the crossing's outer bend (a specific location for Option 3 implementation) would be increased by enhanced/managed flows within the creek (Option 2), which would help maintain a scour pool within the channel bed. [24] Using the techniques described above in Section 4.3, complex cover such as rootwads, logs, and LWD could be installed in the outer bend of the crossing to induce

[24] If the scour pool is created upstream of the crossing, it would have to be designed in such a way that horses could not disrupt the hydraulic control of the pond. If the pool is created downstream of the crossing, it would be susceptible to sedimentation from the crossing unless it is stabilized as in sub-option 5G.

the formation of scour pools and provide refugia for steelhead. Exposed banks would then be actively revegetated with dense plantings of sedges, rushes, and other herbaceous plants so that sight lines could be maintained for safety reasons.

If either of the creek outlet deflection sub-options described under Option 4 is implemented, typical water depths at the equestrian crossing could increase, rendering the crossing impassable for longer periods of time unless a new bridge is built or the existing bridge is retrofitted to accommodate horses. As discussed above, future design analysis of Option 4 must consider the potential upstream impacts of increased water depths at the creek outlet and mouth.

Criterion #8: Level of Community/Stakeholder Project Support. As discussed above, retrofitting the equestrian crossing has already been identified as a watershed enhancement action within the Pilarcitos IWMP. The IWMP was developed by the Pilarcitos Restoration Workgroup with public input, though no local equestrian group was part of the formal Workgroup. Any options that enhance the safety and stability of the crossing are likely to experience support from equestrians. Sub-options that would remove horse contact from the crossing entirely might receive equestrian support because the crossing would be viable during and after high-flow events in the creek (which is not currently the case); however, some equestrians may place a recreation value on direct contact with the creek and may not appreciate losing this opportunity. Resource agencies such as NMFS, CDFG, and the RWQCB are also highly likely to support sub-options that reduce disturbance to the channel bed and banks and improve steelhead and riparian habitat.

Criterion #9: Potential Unintended Consequences. Sub-options 5B and 5C are unlikely to have significant unintended consequences because multiple bridges have been installed in similar environs along the California coast, and the consequences of various designs are fairly well-known and understood. Sub-option 5A is unlikely to have significant unintended consequences unless the symbolic fencing proves to be more mobile than anticipated (e.g., moves under smaller flood flows). Unintended consequences under sub-option 5D will depend on the new crossing location and are thus difficult to assess in this report. Sub-option 5E is highly unlikely to have significant unintended consequences unless the creek channel itself is a primary movement corridor for equestrians, which is unlikely given its location. Sub-options 5F and 5G could have a number of unintended consequences on channel morphology and habitat functions; a rigorous design analysis of these options should include consideration of this fact.

Criterion #10: Costs and Benefits Relative to Actions Above Highway One. Actions at the equestrian crossing primarily address issues of aquatic and riparian habitat quality, including water quality, not fish passage. Actions above Highway One would tend to be actions aimed at improving (1) passage at features such as culverts, plunge pools, and other hydraulic barriers, and (2) spawning habitat, neither of which are present within lower Pilarcitos Creek. In addition, actions at the equestrian crossing would address public recreational concerns, which are typically less of a concern higher in the Pilarcitos watershed where much of the land is privately owned or publicly owned but not yet open to recreation. Therefore, it is difficult to compare costs and benefits under this criterion. The Pilarcitos Working Group and current/future TACs will likely have significant input into any such future analyses.

Criterion #11: Extent Option "Works With Nature". Sub-options that reduce disturbance to the channel bed and banks work with nature by facilitating natural processes of bed/bank erosion, deposition, and revegetation. The design of sub-options that would place structures such as "horse steps" or LWD within or adjacent to channel habitats must consider natural hydrologic, hydraulic, and geomorphic forces; designs that do not "work with nature" in this regard are unlikely to (1) provide target habitat functions and (2) be sustainable in the long-term.

5 Conclusions and Next Steps

In this report, we have described the physical and ecological processes governing the morphodynamics and dependent habitat functions within lower Pilarcitos Creek. We have described why Pilarcitos is different from many of its Central California lagoon peers, owing to its unique combination of natural history coupled with anthropomorphic change in its watershed. We have identified which of its governing processes are potentially subject to intervention in order to benefit target species such as steelhead and Western snowy plover. We have described five habitat enhancement options aimed at improving habitat for these and other species, and analyzed the feasibility of each according to a broad set of criteria.

We anticipate that future efforts to address habitat functions within the lower Pilarcitos Creek system will depend upon: (1) the implementation priorities of stakeholders such as CDPR, resource agencies, and the Pilarcitos Working Group, and (2) the availability of funds from either federal, state, or local sources to perform supplemental planning, analysis, and design. This project is a feasibility analysis, and thus could not include the exceptionally broad range of design analyses needed to move many of the proposed enhancement options forward into implementation. Future efforts should include such analyses as well as continued consultation with the Pilarcitos TAC, Workgroup, and other stakeholders.

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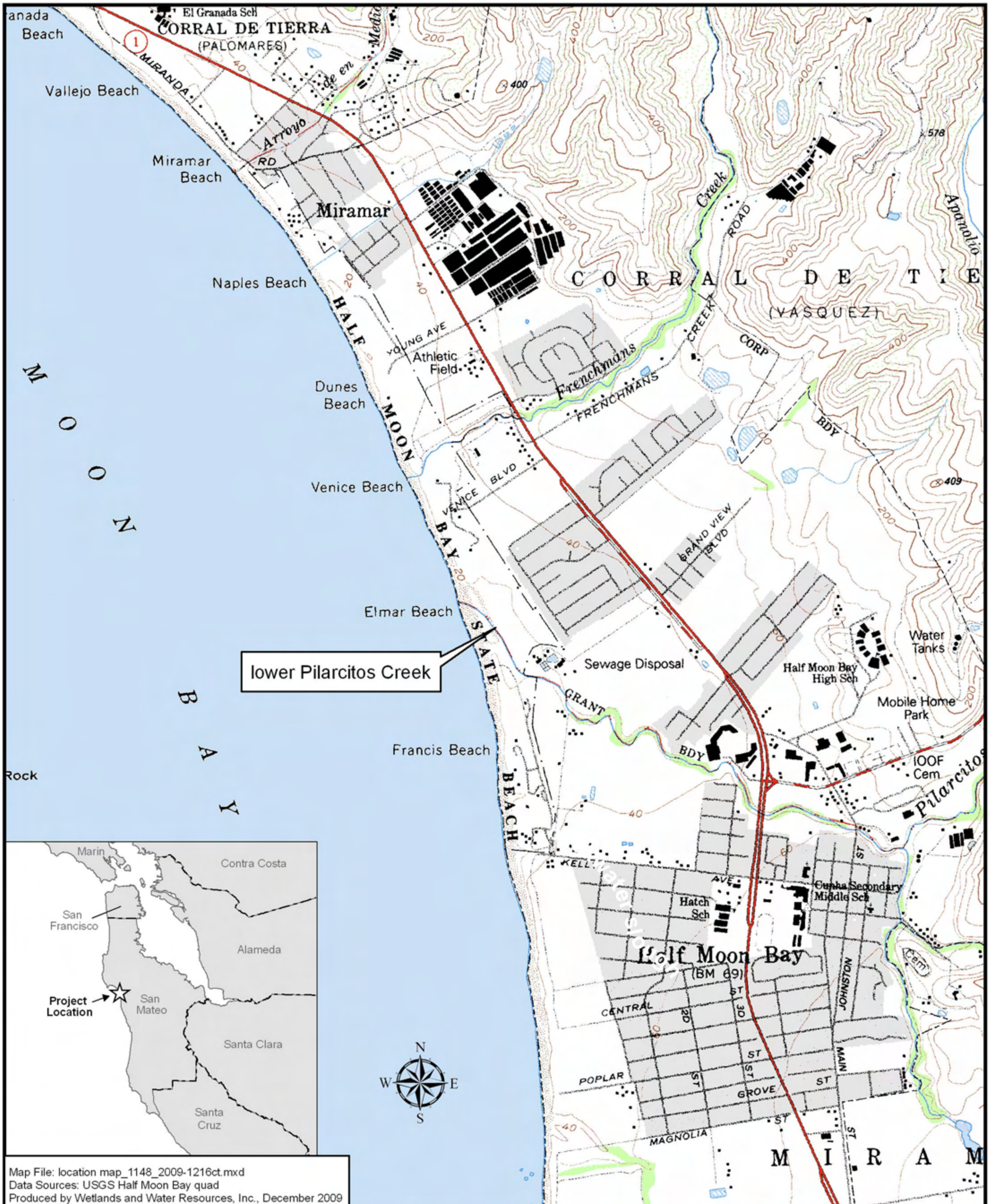
Figures



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0 1,000 2,000 4,000 Feet

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WETLANDS AND WATER RESOURCES, INC.

VICINITY MAP

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County Resource Conservation District
San Mateo County, California

December 2009	Project No. 1148	**Figure 1**

1:4,800; 1"= 400' at letter size

0 200 400 800 Feet

0 50 100 200 Meters

WETLANDS AND WATER RESOURCES, INC.

LOCATION MAP

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County Resource Conservation District
San Mateo County, California

December 2009	Project No. 1148	**Figure 2**

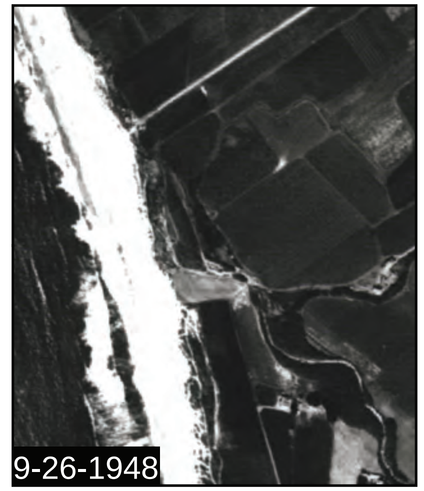
1928

feature	condition
beach berm	single wide berm across mouth
foredune vegetation	foredune patterned vegetation S of Pilarcitos Ck mouth; continuous foredune or transitional foredune/riparian vegetation occupies most of N half of mouth
beach outlet position (longshore drift)	no outlet evident; unvegetated sand funnel pattern in mouth likely represents most recent channel breach shore-normal
beach outlet state	no outlet evident
backbeach channel, lagoon state	no channel or lagoon evident
channel mouth bedforms	none evident; unvegetated sand is likely recent channel outlet
riparian vegetation at mouth	continuous foredune or transitional foredune/riparian vegetation occupies most of N half of mouth
backwater floodplain ponds - mouth	none evident
overwash activity	none evident
terrace agriculture N	active tillage, cropping
terrace agriculture S	active tillage, cropping
Frenchman's Creek mouth connectivity	no backbeach channel north

October 11, 1943

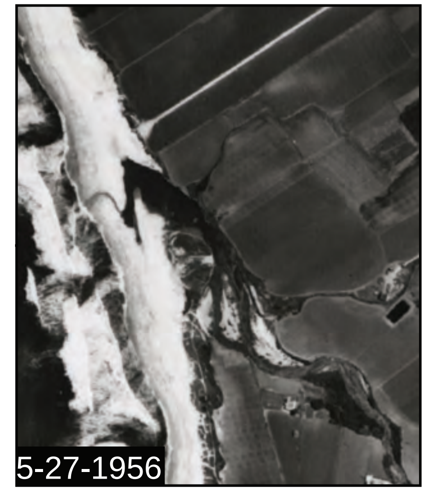
feature	condition
beach berm	single wide berm across mouth, but truncated by N-deflected outlet channel meander
foredune vegetation	present S of mouth; multiple barren foot trails parallel with shore, some reticulate; well-defined discrete foredune hummocks at seaward edge of zone
beach outlet position (longshore drift)	deflected N behind berm, likely N of mid-point to Frenchman's Ck
beach outlet state	not evident; no outflow
backbeach channel, lagoon state	shallow backbeach channel, dry
channel mouth bedforms	planar or braided; darker tone (moist sand) seaward of vegetation in channel bed below bluff
riparian vegetation at mouth	wide zone of sinuous, braided pattern of coarse-grained dark vegetation in most of mouth, likely early succession stages; bare road crossing at head of mouth
backwater floodplain ponds - mouth	none evident
overwash activity	none evident
terrace agriculture N	active tillage, irrigated row crops
terrace agriculture S	active tillage, irrigated row crops
Frenchman's Creek mouth connectivity	potentially linked

September 26, 1948



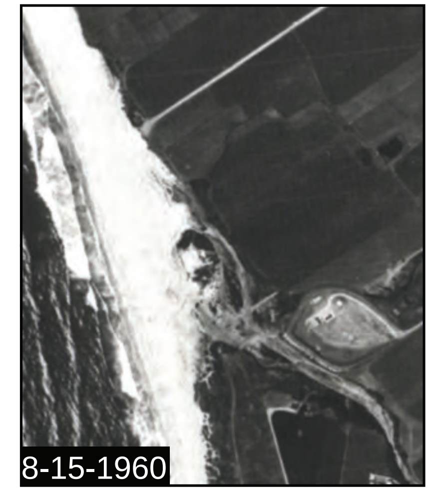
feature	condition
beach berm	single wide berm seaward of foredune edge and mouth
foredune vegetation	present S of mouth; multiple barren foot trails parallel with shore, some reticulate; well-defined discrete foredune hummocks at seaward edge of zone
beach outlet position (longshore drift)	not evident; apparent grading of wide, flat unvegetated (gray tone - moist?) opening across S end of mouth between (dry) channel and beach; possible pre-breach alignment or flood control sediment removal
beach outlet state	not evident
backbeach channel, lagoon state	dry; weakly defined channel braiding pattern in backbeach and riparian vegetation N of mouth
channel mouth bedforms	S half of mouth graded flat; remainder vegetated
riparian vegetation at mouth	continuous vegetation across mouth N of graded opening
backwater floodplain ponds - mouth	none evident
overwash activity	none evident
terrace agriculture N	active tillage, irrigated row crop
terrace agriculture S	active tillage, irrigated row crop
Frenchman's Creek mouth connectivity	none evident

May 27, 1956



feature	condition
beach berm	single berm north of outlet, local double berm at S end of outlet
beach outlet position (longshore drift)	within mouth, directly seaward of backbeach lagoon formed within mouth; short S deflection by berm at N end; relict backshore runnel between inner and outer berm crests suggests recent S deflection
beach outlet state	choked but discharging across berm crest in shallow (sheet flow) wide channel on beach face at low tide
backbeach channel, lagoon state	beach-dammed/choked lagoon (dark) in backbeach and below bluff in N half of mouth
channel mouth bedforms	(submerged in lagoon); braided mid-channel bars and point bars immediately upstream of lagoon, S half of mouth
riparian vegetation at mouth	sparse or none in channel; extensive erosion or deposition since 1948; early succession
backwater floodplain ponds - mouth	none evident
overwash activity	none evident; possible relict washover fan vegetated in S half of mouth
foredune vegetation	not detectable; mostly bare except landward edge
terrace agriculture N	active tillage, irrigation
terrace agriculture S	active tillage, irrigation
Frenchman's Creek mouth connectivity	none

August 15, 1960



feature	condition
beach berm	very wide, unvegetated up to bluff toe north of mouth; low-relief NW-oriented transverse dune pattern on beach
foredune vegetation	local, south of mouth only; unvegetated below bluff north (post-erosion)
beach outlet position (longshore drift)	none
beach outlet state	none
backbeach channel, lagoon state	no backbeach channel or lagoon
channel mouth bedforms	traces of meandering, braided bed and mid-channel, point bars terminating in mouth
riparian vegetation at mouth	very sparse, low, in braided channel; single patch (relict foredune?) in center of mouth
backwater floodplain ponds - mouth	none
overwash activity	likely from previous winter (foredunes eliminated N of mouth)
terrace agriculture N	active tillage, irrigated row crops
terrace agriculture S	active tillage, irrigated row crops
Frenchman's Creek mouth connectivity	none

July 8, 1963

feature	condition
beach berm	double berms (inner = primary berm, outer = beach dam) across mouth
beach outlet position (longshore drift)	trace of slender outlet channel in runnel between inner and outer berms, S end of mid-beach lagoon
beach outlet state	closed
backbeach channel, lagoon state	mid-beach position (backshore runnel between inner and outer berms, offset immediately N of mouth)
channel mouth bedforms	braided, reticulate bed
riparian vegetation at mouth	consolidated low (herbaceous?) patches on deltaic mid-channel bars
backwater floodplain ponds - mouth	none
overwash activity	
foredune vegetation	not detectable; mostly bare except landward edge
terrace agriculture N	active tillage, irrigation
terrace agriculture S	active tillage, irrigation
Frenchman's Creek mouth connectivity	none

May 15, 1968

feature	condition
beach berm	single berm, narrowing northward
foredune vegetation	south of mouth only
beach outlet position (longshore drift)	deflected far north towards Frenchman's Creek
beach outlet state	(not visible; likely closed)
backbeach channel, lagoon state	Shore-parallel, slender elongated mid-beach channel lagoon (backshore runnel), deepening (darkening) northward
channel mouth bedforms	truncated, acute seaward-pointing cusp of riparian (herbaceous) vegetation within mouth suggests recent breach at mouth, subsequent northward deflection
riparian vegetation at mouth	little woody riparian vegetation evident; herbaceous vegetation likely in deltaic flats
backwater floodplain ponds - mouth	none evident
overwash activity	none evident
terrace agriculture N	active tillage, irrigated row crops
terrace agriculture S	active tillage, irrigated row crops
Frenchman's Creek mouth connectivity	likely

graphic file: Fig-3A_Lagoon Morpohology Evolution_2009-1009ct.ai

WETLANDS AND WATER RESOURCES, INC.

LAGOON MORPHOLOGY, 1928 - 1968

Pilarcitos Lagoon Enhancement Feasibility Project
San Mateo County Resource Conservation District
Half Moon Bay, California

October 2009	Project No. 1148	**Figure 3A**

April 2, 1970

feature	condition
beach berm	single narrow berm
foredune vegetation	south of mouth only; mostly discontinuous discrete hummocks
beach outlet position (longshore drift)	channel lagoon and outlet deflected north of mouth, terminating at bluff toe north of mouth (slender outlet channel deflects slightly south of lagoon terminus)
beach outlet state	narrowly open/choked with active outflow below berm crest, across beach face
backbeach channel, lagoon state	narrow channel bed below bluff toe, deepest (darkest) near terminus
channel mouth bedforms	submerged braided bedforms, broad mid-channel and point bars
riparian vegetation at mouth	predominantly unvegetated bed with low, extensive (likely herbaceous) patches; possible low riparian scrub fringing toe of bluff, N end of mouth and local at head of mid-channel bar
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	active tillage, irrigated row crops
terrace agriculture S	active tillage, irrigated row crops
Frenchman's Creek mouth connectivity	none

May 4, 1977

feature	condition
beach berm	single berm; cusped
foredune vegetation	discrete foredune hummocks, few larger consolidated foredune vegetation patches, south of mouth only; no barrier foredunes or embryo foredunes across mouth
beach outlet position (longshore drift)	centered at mouth, oriented NE-SW
beach outlet state	open (no berm or swash bar dam), dry; relict scarps evident along flanks of outlet
backbeach channel, lagoon state	short shore-normal channel (direct breach of berm), dry; aggraded terminal meander, partly vegetated (herbaceous) across most of seaward half of mouth
channel mouth bedforms	vegetated (herbaceous) across most of seaward half of mouth; braided and unvegetated at inside bend landward
riparian vegetation at mouth	large cusp of low herbaceous (likely seasonal wetland) vegetation across seaward half of mouth; patchy woody vegetation on meander bars upstream N and S of crossing and treatment plant
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
Frenchman's Creek mouth connectivity	none

August 6, 1978

feature	condition
beach berm	double berm at mouth, single berm N and S
foredune vegetation	foredune hummocks S of mouth; no barrier foredunes across mouth; little change since 1977
beach outlet position (longshore drift)	centered at mouth; channel oriented NW at base of bluff, deflected S by beach to center of mouth at terminus
beach outlet state	closed (outer berm = beach dam)
backbeach channel, lagoon state	mid-beach (backshore runnel) position, shallow flooded near terminus (emergent bars)
channel mouth bedforms	aggraded point bars; single-thread channel
riparian vegetation at mouth	large cusp of low herbaceous (likely seasonal wetland) vegetation consolidated across seaward half of mouth, supporting incipient woody riparian vegetation; expansion, consolidation of woody riparian vegetation on meander bars upstream N and S of crossing and treatment plant
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
Frenchman's Creek mouth connectivity	none

September 22, 1980

feature	condition
beach berm	single berm
foredune vegetation	embryo foredunes sparse across mouth, seaward of antecedent cusp of riparian vegetation, broad sand accretion lobes (wind deposited) at seaward edge of riparian vegetation. Breach at S end of mouth across foredunes – outfall construction. Foredune vegetation expands, consolidates S of mouth
beach outlet position (longshore drift)	shore-normal at N end of mouth
beach outlet state	closed, truncated channel flooded at terminus in berm
backbeach channel, lagoon state	truncated channel flooded at terminus in berm; short, slender relict channel spur flooded at toe of bluff; emergent deltaic bed (bar and shallow braided channels) within mouth
channel mouth bedforms	braided deltaic bed emergent within mouth
riparian vegetation at mouth	mostly continuous woody riparian vegetation cover across wide point bars, defining unvegetated meandering channel zone
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
Frenchman's Creek mouth connectivity	none

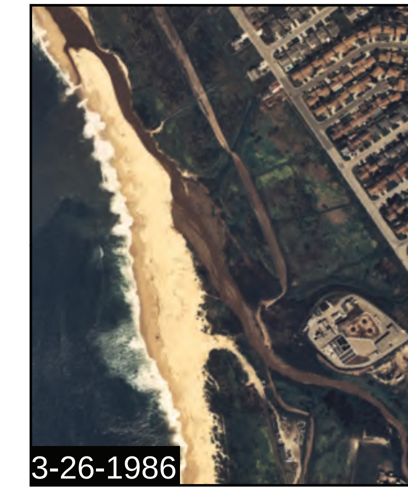
January 7, 1982

feature	condition
beach berm	single berm obliquely truncated by active fluvial channel, NW-SE; upper foreshore cusps
foredune vegetation	consolidated foredunes intact S of mouth; narrow line of foredunes at seaward edge of channel-truncated riparian vegetation remnant across mouth.
beach outlet position (longshore drift)	far N, likely deflected by artificial training or crib wall installed in beach at N end of mouth during outfall construction (in progress)
beach outlet state	open; active discharge, near flood stage
backbeach channel, lagoon state	open; active discharge, near flood stage, subparallel with berm
channel mouth bedforms	submerged
riparian vegetation at mouth	mostly continuous woody riparian vegetation cover across wide point bars, defining unvegetated meandering channel zone
backwater **floodplain** ponds - mouth	none
overwash activity	none evident; seaward edge of riparian vegetation at mouth truncated by creek bank, not overwash
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
Frenchman's Creek mouth connectivity	likely

March 1984

feature	condition
beach berm	single berm
foredune vegetation	hummock pattern weak, diffuse; possible overwash influence
beach outlet position (longshore drift)	narrow outlet at N end of mouth, possibly deflected/dammed by anomalous (artificial?) sand berm oriented E-W extending from toe of bluff at end of drainage ditch
beach outlet state	open; active discharge, low flow in slender channel across berm and beachface
backbeach channel, lagoon state	no lagoon; emergent moist/wet deltaic braided bed within mouth
channel mouth bedforms	braided
riparian vegetation at mouth	persistent, consolidated remnant of pre-1984 woody riparian vegetation across S half of mouth at seaward edge; consolidated stands of woody riparian cover in matrix of herbaceous/grass-like vegetation on wide point bars, clearly defining unvegetated meandering channel zone
backwater **floodplain** ponds - mouth	none
overwash activity	likely overwash at N half of mouth
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
FC mouth connectivity	none

March 26, 1986



feature	condition
beach berm	single berm, forms spit bordering intertidal swash bar at outlet; cusped
foredune vegetation	embryo foredune hummocks expand along seaward edge of riparian vegetation extending further N across mouth
beach outlet position (longshore drift)	outlet drains backbeach channel south of terminus; outlet located mid-point between Frenchman's and Pilarcitos Ck mouths (main channel terminus further N)
beach outlet state	open; active discharge, low flow in slender channel across berm and beachface
backbeach channel, lagoon state	backbeach lagoon flooded in bluff-toe backbeach channel occupying half or more of berm profile; emergent deltaic braided beds, shallow sheet flow, within mouth.
channel mouth bedforms	braided in mouth; submerged along bluff-toe backbeach channel
riparian vegetation at mouth	northward extension of persistent, consolidated remnant of pre-1984 woody riparian vegetation across seaward edge of mouth; continued consolidated stands of woody riparian cover in matrix of herbaceous/grass-like vegetation on wide point bars, clearly defining unvegetated meandering channel zone
backwater **floodplain ponds** - mouth	none
overwash activity	none
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
FC mouth connectivity	likely

graphic file: Fig-3B_Lagoon Morpohology Evolution_2009-1009ct.ai

WETLANDS AND WATER RESOURCES, INC.

LAGOON MORPHOLOGY, 1970 - 1986

Pilarcitos Lagoon Enhancement Feasibility Project
San Mateo County Resource Conservation District
Half Moon Bay, California

October 2009 | Project No. 1148 | **Figure 3B**

October 3, 1987

feature	condition
beach berm	single berm
foredune vegetation	foredunes consolidate, expand north over former riparian wetland vegetation across mouth, forming continuous barrier; foredune hummocks, reticulate trails remain S of mouth; outfall gap in foredunes mostly bare
beach outlet position (longshore drift)	relict, dry S-shaped outlet channel at same position as 1986 anomalous (artificial?) berm opposite mouth of ditch, possible managed deflection point
beach outlet state	open; slightly moist bed (darker than adjacent berm)
backbeach channel, lagoon state	no lagoon; emergent moist well-defined unvegetated channel bordered by continuous riparian vegetation (mostly herbaceous) within mouth
channel mouth bedforms	braided? (pattern indistinct)
riparian vegetation at mouth	mouth is dominated by persistent, consolidated riparian vegetation both seaward and landward ends, confining well-defined channel oriented NW-SE; consolidated stands of woody riparian cover on wide point bars, gently meandering channel zone
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
Frenchman's Creek mouth connectivity	none

October 31, 1991

feature	condition
beach berm	single berm
foredune vegetation	continuous foredune vegetation across most of mouth, narrowing northward
beach outlet position (longshore drift)	mid-point between Frenchman's and Pilarcitos Ck mouths
beach outlet state	open, discharging across berm and beachface
backbeach channel, lagoon state	backbeach bluff-toe channel; moist or wet, darker than adjacent berm (unidentifiable)
channel mouth bedforms	unidentifiable
riparian vegetation at mouth	expansion of riparian vegetation narrows single channel throughout mouth, dominates floodplain
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	no recent tillage; fallow, pioneer old field succession pattern
terrace agriculture S	no recent tillage; fallow, pioneer old field succession pattern
Frenchman's Creek mouth connectivity	none

April 19, 1993

feature	condition
beach berm	single berm
foredune vegetation	discrete foredune hummocks extend across mouth, bordering seaward edge of riparian vegetation across mouth, tapering N
beach outlet position (longshore drift)	far N (likely at or near Frenchman's Ck mouth)
beach outlet state	likely choked, partly open
backbeach channel, lagoon state	backbeach bluff-toe channel flooded N of mouth, emergent aggraded, (wet/sheetflow) deltaic flats within mouth
channel mouth bedforms	braided deltaic flats
riparian vegetation at mouth	continuous woody riparian vegetation across mouth at seaward edge; floodplain dominated by continuous riparian vegetation, mostly woody; natural levee patterning of woody vegetation evident; new pioneer colonization of mid-channel bars
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	no recent tillage; old field scrub
terrace agriculture S	no recent tillage; old field scrub
Frenchman's Creek mouth connectivity	likely

June 22, 1994

feature	condition
beach berm	single berm
foredune vegetation	discrete foredune hummocks enlarge, extend further N across mouth; enlarging barrier to overwash
beach outlet position (longshore drift)	far N (likely at or near Frenchman's Ck mouth)
beach outlet state	likely choked, partly open
backbeach channel, lagoon state	backbeach bluff-toe channel with emergent bed, long-attenuated N
channel mouth bedforms	braided deltaic flats with diffuse incipient stabilizing vegetation
riparian vegetation at mouth	continuous woody riparian vegetation across mouth at seaward edge; floodplain dominated by continuous riparian vegetation, mostly woody; natural levee patterning of woody vegetation evident; further new pioneer colonization of mid-channel bars
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	old field scrub
terrace agriculture S	old field scrub
Frenchman's Creek mouth connectivity	likely recent

June 7, 2001

feature	condition
beach berm	single berm
foredune vegetation	discrete foredune hummocks connected by matrix of (creeping) ground layer foredune vegetation, extended across mouth, enlarging barrier to overwash
beach outlet position (longshore drift)	far N (likely at or near Frenchman's Ck mouth)
beach outlet state	likely choked, partly open
backbeach channel, lagoon state	backbeach bluff-toe channel (wet/sheetflow) parallel to bluff and beach north of mouth; dry
channel mouth bedforms	channel reduced to narrow, well-defined zone within woody riparian vegetation matrix; most of active bed partly vegetated (drought)
riparian vegetation at mouth	continuous woody riparian vegetation across mouth at seaward edge; floodplain dominated by continuous riparian vegetation, mostly woody; natural levee patterning of woody vegetation evident; new pioneer colonization of mid-channel bars
backwater **floodplain** ponds - mouth	none
overwash activity	none evident
terrace agriculture N	old field scrub
terrace agriculture S	old field scrub
Frenchman's Creek mouth connectivity	likely

October 2005

feature	condition
beach berm	single berm
foredune vegetation	extensive embryo foredune vegetation established in backbeach within and N of mouth; expansion of foredune hummocks and ground layer vegetation across mouth; enlarging barrier foredune
beach outlet position (longshore drift)	far N (likely at or near Frenchman's Ck mouth)
beach outlet state	likely closed
backbeach channel, lagoon state	backbeach bluff-toe channel (dry or moist) parallel to bluff and beach north of mouth; braided bed emergent
channel mouth bedforms	braided deltaic bed at N end of mouth and backbeach supports herbaceous wetland vegetation (bright green); channel mostly shaded by tall riparian woodland upstream of mouth, not visible
riparian vegetation at mouth	continuous woody riparian vegetation across floodplain; floodplain dominated by continuous riparian vegetation, including mid-channel bars; mostly woody; natural levee patterning of woody vegetation evident
backwater **floodplain** ponds - mouth	none evident
overwash activity	none evident
terrace agriculture N	old field scrub
terrace agriculture S	old field scrub
Frenchman's Creek mouth connectivity	likely

June 2006

feature	condition
beach berm	single berm
foredune vegetation	embryo foredune vegetation N of mouth eliminated; continued expansion and coalescence of foredune hummocks and ground layer vegetation across mouth; enlarging barrier foredune
beach outlet position (longshore drift)	far N (likely at or near Frenchman's Ck mouth)
beach outlet state	likely closed
backbeach channel, lagoon state	backbeach bluff-toe channel (wet/sheetflow) parallel to bluff and beach north of mouth; braided bed emergent
channel mouth bedforms	braided deltaic bed at N end of mouth and backbeach is unvegetated; narrow riparian vegetation-confined channel bed again exhibits visible bare sediment upstream of mouth (erosion reduces channel bed vegetation)
riparian vegetation at mouth	continuous woody riparian vegetation across floodplain; floodplain dominated by continuous riparian vegetation, including mid-channel bars; mostly woody; natural levee patterning of woody vegetation still evident
backwater **floodplain** ponds - mouth	none evident
overwash activity	none evident
terrace agriculture N	old field scrub
terrace agriculture S	old field scrub
Frenchman's Creek mouth connectivity	likely

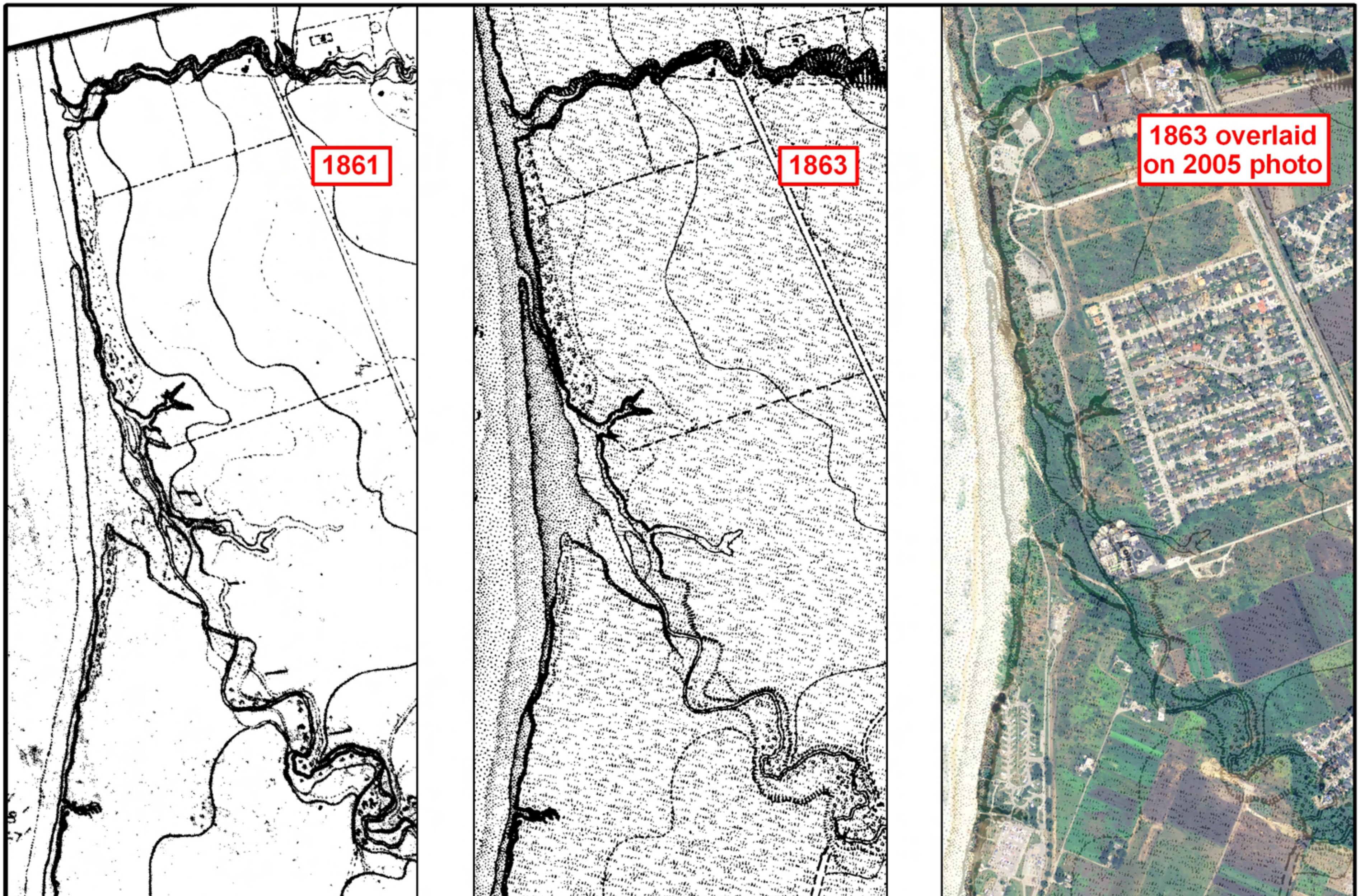
WETLANDS AND WATER RESOURCES, INC.

LAGOON MORPHOLOGY, 1987 - 2006

Pilarcitos Lagoon Enhancement Feasibility Project
San Mateo County Resource Conservation District
Half Moon Bay, California

October 2009	Project No. 1148	**Figure 3C**

graphic file: Fig-3C_Lagoon Morpohology Evolution_2009-1009ct.ai



N

~ 1:12,000; 1 inch ~ 1,000 ft at letter size

0 500 1,000 2,000 Feet

0 250 500 Meters

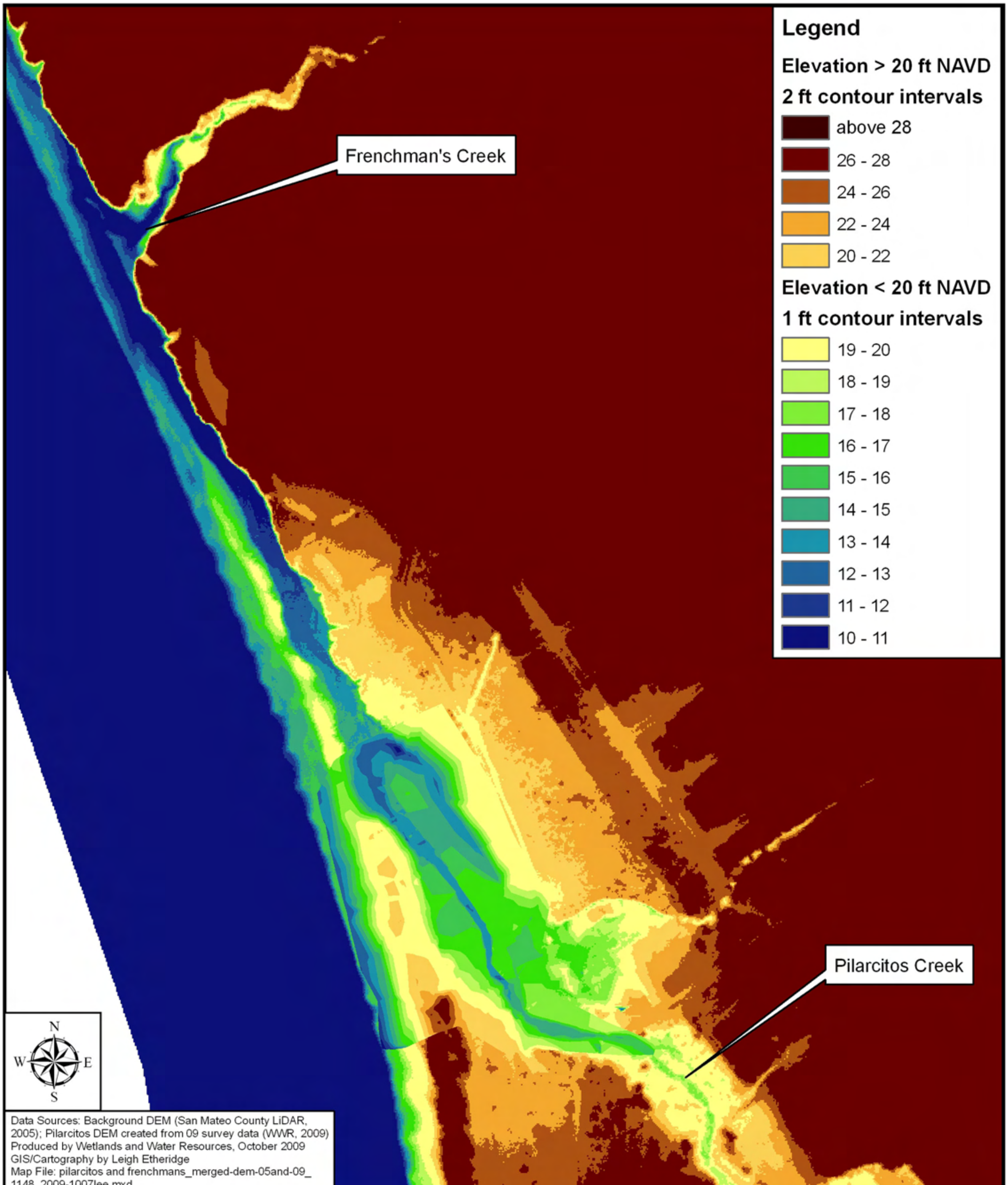
Map File: 1861-1863_coast-survey-maps_2009-0531ct.mxd
Data Sources: historic US Coast Survey maps:
UC-Berkeley (1861), Keith Mangold (1863)
2005 photo: USDA NAIP
Produced by Wetlands and Water Resources, Inc., May 2009
GIS/Cartography by Leigh Etheridge and Christina Toms

WETLANDS AND WATER RESOURCES, INC.

1861 AND 1863 US COAST SURVEY MAPS

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County Resource Conservation District
San Mateo County, California

May 2009	Project No. 1148	**Figure 4**

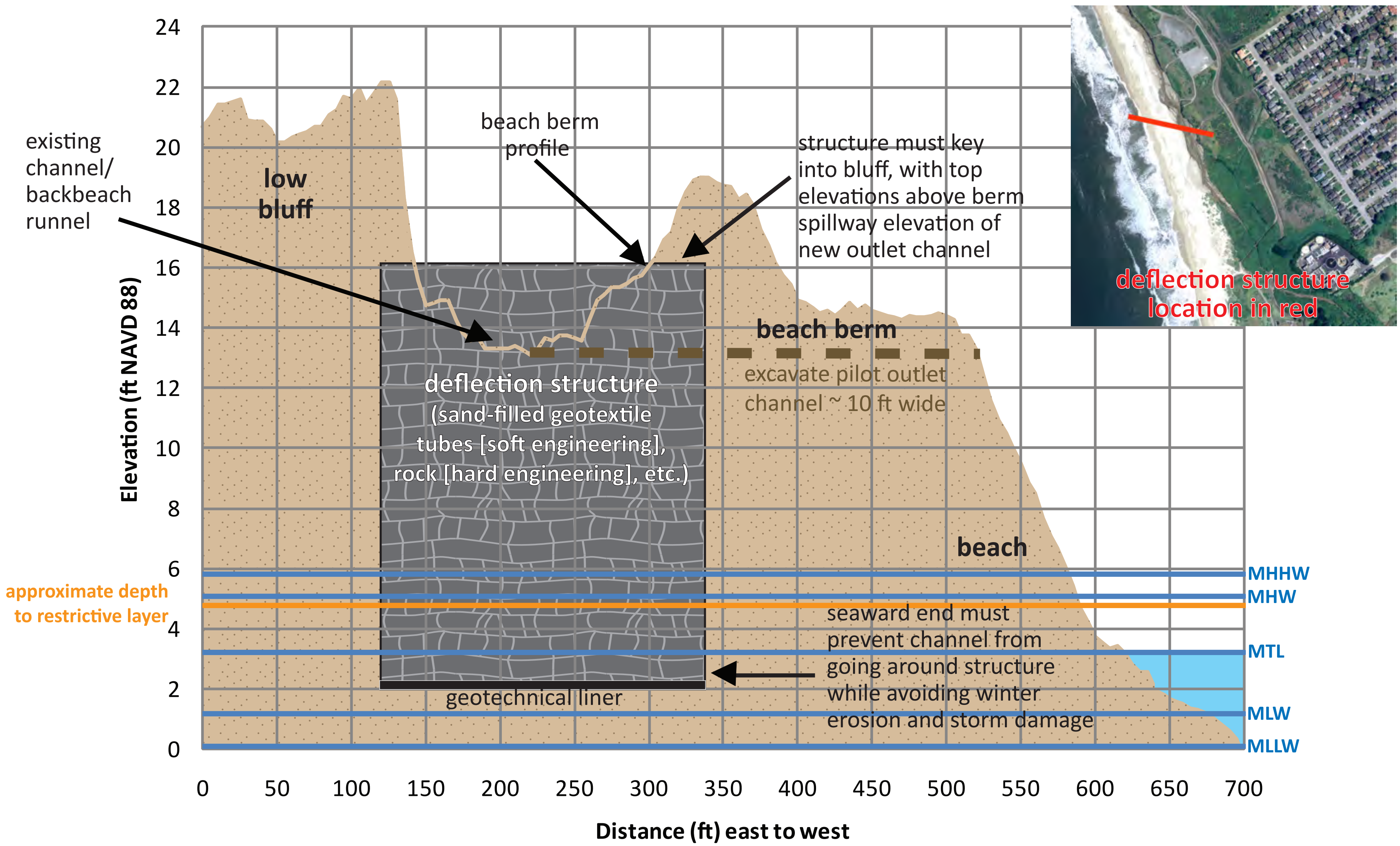


WETLANDS AND WATER RESOURCES, INC.

DIGITAL ELEVATION MODEL

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County Resource Conservation District
San Mateo County, California

October 2009	Project No. 1148	**Figure 5**



Note: All locations and dimensions are DRAFT and for purposes of discussion only. Final design may have a significantly different configuration. Figure not to scale.

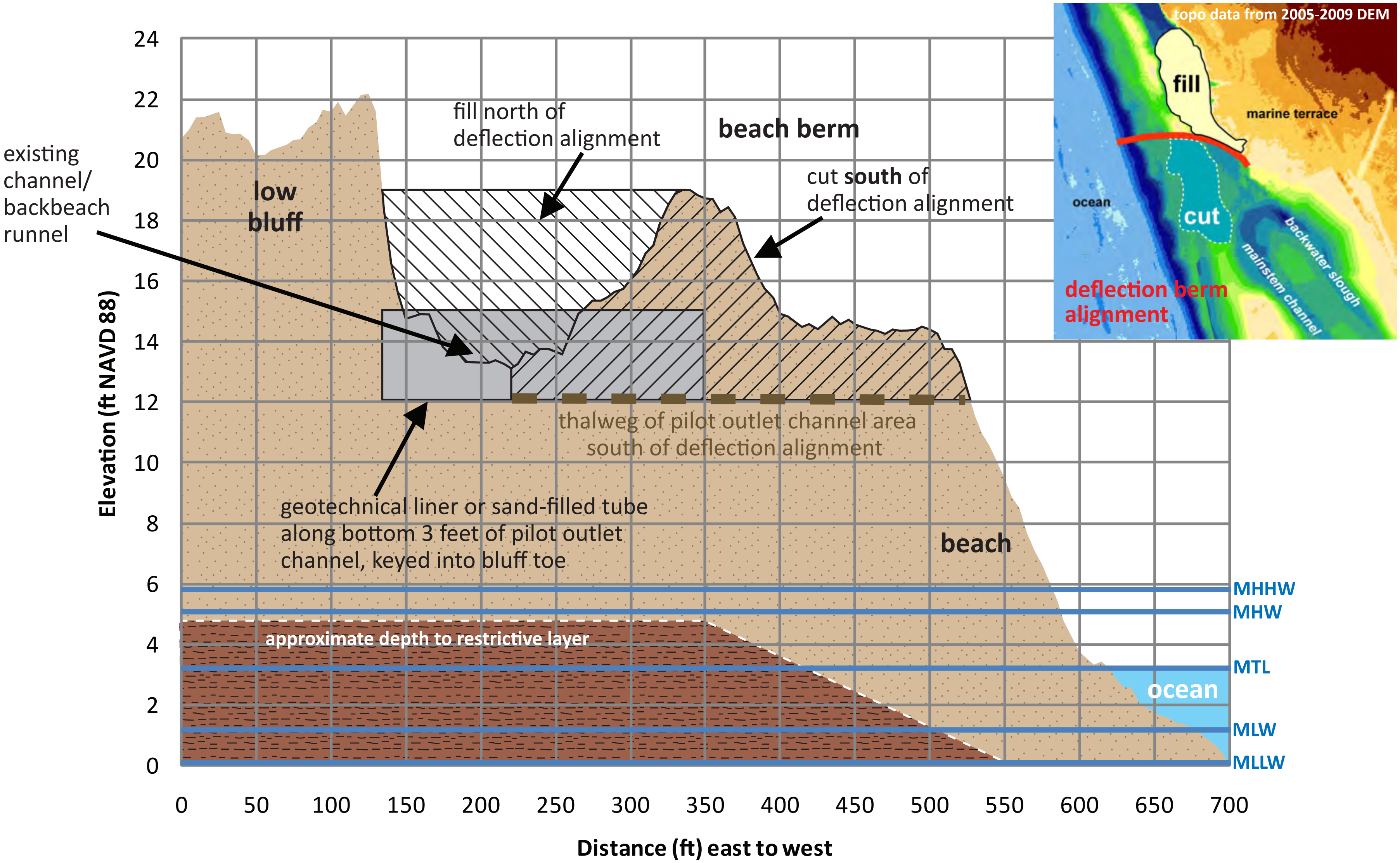
WETLANDS AND WATER RESOURCES

TOPOGRAPHIC CROSS-SECTION, POTENTIAL DEFLECTION STRUCTURE

Pilarcitos Lagoon Habitat Enhancement Feasibility Project
San Mateo County Resource Conservation District
Half Moon Bay, San Mateo County, California

December 2009	Project No. 1148	Figure **6**

Data source: deflection structure option 1_2009-1117ct.xls
Graphic file: Fig 06_deflection structure_2009-1216ct.ai



Note: All locations and dimensions are DRAFT and for purposes of discussion only. Final design may have a significantly different configuration. Figure not to scale.

WETLANDS AND WATER RESOURCES

TOPOGRAPHIC CROSS-SECTIONS, CUT AND FILL AREAS AROUND DEFLECTOR

Pilarcitos Lagoon Habitat Enhancement Feasibility Project
San Mateo County Resource Conservation District
Half Moon Bay, San Mateo County, California

December 2009	Project No. 1148	Figure 7

Profile source: deflection structure option 1_2009-1117ct.xls
Graphic file: Fig 07_deflection berm_2009-1216ct.ai

Appendices

Appendix A

Conceptual Model

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Pilarcitos Lagoon Habitat Enhancement Feasibility Project: Conceptual Model

30 March 2010

Prepared for:

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With:

Balance Hydrologics, Inc.®

Peter Baye, PhD
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Project No. 1148

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1. Abstract

The primary goal of the **Pilarcitos Lagoon Habitat Enhancement Opportunities Study** is to determine what, if any, lagoon fish passage and habitat enhancement approaches have the potential to provide significant benefits for fish or other species of concern, or to improve ecological functions for multiple target species.

We have synthesized historic and contemporary evidence (including topography, shore morphology, water quality, streamflow, sediment cores, vegetation, fish habitat conditions) describing the range of variability in ecological, hydrological, and geomorphic conditions and processes at the Pilarcitos Creek mouth to provide a working conceptual model of its lagoon form and dynamics. We apply the conceptual model to interpret recent conditions, and evaluate feasible modifications of hydrologic and ecological functions to special-status species habitats associated with specific alternate states of the system.

The Pilarcitos Creek mouth is distinctive among other lagoon systems along the Central Coast in its historic and modern lack of geomorphic space for a large-scale lagoon. The creek bed at the mouth does not appear to incise to intertidal elevations. Intermittent lagoon formation by the creek appears to have been confined to the channels and depressions in the beach. Without creek channel incision to intertidal elevation ranges, there is minimal potential to form a beach-dammed lagoon with fresh to brackish gradients suitable for smolt osmotic regulation and other habitat functions.

The Pilarcitos stream mouth and adjacent floodplain (the potential lagoon positions) are extensively vegetated and aggraded with sand and silt to elevations well above the tidal range. The mouth forms a deltaic channel behind a coarse-grained, permeable beach ridge with high potential for subsurface discharge (seepage) losses. The creek floodplain (willow woodland) is aggraded to the elevation range of the beach backslope.

The creek and floodplain at the mouth are strongly depositional sedimentary environments. Our team estimated a mean annual sediment yield of almost 5,000 m^3 per year to the local beach sand budget. Water surface elevations in the deltaic channel reach crossing the backbeach are likely limited by high beach seepage rates. The beach outlet of the creek channel often drifts far to the north of the mouth, extending the length and channel bed area along the back of the coarse-grained, permeable beach. The estimated seepage potential through the beach is proportional with the length of the beach outlet channel. The creek outlet position was historically variable, but tended to drift northward towards Frenchman’s Creek. In recent decades, the northward deflection and attenuation of the channel outlet appears to have become the prevalent condition. Direct breaching of the beach at the mouth has become

increasingly restricted by stabilized woody riparian vegetation and a substantial foredune ridge established in recent decades.

Sediment cores at the Pilarcitos Creek mouth beach and floodplain revealed no fine-grained lagoon deposits, peats, or restrictive layers (sandy clay) within the upper 6 ft that may inhibit seepage losses of stream discharge through the beach. In contrast, restrictive clay layers were encountered at 3 ft depth below the beach at Frenchman's Creek, which regularly forms a small lagoon.

Maximum lagoon water surface elevations in the creek are ephemeral and associated with brief extreme high tides, overwash, or fluvial flood peaks during open beach outlet conditions in the winter/early spring. Maximum *sustained* lagoon WSEs during beach-dammed/choked outlet conditions in the summer are below the floodplain surface elevations.

The lower creek and "lagoon" have a predominantly freshwater salinity regime; there little or no evidence of a persistent, residual brackish influence in vegetation composition or structure. The mouth and potential lagoon area of Lower Pilarcitos Creek supports predominantly salt-sensitive freshwater marsh and riparian scrub vegetation throughout. Water in the lower creek has a chemical "fingerprint" similar to that of water above Stone Dam.

The ecological trajectory of the creek mouth shifted from an unstable, sparsely vegetated state evident in 1861 U.S. Coast Survey maps up until the 1970s, when extensive riparian vegetation began to establish, persist, and spread. The El Nino storm disturbances of the early 1980s temporarily reversed vegetation trends, but riparian woodland, freshwater marsh, and coastal foredune vegetation established a trend of increasing vegetative stabilization of the mouth by the 1990s.

The conceptual model implies that substantial inherent limitations may exist for "enhancing" lagoon conditions identified with other coastal stream mouths that are not geomorphically supported by this system. Steelhead habitat improvements compatible with the system as it currently exists may include placement of scour objects (e.g. large woody debris) to increase the depth and area of channel pools. Establishing fresh to brackish salinity gradients in the creek mouth to benefit smoltification of juvenile steelhead may be infeasible due to the channel's location well above the tides. Improvement of steelhead passage conditions may potentially be improved by restricting the northward drift of the stream outlet along the beach, with an objective of prolonging critical outflows for smolts. Increased outflows during spring and fall months may also improve fish passage. Future opportunities for engineering better steelhead habitat may arise following natural catastrophic storm disturbance to the mouth.

2. Introduction

a. Goal of the Pilarcitos Lagoon Habitat Enhancement Opportunities Study

i. To determine what, if any, lagoon fish passage and habitat enhancement approaches have the potential to provide significant benefits for fish or other species of concern and should therefore be considered for future development as a watershed enhancement project.

b. Specific Objectives of this Conceptual Model

i. Identify feasible options for modifications within and beyond the lagoon to improve ecological functions for multiple target species with contrasting habitat requirements

ii. Synthesize historic and contemporary evidence on the natural range of site-specific geomorphic variability inherent in the stream mouth/beach system, with emphasis on primary physical and ecological controls, to guide formulation of alternatives

iii. Identify hydrological and ecological functions (special-status species habitats) associated with specific alternate states of the stream mouth that occur within its natural or artificially modified range of variability;

iv. Assess the degree to which the system has been or continues to be altered or constrained by contemporary anthropogenic conditions;

c. Basis of the Conceptual Model

i. New field data collection – topography, hydrology, water quality, soils, biological communities, comparative geomorphology

ii. Review of broad range of recent and historical data from a variety of sources – historic aerial photographs, historic US Coast Survey maps, USGS publications, consultation with local experts, wastewater treatment plant engineering drawings, reports for related projects within the watershed, literature reviews, etc.

d. Summary of Key Findings

i. The Pilarcitos stream mouth (the potential lagoon position) is aggraded well above tidal range behind a coarse-grained, permeable beach ridge with high potential for subsurface discharge (seepage) losses

Pilarcitos Tidal Datums

Monterey Station ID 9413450				**San Francisco Station ID 9414290**					**Pilarcitos**	
Approx 65 miles south				**Approx 25 miles north**					**(linear interpolatic**	
datum	m MLLW	ft MLLW	**ft NAVD**	datum	m MLLW	ft MLLW	**ft NAVD**		datum	**ft NAVD**
HOWL	2.401	7.88	**8.0**	HOWL	2.64	8.66	**8.7**			
MHHW	1.626	5.33	**5.5**	MHHW	1.78	5.84	**5.9**		MHHW	**5.8**
MHW	1.412	4.63	**4.8**	MHW	1.595	5.23	**5.3**		MHW	**5.1**
MTL	0.873	2.86	**3.0**	MTL	0.97	3.18	**3.2**		MTL	**3.2**
MSL	0.862	2.83	**3.0**	MSL	0.951	3.12	**3.2**		MSL	**3.1**
MLW	0.333	1.09	**1.2**	MLW	0.346	1.14	**1.2**		MLW	**1.2**
MLLW	0	0.00	**0.1**	MLLW	0	0.00	**0.1**		MLLW	**0.1**
NAVD	-0.043	-0.14	**0.0**	NAVD	-0.018	-0.06	**0.0**		NAVD	**0.0**
LOWL	-0.723	-2.37	**-2.2**	LOWL	-0.877	-2.88	**-2.8**			

data from: http://www.tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Bench+Mark+Data+Sheets

Table 1. *Approximate tidal datums at the Pilarcitos mouth.*

ii. The lower creek and "lagoon" have a predominantly freshwater salinity regime; there little or no evidence of residual brackish influence in vegetation composition or structure

iii. Creek mouth interaction with beach processes frequently results in significant northerly longshore deflection and attenuation of the outlet channel along the bluff toe, behind the beach berm crest

iv. A broad range of structural geologic controls influence the alignment of the creek mouth, consistent with its northerly longshore drift-deflection and attenuation of the beach outlet channel

v. The stream mouth channel bed and backbeach have converted from predominantly unvegetated and dynamic features to a vegetatively stabilized, consolidated, mature floodplain and foredune

3. <u>Important Findings and Inferences</u>

a. Methods

i. Field data collection

1. New ground-based topographic surveys of the lower creek, floodplain, dunes, and beach

2. Installation and monitoring of a flow gage at the pedestrian bridge

3. Water quality and fish community monitoring at Pilarcitos and two other creek/lagoon systems, Gazos and San Gregorio Creeks

4. Soil core sampling along the creek mouth and floodplain

5. Multiple field visits to characterize vegetation communities, wildlife use, local geology, fluvial and beach sediment, and creek mouth morphodynamics

ii. Review of historic materials

1. 21 historic aerial photographs of the creek mouth and surrounding area from 1928-2006, scanned from the UC-Santa Cruz Map Library

2. 1861 (preliminary) and 1863 (final) US Coast Survey maps of Half Moon Bay obtained from the UC-Berkeley Earth Sciences Library and NOAA

3. Engineering drawings for the SAM wastewater treatment plant upgrades of the late 1970s – early 1980s

iii. Literature review

1. Multiple USGS publications on topics such as: coastal geology, geomorphology, and evolution; marine terrace morphology, fault dynamics, and more

2. Scientific papers describing wave refraction, longshore sediment transport, beach sand grain size, and beach slope in Half Moon Bay (Bascom 1951 and 1954)

3. Previous work done within the Pilarcitos watershed, including work done by Balance on basin sediment supply/dynamics and hydrology

4. Publications by Gary Griggs and others at UC-Santa Cruz describing coastal geology and sediment dynamics

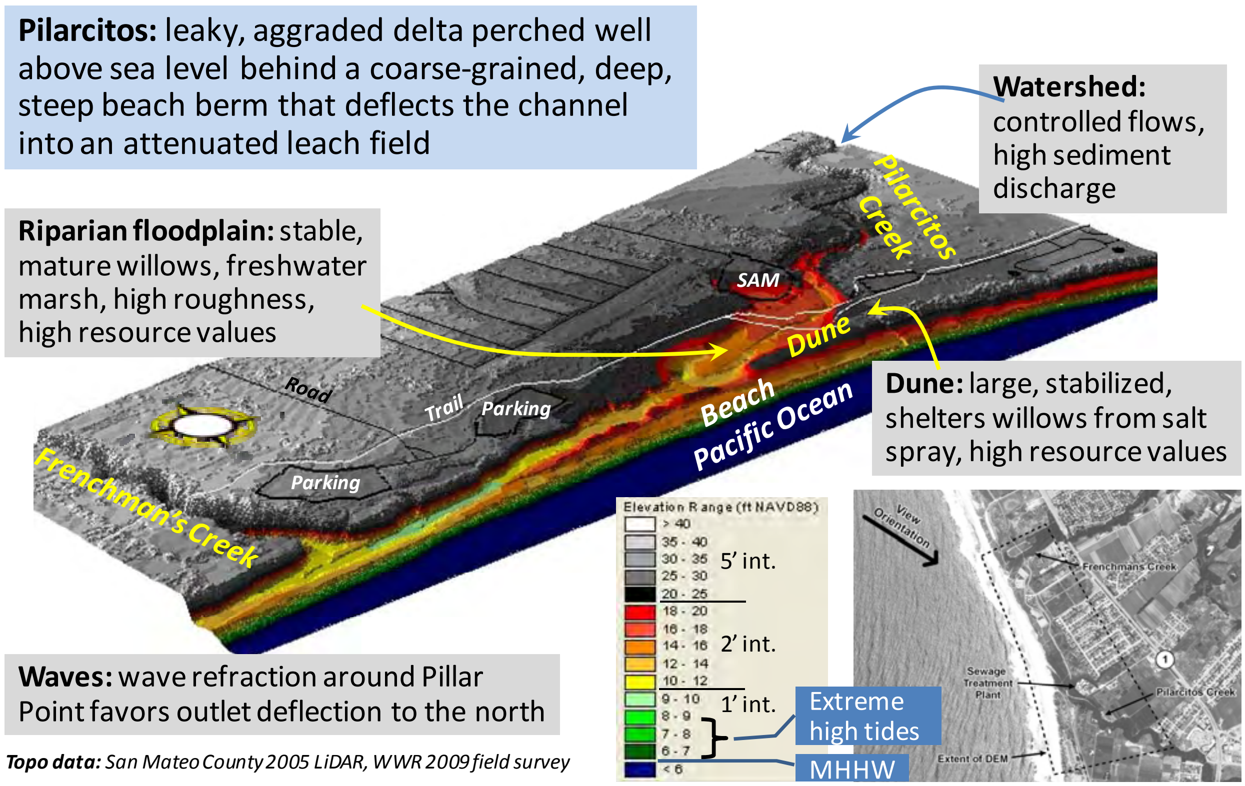
5. Draft maps of seafloor geology, sediment, faulting, and more from the California Coastal Mapping Project (joint project between USGS, CA Coastal Conservancy, CSU Monterey Bay, California Geological Survey, California Ocean Protection Council, and Fugro)

b. Key Interpretations and Conclusions About Contemporary Physical Controls on the Pilarcitos Creek System

i. <u>Pilarcitos Creek mouth morphology, dynamics, and topography discourage or preclude the formation of "typical" San Mateo Coast lagoon morphology</u>

ii. <u>There is a significant lack of geomorphic space for a large-scale lagoon and backbarrier marsh common to other lagoon systems along the Central Coast, such as at Pescadero, Scott, Waddell, and Laguna Creeks</u> (Graphic 1, Figure 1)

The Mouths of Pilarcitos and Frenchman's Creeks: A Morphological View of Key Controls



***Graphic 1**: A 3-D Digital Elevation Model (DEM) of the Pilarcitos-Frenchman's Creek mouths. Unlike many other coastal creek systems in San Mateo and Santa Cruz counties, there is no room for the development of a broad open water/vegetated marsh system behind the beach berm. Instead, the highly aggraded Pilarcitos delta exits a narrow canyon incised out of the marine terrace and is deflected north along the bluff-toe by a combination of antecedent geology, wave refraction around Pillar Point, and a stabilized dune system at the creek mouth. This deflection subjects the channel to high seepage losses through the coarse-grained beach as flows head north, towards the usual confluence with Frenchman's Creek. Almost the entire system sits well above MHHW and the highest tides.*

1. The lower creek channel bed in Pilarcitos Creek is aggraded to the elevation range of the beach, above the tidal frame (see Figure 2 and tidal datums in Table 1 above); the creek has no intertidal or subtidal channel incision potential to form a beach-dammed lagoon unless sediment inputs from the watershed are greatly reduced.

2. Maximum lagoon water surface elevations in the creek are temporary and are associated with extreme tides, overwash, or fluvial flood peaks during open beach outlet conditions in the winter/early spring.

    a. These flooding conditions are out of phase with the summer lagoon impoundment season; this contrasts with Laguna Creek and its allies, where the highest water surface elevations (WSEs) are associated with closed beach outlet and summer stream flow conditions.

3. Maximum *sustained* lagoon WSEs during beach-dammed/choked outlet conditions in the summer are below the floodplain surface elevations (Graphic 2, Figure 3); WSEs here are likely limited by high beach seepage rates (Graphic 3, Figure 4).

4. The creek floodplain (willow woodland) is aggraded to the elevation range of the beach backslope (supratidal delta/backbeach channel); any depressional backwaters (ponds) are isolated features (Figure 5).

***Graphic 2**: A diagram of the backbeach channel/ lagoon in May 2009. At the time, and as is typical for the system during closed conditions, the Pilarcitos lagoon had merged with the Frenchman's lagoon. Photo: P. Baye, May 2009.*

Graphic 3*: Even in the absence of a beach dam, rapid infiltration of low flows in the attenuated, supratidal Pilarcitos backbeach lagoon (more of a drift-deflected channel) may inhibit lagoon formation. Photos: P. Baye 2009.*

iii. <u>The Pilarcitos stream mouth (the position of the potential lagoon) is aggraded well above the tidal range behind a coarse-grained, permeable beach ridge; this position creates the potential for high subsurface discharge (seepage) losses from the creek</u>

1. The sediment regime at the mouth is strongly aggraded (Figure 6), and contributes significant amounts of sediment (mean annual yield of almost 5,000 m3 per year) to the beach sand budget. Estimated potential longshore sediment transport on the beach is an order of magnitude greater (mean estimated annual yield of about 130,000 m3/year). [Note that these estimates are just that – estimates – due to the limitations of current longshore sediment transport models.] A lack of beach retreat, even during El Nino years, demonstrates the consistently significant delivery of sand to the beach. Further evidence for high rates of sand delivery to this beach is found in the existence of a sand quarry operation north of the Pilarcitos Creek mouth that operated on the beach adjacent to the Ocean Shore Railroad (roughly the location of the current multi-use trail) which operated from 1910 to 1916 (J. Schmale, pers. comm. 2009). All topographic traces of this quarry were gone by the time the earliest known aerial photograph of the area was taken in 1928.

2. Pilarcitos Creek also experiences a high rate of sediment delivery and transport related to the granitic geology in the northern half of the watershed and the steeper gradient channel in the lower watershed (relative to other San Mateo-Santa Cruz coastal streams). See Appendix A for more information about sediment delivery to the Pilarcitos mouth.

3. The texture of this sediment and the beach sand is subangular, coarse to medium sand, which is highly transmissive above MHW. Note that as per Bascom 1951, at HMB, high wave energy decreasing from south → north creates less

steep beach slopes from south → north with corresponding decreases in beach grain size. The Pilarcitos mouth is at the coarser end of this gradation (see Graphic 4 below).

4. The bluff-toe beach and aggraded delta at Pilarcitos Creek are comprised of thick layers of sand; we encountered no peat, gravels, or restrictive clay layers within the top 6 ft of the beach/floodplain sediment cores (Figure 7).

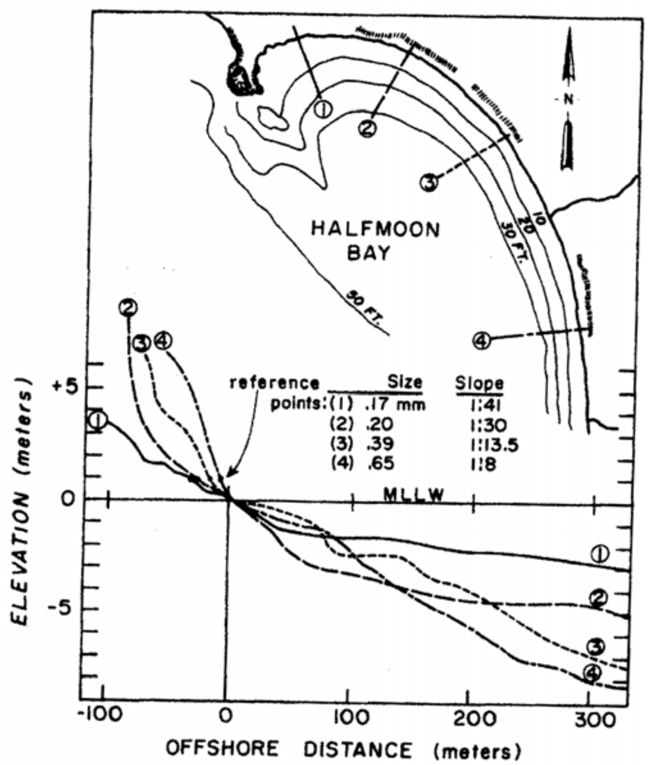
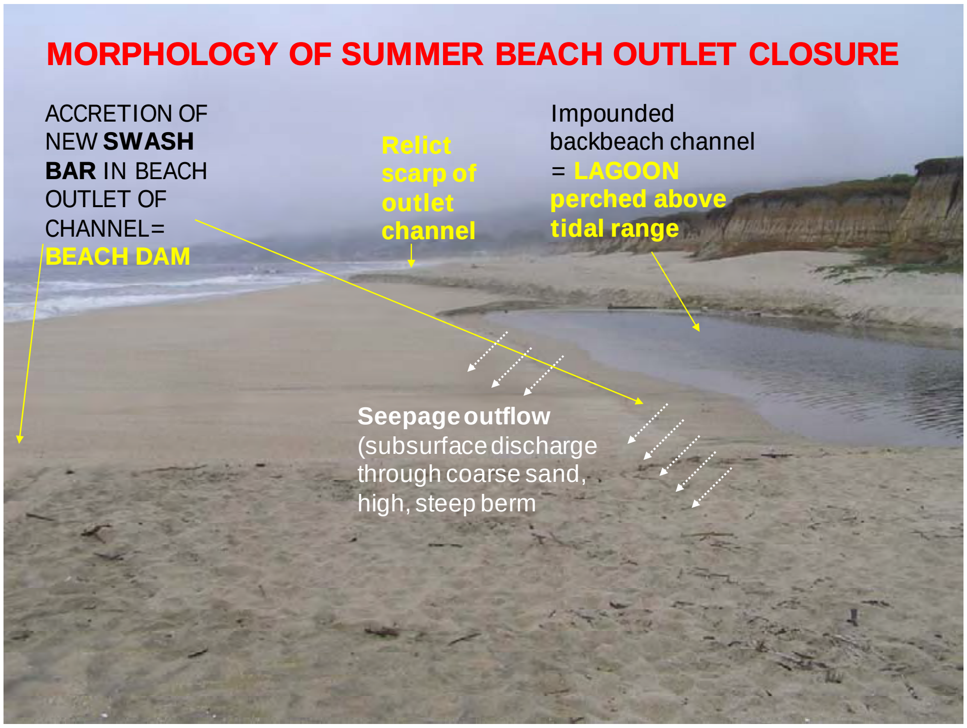


Figure 7-18 Systematic changes in beach slopes along the length of Halfmoon Bay, California, due to longshore variations in beach sediment grain sizes and exposure to the waves. [Adapted with permission of American Geophysical Union, from W. H. Bascom, The Relationship Between Sand Size and Beach Face Slope, *Transactions American Geophysical Union 32*, p. 872. Copyright © 1951 American Geophysical Union.]

Graphic 4*: Beach sand grain size and slope data from Bascom 1951 as presented in Komar 1998. Note that this data was collected before construction of the breakwater in the 1960's, however, the same general pattern in HMB holds true: As wave energy decreases from south → north due to wave refraction around Pillar Point, the steepness of the beach slope and the median grain size of the beach sand also decrease.*

5. A less-permeable geologic layer (potentially derived from the Purisima formation) slopes underneath the porous, poorly consolidated marine terrace (sandstone) deposits from north → south (Figure 8). The relative impermeability of this layer is evidenced by seeps at the contact between layers that support filamentous algae and other plants. This layer is exposed in the bluffs (wave-cut platform) at Frenchman's Creek (and was encountered in a soil core near Frenchman's Creek at only 3 ft below the beach surface), but is buried well under the existing beach at Pilarcitos Creek. The burial of this layer at Pilarcitos likely

results in resulting in relatively greater seepage here relative to Frenchman's Creek, and thus less ability for Pilarcitos Creek to form and maintain a back-beach lagoon. This layer may explain why Frenchman's consistently supports a backbarrier lagoon throughout the summer, while Pilarcitos does not.



***Graphic 5**. Diagram of summer beach outlet closure conditions at the merged Pilarcitos-Frenchman's Creek lagoon, May 2009. Photo: P. Baye.*

iv. <u>The lower creek and "lagoon" (bluff-toe channel) have a predominantly freshwater salinity regime</u>

1. There are no long-term aqueous salinity records, though monitoring done as part of this project did not record salinity at any location within lower Pilarcitos greater than 0.3 ppt between April and September 2009.

2. Water in the lower creek has a chemical "fingerprint" similar to that of water above Stone Dam (Figure 9).

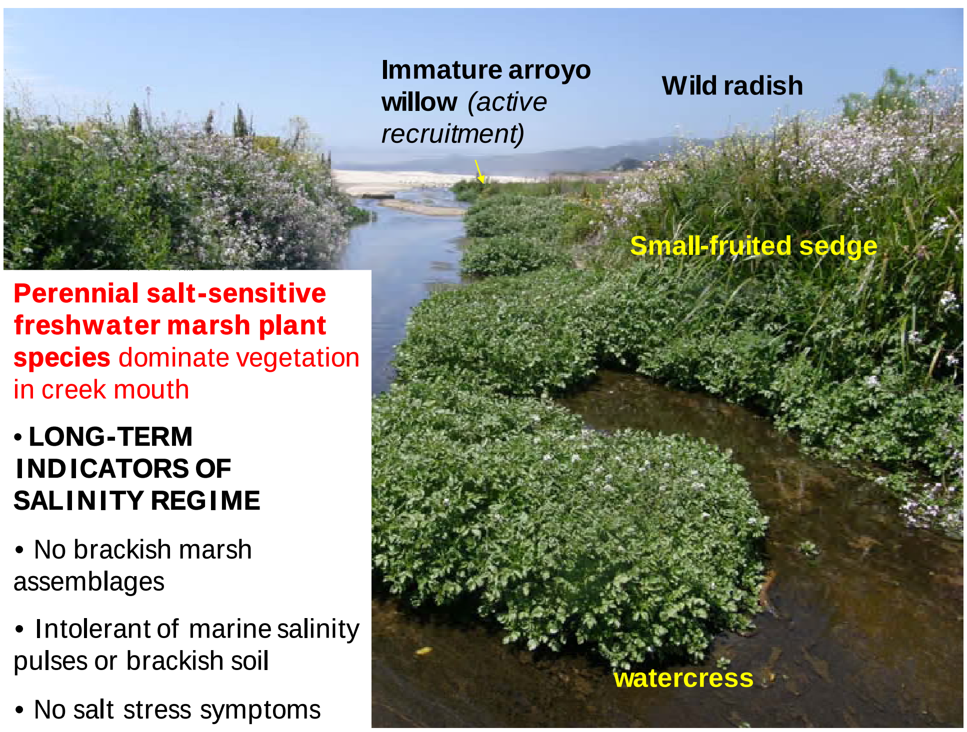
3. In the absence of long-term records, vegetation can be used as a proxy indicator of long-term salinity, and the dynamics and magnitude of salinity variability, such as peaks and duration of salinity events. The vegetation communities at lower Pilarcitos are predominantly salt-sensitive freshwater marsh and riparian scrub vegetation throughout the mouth/"lagoon" area (Graphics 6 and 7).

a. Salt-sensitive wetland vegetation dominates the floodplain behind the foredune and the beach ridge.

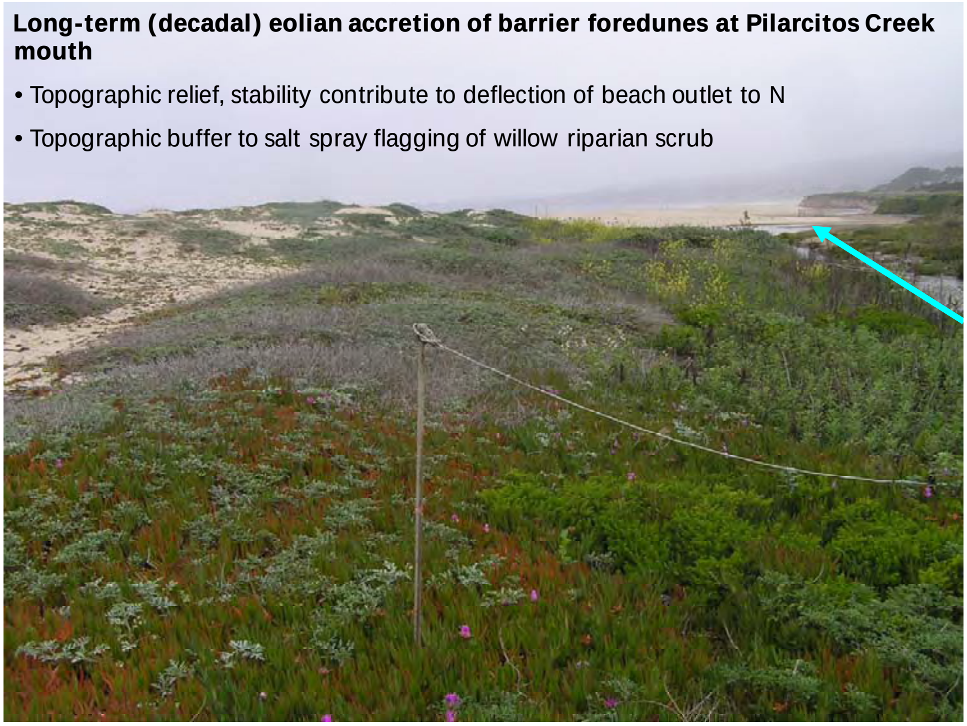
b. There are no brackish marsh assemblages in the mouth/"lagoon" indicative of a persistent brackish influence within either soils or the water column. Instead, the vegetation has a strong freshwater gradient signature. This is in contrast with systems such as Pescadero, Waddell, Scott, and Laguna Creek, which feature brackish marsh assemblages at the seaward end of their lagoon areas.

c. The freshwater signature of the Pilarcitos vegetation is consistent with the supratidal position of the "lagoon"/mouth.

d. A large, mature dune system at the creek mouth shelters the willow woodland and freshwater marsh from the full impact of overwash and salt spray (Graphic 7).



Graphic 6. *Vegetation communities at the Pilarcitos Creek mouth. Photo: P. Baye, May 2009.*

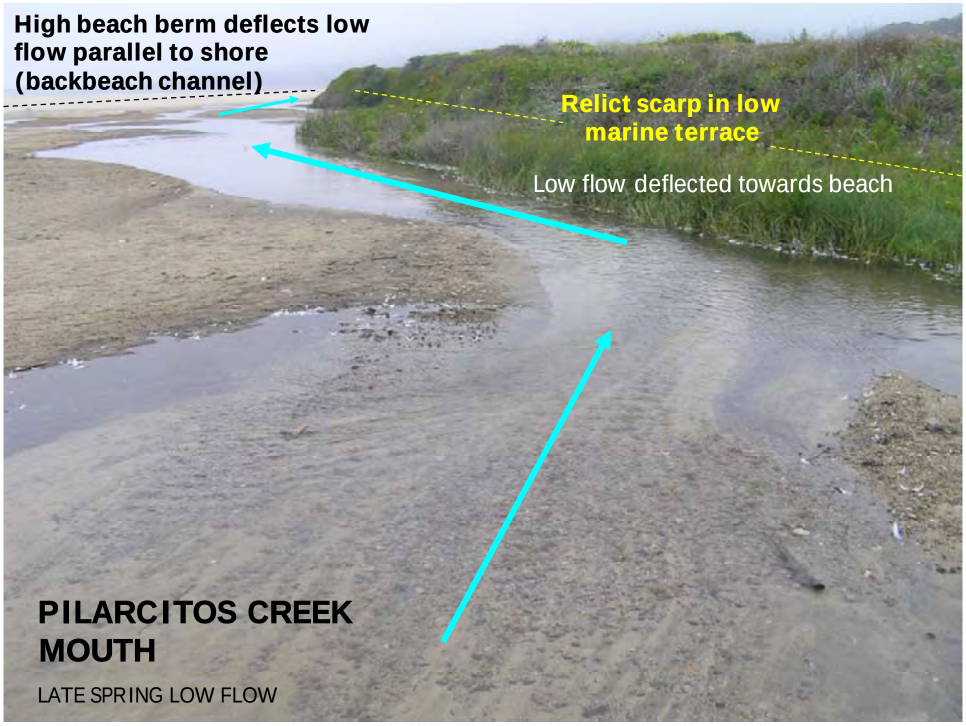


Graphic 7*. The extensive, heavily vegetated foredunes at the Pilarcitos mouth not only help to deflect the channel to the north, but they also block salt spray from reaching the salt-sensitive wetland vegetation at the mouth and in the riparian canyon. Photo: P. Baye, May 2009.*

v. <u>Lower Pilarcitos Creek experiences recurrent deflection and attenuation of the stream mouth channel and outlet across the beach berm crest</u>

1. The estimated seepage potential through the beach is proportional with the length of the beach outlet channel (the wetted bed surface area in the beach): the longer the channel length, the greater the bed area, and therefore the greater amount of seepage from the system (Graphic 5, Figure 10).

2. The beach outlet's position is influenced by the nearshore wave energy gradient. As wave energy decreases from south → north, so too does dune size. Therefore, the Pilarcitos outlet has a consistent northward longshore drift towards (and sometimes past) the Frenchman's Creek mouth (Graphic 8, Figure 11).



Graphic 8*: Deflection of the Pilarcitos Creek backbeach channel against the bluff-toe. Photo: P. Baye, May 2009.*

3. This northward longshore drift tendency is described by Bascom 1954 (Graphic 9). In this seminal paper, Bascom describes how the stream mouth outlet position in shallow embayed California littoral cells is controlled by wave refraction (in the case of Pilarcitos, the wave refraction gradient created by the Pillar Point headland).

4. Pilarcitos Creek exists within a local syncline of late Pleistocene (older) alluvial deposits graded to lower sea level (Graphics 10 and 11, LaJoie 1986, Weber et al. 1979). This is in contrast with Frenchman's Creek, which exists within Holocene (newer) deposits graded to sea level. The syncline sinks from the SE to the NW, reinforcing the longshore drift deflection of the stream outlet to north and setting the location of Pilarcitos Creek above the beach. This syncline might also explain the observed southward-trending dip in the less-permeable soil layer observed at the Frenchman's Creek mouth but buried at the Pilarcitos Creek mouth.

***Graphic 9**: Figure 1 from Bascom 1954. This conceptual diagram demonstrates how stream outlets in shallow bays with a sheltering headland will be located in the area most sheltered from wave energy by the headland. Areas between orthogonal lines have the same amount of wave energy – therefore, the area where these lines are farthest apart (where energy is dissipated over the relatively largest extent of the shoreline) is where the stream outlet is located.*

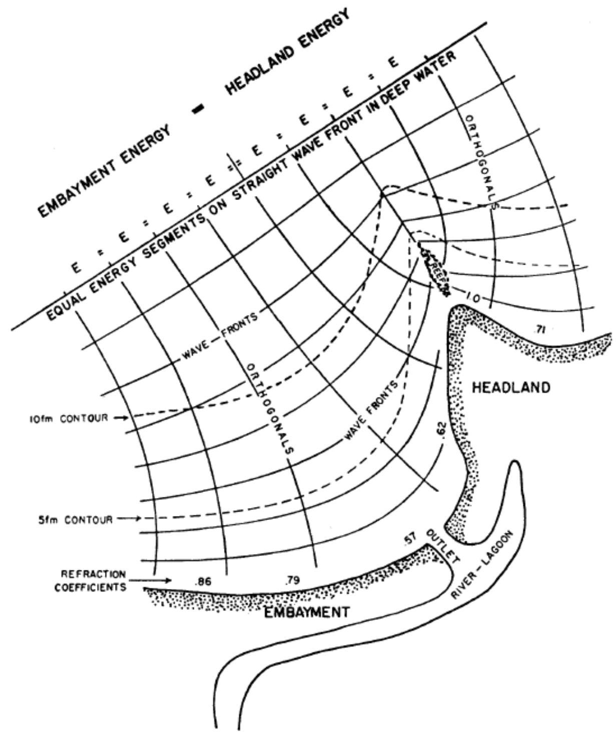
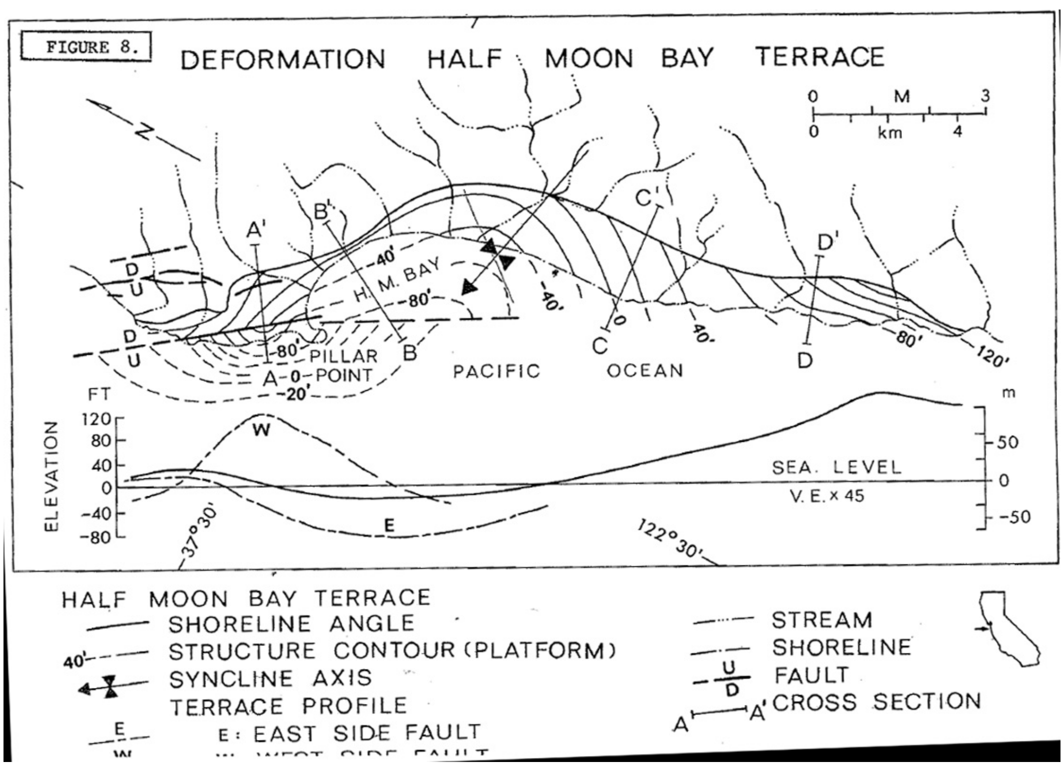
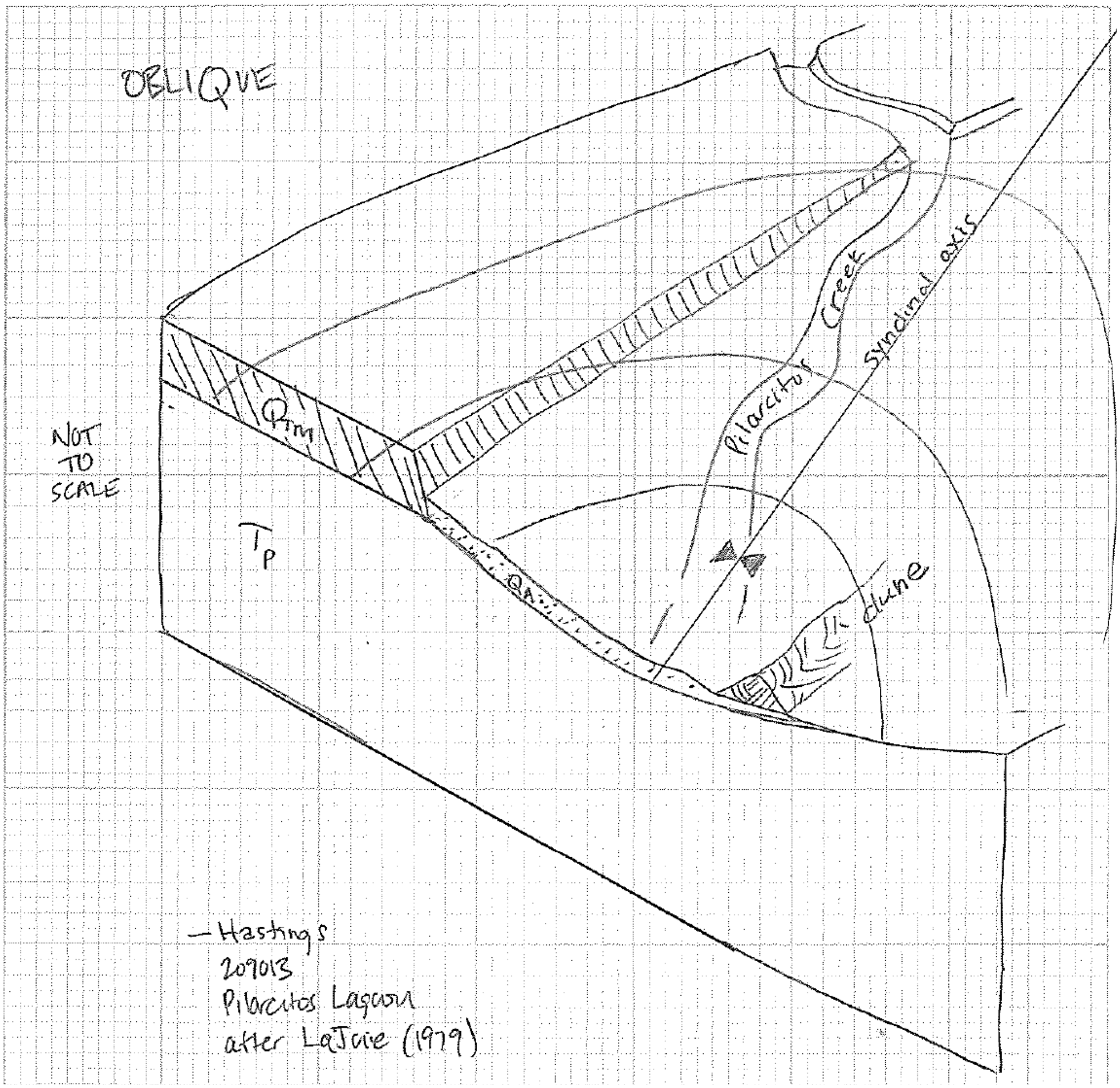


FIG. 1.—Low berm adjacent to a headland



***Graphic 10**: Figure 8 from Weber et al. 1979, displaying deformation within the Half Moon Bay marine terraces east of the San Gregorio fault system. Pilarcitos Creek occupies the SE → NW trending syncline located in the center of the graphic.*



Graphic 11: *Modified 3-D sketch of the syncline described in Weber et al. 1979.*

vi. The stream mouth flood plain and foredune have stabilized thanks to the maturation of late-20th century vegetation

1. Mature, continuous riparian wetland scrub vegetation (predominantly willow, Salix spp.) dominates the Pilarcitos floodplain. This vegetation is unprecedented in the 20th century (Figure 11), and was most likely absent in the 19th century (Figure 12).

2. The willows and sedges (understory) form a root mesh with high shoot density, which strongly favors floodplain accretion of silt and resists erosion.

vii. The relative homogeneity of the riparian canyon (similarly-aged willow thicket), coupled with the significant distance between creek headwaters and the mouth and the likely debris-filtering effect of the Highway 1 bridge, has resulted in an lack of large LWD and other scour-inducing structures in the lower creek system. As a result, the channel bed is highly uniform and contains only minor pool formation around a few living trees that have leaned/toppled into the creek.

c. Key Inferences About Pilarcitos Creek Based On Field Data, Historic Materials, and Observations

i. There is little evidence for the existence of a lagoon at Pilarcitos Creek in the agricultural era.

1. There is no evidence of a lagoon in the historic aerial photos dating back to 1928. That being said, it is important to note that these photos illustrate the potential range of variability at Pilarcitos Creek, and are not necessarily representative of every possible morphological state (Figure 11, Figures 12A-12C).

2. Early US Coast Survey maps from the 1860s display Pilarcitos mouth deflection to the north, with little to no mapping of backbarrier wetlands (Figure 13).

3. We encountered no marsh peat or fine lagoon sediment deposits in limited soil coring at the Pilarcitos mouth and along its floodplain.

4. It is possible that prior to the construction of Pilarcitos Lake and Stone Dam, floods would have been larger and baseflow would have been higher, which might have pushed more sediment out of the creek mouth into the ocean.

ii. The shallow depth of the clayey restrictive layer in the wave-cut marine terrace at/below the beach at the Frenchman's Creek mouth likely restricts lagoon subsurface discharge (favors lagoon impoundment), but the (syncline-controlled) greater depth of restricted layer at Pilarcitos mouth likely facilitates greater seepage through the beach (Figure 8).

iii. Before the 1970s, episodic events in the creek allowed for the deposition and erosion of features such as point bars and scoured depressions evident in aerial photographs. The 1975-1979 drought, combined with long-term reduced flows in the creek, allowed for the establishment of a willow thicket that helped to stabilize the present creek configuration. Portions of this willow thicket (primarily on point bars along the eastern side of the channel) blew out in the 1982 and 1986 floods, but these willows have since recovered to form a broad thicket between the existing channel and the bluff-toe. A core area of willows (the "triangle" south of the channel in the 1982 photo) that survived the 1982 and 1986 floods served as the nucleation center for the existing willow thicket along the channel's western side, which has grown from the late 1970s to the present-day (Figure 11, Figures 12A-12C). Appendix B contains a series of three slides that illustrate the evolution of the lagoon system between 1986 and 2006. Decreased flows during this time allowed for the rapid expansion of willow thickets into the exposed, deltaic channel bed, dramatically reducing the lateral space in which the channel could move.

iv. The vegetatively stabilized foredune and willow floodplain interact with geologic controls to deflect the outlet breach position to the north, forming a barrier to direct flood-discharge breaches across the dunes and beach (Graphic 1, Figure 1).

4. Comparisons and Contrasts With Other Central Coast Lagoon Systems

a. Position Above the Tidal Frame

i. Other San Mateo-Santa Cruz lagoons, such as Laguna Creek Lagoon, have backbarrier/floodplain marshes that are above the tidal frame but are subject to overwash surges or extreme high tides where areas are connected by intertidal channels. These salinity events are visible in water quality data (increased salinities during winter months when creek/lagoon mouths are open to marine influence, with decreasing salinities throughout the summer as freshwater floods the backbarrier marsh) and vegetation signals (silverweed, salt rush, etc. – plants that can tolerate prolonged, flooded freshwater conditions as well as periodic near-marine salinity pulses).

ii. The Pilarcitos supratidal floodplain is isolated from summertime spring tides by the high beach crest and foredune, which create a barrier to tidal inflows; there is no potential intertidal channel to convey tidal inflows into the floodplain. No storm overwash occurs during the summer, and even when summer swell coincides with summer spring tides these tides are still well below the Pilarcitos floodplain.

iii. The Pilarcitos supratidal floodplain during the winter is subject to fluvial flooding, but as in the summer, the high foredune restricts storm overwash from the ocean. Any potential overwash surges during winter storms would coincide seasonally with peak fluvial discharge events, which would rapidly flush any residual salts out of the system.

PILARCITOS CREEK "lagoon" contrasts with typical Central Coast lagoons

- Most lagoons = **intermittently tidal channels** within tide elevation range
- **Deeper lagoon habitat** = beach-dammed **incised creek channel** & relict channels *within tidal elevation range*
- **Perched lagoons** = intermittently **drowned floodplain** during high lagoon stands (high beach dam, moderate creek outflow)
- Characteristic **mixed brackish and freshwater wetland vegetation** (discrete brackish marsh vegetation stands)
- **Submerged aquatic vegetation** (SAV) seasonally common

PILARCITOS CREEK "lagoon" features

- Deltaic channel bed at mouth aggraded above tidal range; no basin, no brackish mixing
- No lagoon formation within floodplain or channel above mouth
- All lagoon formation in backbeach zone (backshore runnel morphology)
- Lagoon bed over deep coarse sand, braided channel bed; rapid infiltration

Graphic 12*: A summary of features common to other Central Coast lagoons, in contrast with conditions at Pilarcitos Creek. Photos: P. Baye, summer 2009.*

b. Lack of Sustainable Physical Space for a Lagoon

i. Subregional patterns in lagoon morphology appear to exist throughout the San Mateo-Santa Cruz coast. Many modern lagoons along this coast appear to be either:

1. Holocene drowned floodplain valleys within the Coast Range (e.g. Scott Creek and Waddell Creek, Pescadero-Butano Creek being an extreme example), or

2. Broad backbarrier marsh systems in wide canyons between uplifted Pleistocene marine terraces w/ Miocene foundations (e.g. Wilder Creek and Laguna Creek), where the backbarrier marsh is built on alluvial material deposited during Holocene

3. Periodic tidal influences (winter storm overwash, spring tide overwash) in these areas prevent marshes from becoming dominated by willows, and non-marine terrace (i.e. less permeable) basements may help systems to retain water.

4. There are no extensive stream-mouth/backbarrier lagoons within the Holocene-Pleistocene coastal terraces in San Mateo County.

   a. Most of these systems, including Pilarcitos Creek, are eroded into narrow riparian canyons that provide little room for the development of a broad backbarrier marsh.

   b. Hypothesis: Less uplift along the Half Moon Bay marine terraces (relative to the marine terraces in the Santa Cruz-Davenport area, home of the Laguna and Wilder Creek lagoons) results in creeks graded to modern sea level within a highly permeable Pleistocene marine terrace, without a Miocene basement like Wilder and Laguna Creeks. Stoffer 2005, Weber and Allwardt 2001, Anderson and Menking 1994, and others hint at this hypothesis, but it requires further analysis that is outside the scope of this project.

c. Magnitude of Water Diversions

i. Significant water diversions exist within the Pilarcitos watershed on a magnitude not seen in many other coastal creek systems, with the possible exceptions of northern Santa Cruz County creeks such as Laguna, Liddell, and Majors Creeks, which supply water to the City of Santa Cruz. Pilarcitos supports significant diversions from SFPUC, CCWD, and local groundwater pumping. In addition, summer baseflows in many other local coastal lagoons (especially ones in Santa Cruz County) are supported by karst geology, which is not a major factor in the granitic-dominated Pilarcitos watershed.

ii. It is difficult to quantify the effects of these diversions due to poor data resolution, but it is easier to qualify that dramatically reduced flows in Pilarcitos hamper the creek's ability to maintain suitable in-creek habitat for salmonid summer rearing, and prolonged periods of flow to the ocean to support the outmigration of smolts and possibly the inmigration of breeding adults.

5. Implications for Existing Habitat Conditions

a. The Pilarcitos system is much less dynamic than other coastal lagoons in San Mateo and Santa Cruz counties. The popular model of a dynamic system that supplies variable extents of habitat from year to year may not apply as well here as it does in more variable lagoon locations.

b. The long, shallow, braided creek channel along the bluff-toe provides little habitat for oversummering or outmigrating salmonids, and presents a high likelihood of predation to any fish in the system.

c. The back-beach channel "lagoon" (really an emergent delta) sits above the tidal frame, and thus it rarely provides osmotic regulation for salmonid smolts. Only the very lowest portions of this channel, at the beach outlet, may experience extreme high tide and/or large wave overwash saline influences.

d. It is difficult to quantify the effect of the creek-mouth geomorphology on adult salmonids. The long, shallow, braided channel with an inlet across a steep beach face likely decreases the amount of time the inlet is open and large enough to allow adults in. The project team plans on analyzing BeachWatch data (Gulf of the Farallones NMS) to produce a chart of open inlet timing during BeachWatch monitoring years.

e. Minimal step-pool formation in the channel upstream of the beach provides little opportunities for smolts to "wait out" low-flow conditions until flows are high enough for outmigration.

f. The former creek channel to east of the current thalweg has become a back-water area that receives high-nutrient nuisance flows. This area regularly experiences high temperatures, low dissolved oxygen levels, and is filled with freshwater marsh vegetation. High nutrient loads are also likely contributed to this area by the equestrian crossing.

g. There are considerable special-status bird populations and other natural resource values along the beach and the riparian corridor, such as snowy plovers and Caspian terns. The creek canyon may be a movement corridor for marbled murrelet.

6. Enhancement Options, Their Conceptual Models, and Opportunities and Constraints

a. Feasible Enhancement Goals and Objectives

i. Principal target species: Salmonids

1. The primary goal for salmonids is generating increased windows of time of fish passability for spawning migration and smolt emigration. This goal can be achieved through realizing the following objectives:

a. Generating longer periods of time in which the beach outlet is open to the ocean, to allow ingress and egress

b. Generating greater depths of water in the backbeach channel, to reduce the risks of stranding and predation

c. Generating suitable water quality (low temperatures, high dissolved oxygen) in the backbeach channel

d. Providing refugia for outmigrating smolts in the lower creek channel so they can "wait out" closed inlet conditions and exit to the ocean when the inlet re-opens

ii. Secondary target species: California red-legged frog (CRLF)

1. The primary issues of management concern to CRLF are (a) predation from raccoons, bullfrogs, and other predators, and (b) the presence of cool (less than app. 20°C), deep (app. 2.5 ft), and suitably fresh (less than 5 ppt) pools within the riparian corridor. While (a) is outside the scope of this work, (b) is not. Measures to improve refugia for outmigrating smolts in the lower creek corridor will improve habitat for CRLF.

iii. Secondary target species: snowy plover, Caspian tern, marbled murrelet, riparian passerines, and allies

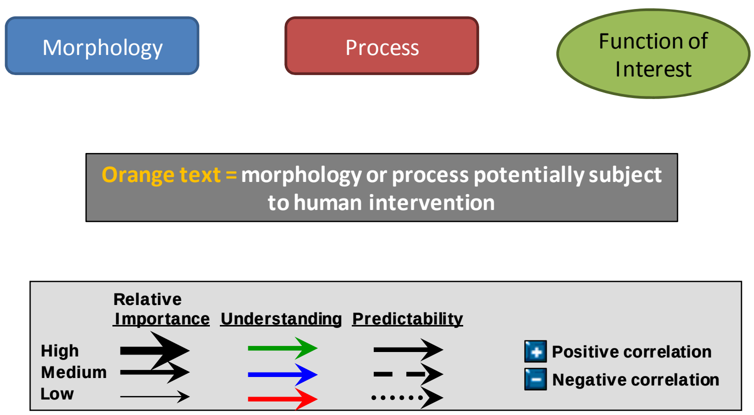
1. Existing habitat conditions at Pilarcitos Creek and Half Moon Bay State Beach are already favorable for these species. California State Parks has implemented/is implementing a number of habitat enhancement projects for these species (nest monitoring, seasonal fencing, invasive plant removal). ***Enhancement options for salmonids and CRLF must consider the potential impacts such options would have on these considerable natural resources.***

b. Conceptual Models and Enhancement Options

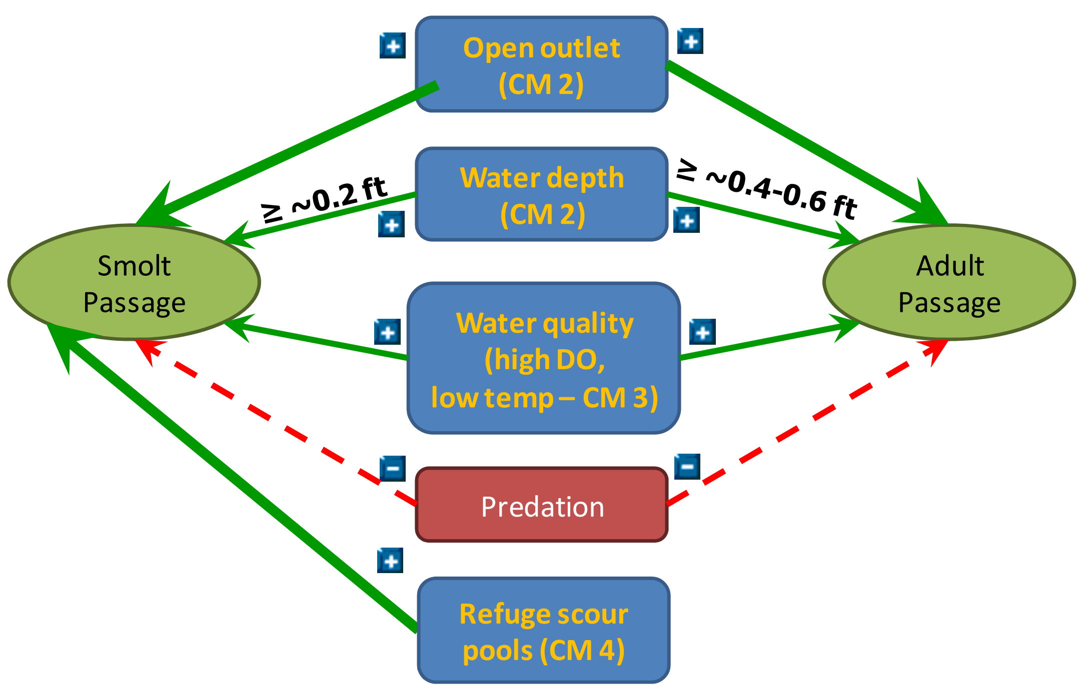
i. **Conceptual Model #1** (Graphic 14) summarizes the relationships between the habitat enhancement goals and objectives described in Section 6.i.a.1 above. Conceptual Models #2-4 describe the morphologies and processes that exert primary controls on these factors. Secondary controls, such as the effect of antecedent geology (e.g. deformation [syncline] in the marine terrace) on creek morphology, are not part of the models in order to simplify their presentation.

Conceptual Model Key

***Graphic 13**: Key to the conceptual models presented below.*



Conceptual Model 1, Salmonid Passage: Ocean ↔ Backbeach Channel



Graphic 14*: Conceptual Model #1, describing salmonid passage between the ocean and backbeach channel.*

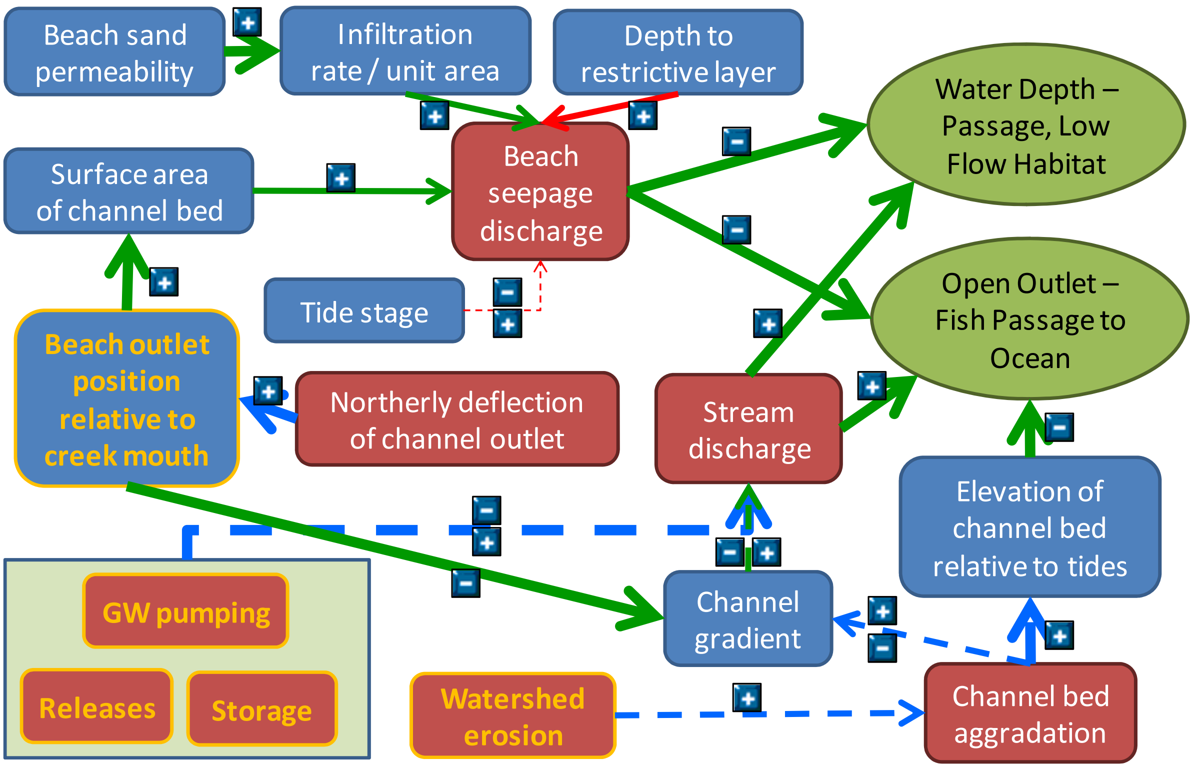
ii. **Conceptual Model #2** describes the processes and morphologies that control whether or not the beach outlet to the ocean is open, and the depth of water in the backbeach channel and at the beach outlet. There are two processes and one morphology in this conceptual model that present potential options for enhancement:

1. **Process: Groundwater pumping and storage in/releases from dams.** Decreased groundwater pumping, decreased storage, and increased releases (relative to existing conditions) could all increase stream discharge in the lower creek, which could increase water depth in the backbeach channel and beach outlet and increase the amount of time that the outlet would be open to the ocean. The interactions between these factors, however, are complex and difficult to predict, especially in the absence of reliable groundwater pumping data. Note that if the net volume of releases cannot be changed, then the timing of the releases (releasing more water less frequently, as opposed to less water more frequently) may also be manipulated to have a positive effect on depth/open conditions at the beach outlet.

2. **Process: Watershed erosion.** Decreasing watershed erosion could decrease the rate of aggradation within the channel bed, which could help keep the elevation of the channel bed lower relative to the tides. This, in turn, could help increase the amount of time that the beach outlet is open to the ocean. Decreasing channel bed aggradation would also help to maintain a steeper channel gradient, which would increase the velocity of stream discharge and help to maintain an open beach outlet. The RCD is already implementing a number of projects aimed at identifying and reducing sediment discharge from highly erosional areas; these efforts should be continued.

3. **Morphology: Beach outlet position relative to creek mouth.** The farther away the beach outlet is from the creek mouth, the larger the wetted area of the channel bed becomes, which facilitates greater seepage losses from the backbeach channel. Longer distances between the mouth and the outlet also serve to decrease the channel gradient in this area, which decreases scouring velocities and decreases the potential for the outlet to become or stay open. Decreasing the distance between the mouth and the outlet could potentially be achieved by installation of a deflection structure that is keyed into the bluff-toe. Such a structure would help deflect the creek into Half Moon Bay at a position farther south than its typical outlet position closer to Frenchman's Creek.

Conceptual Model 2: Backbeach Channel Opening and Water Depth



Graphic 15*: Conceptual Model #2, describing opening/closing dynamics and water depth at the mouth and backbeach channel.*

iii. **Conceptual Model #3** (Graphic 17) describes the processes and morphologies that control water quality in the backbeach channel. There are two processes and six morphologies that present potential options for enhancement:

1. **Process: Groundwater pumping and storage in/releases from dams.** As in Conceptual Model #1, decreased groundwater pumping, decreased storage, and increased releases (relative to existing conditions) could all increase stream discharge in the lower creek, which could improve water quality in the lower creek by helping to maintain low temperatures and high dissolved oxygen. Increased releases could also potentially increase turbidity, however, by increasing the potential for erosion within the channel.

2. **Process: Watershed erosion.** Decreasing watershed erosion would help to decrease the volumes of nutrients and sediment that wash out of the watershed into the creek. Nutrient levels have a direct impact on vegetation communities in

the lower creek, which in turn influence DO levels and temperatures in the creek (see below). In general, increased nutrient levels and increased turbidity decrease habitat suitability for a broad range of aquatic organisms.

3. **Morphology: Land use.** In general, areas with urban and agricultural land use contribute more nutrients and sediment to runoff than areas with undeveloped land uses such as forest. While this is more of a landscape-level morphology, lower Pilarcitos Creek does experience site-specific sources of pollution, primarily from the drainage ditch that routes runoff away from the development immediately to the northeast of the creek (west of Highway 1) and the equestrian crossing upstream of the pedestrian bridge. These sources have an especially significant impact on water quality within the backwater channel (former creek channel) to the east of the existing Pilarcitos creek channel (see below). Addressing these point sources of pollution would likely significantly improve water quality in the lower creek.

4. **Morphology: Equestrian crossing.** See above under "Land use."

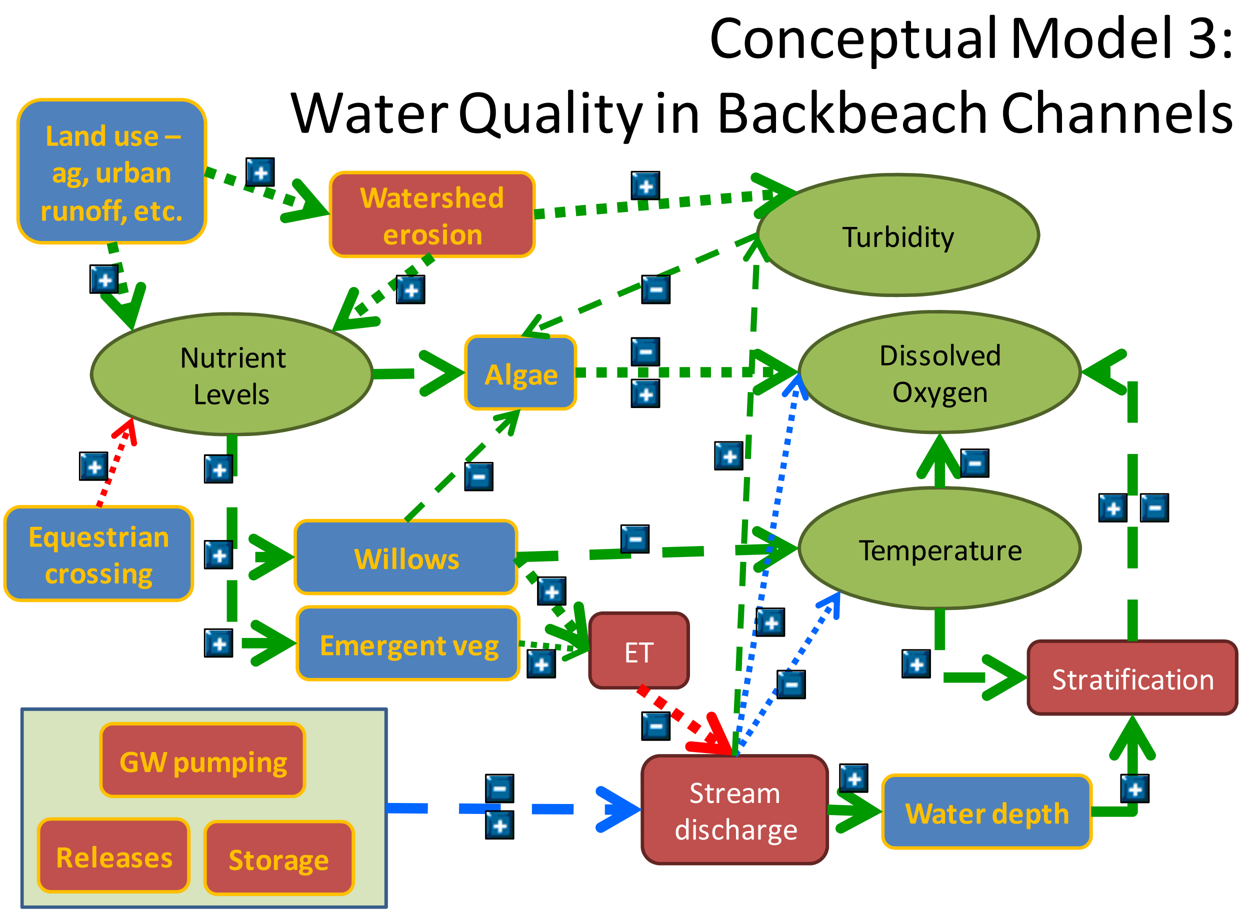
5. **Morphology: Algae.** Algae species such as Cladophera and others grow in response to elevated nutrient levels in unshaded locations (a common process known as eutrophication). Such algae communities are common in the nutrient-enriched backwater channel (former creek channel) to the east of the existing Pilarcitos creek channel (Graphic 16). While algae can increase DO levels (often to the point of supersaturation) during the day through photosynthesis, respiration and the decomposition of dead algae can decrease DO levels, sometimes to hypoxic (< 5 mg/L) or anoxic (< 2 mg/L) levels. These effects are often more pronounced when the water column is stratified (in the case of Pilarcitos, potential stratification would be due to more to temperature differentials than salinity differentials): the upper surface of the water column can become relatively warmer with higher DO levels, then deeper waters which accumulate decomposing organic matter and thus have low DO levels. In the somewhat stagnant backwater channel, eutrophication has resulted in the development of hypoxia in bottom waters, evidenced by large volumes of highly sulfidic (reduced) sediment on the channel bottom.

Graphic 16*: Filamentous algae attached to emergent plants in the backwater channel, April 2009. Photo: C. Toms.*

6. **Morphology: Willows.** Willows also respond positively to nutrient enrichment, though uptake rates are slower than those of algae and emergent wetland plants (such as the Sparganium eurycarpum, or bur-reed, common in the backwater channel). Willows help to shade the lower creek channel, maintaining lower temperatures and decreasing light availability for algae, though they also help increase evapotransipration (ET), which decreases net overall discharge from the creek.

7. **Morphology:** Emergent vegetation. Emergent vegetation responds positively to nutrient enrichment, as evidenced by the extensive communities of bur-reed, watercress, and other emergent plants in the backwater channel and near the creek mouth (Graphic 6). While emergent vegetation has relatively less of a shading impact on the water column than willows, its presence can increase ET losses and decrease net overall discharge from the creek.

8. **Morphology:** Water depth. The deeper the water within the creek channel, the greater the likelihood of stratification. Stratification can isolate portions of the water column from each other, potentially magnifying the impact of low-DO bottom waters (as discussed in the "Algae" section above), or, in a system with less organic material, separating cooler, higher-DO bottom waters (salmonid refugia) from warmer, more productive surface waters (salmonid food source). Water quality monitoring from April – September 2009 indicate that during this period, the Pilarcitos channel between the beach outlet and the pedestrian was rarely more than 0.25 m (0.8 ft), and as a result was generally well-mixed and not stratified.



__Graphic 17__: Conceptual Model #3, describing water quality in the backbeach channel.

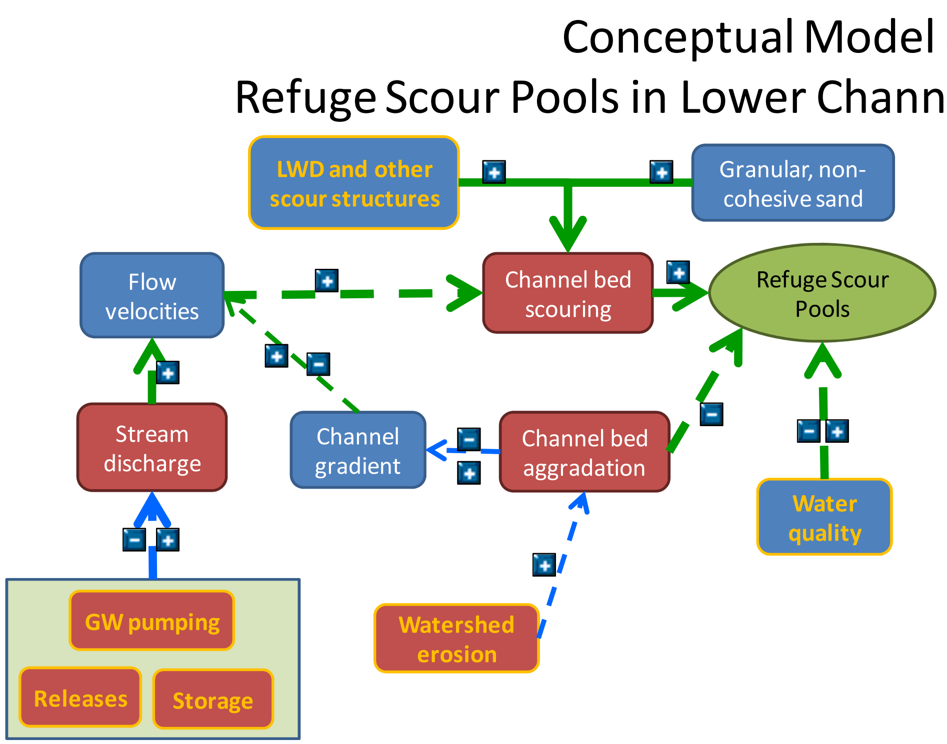
iv. **Conceptual Model #4** (Graphic 18) describes the processes and morphologies that control the presence/absence of refuge scour pools in the lower creek channel. Two processes and two morphologies present potential options for enhancement:

1. **Process: Groundwater pumping and storage in/releases from dams.** As in Conceptual Model #1, decreased groundwater pumping, decreased storage, and increased releases (relative to existing conditions) could all increase stream discharge in the lower creek, which could increase flow velocities and the potential for scouring of the channel bed.

2. **Process: Watershed erosion.** Decreasing watershed erosion could decrease the rate of aggradation within the channel bed, which could decrease the rate at which scour pools fill in with new bedload sediment.

3. **Morphology: Large woody debris (LWD) and other scour structures.** LWD and similar structures are necessary to induce scour within the channel bed. Such structures are designed to locally constrain flows adjacent to the channel bed, causing local increases in flow velocities which then scour pools into the non-cohesive sand within the channel bed.

4. **Morphology: Water quality.** In order for scour pools to provide refugia for salmonid smolts, they must have adequate water quality (low temperatures, high dissolved oxygen). Conceptual Model #3 describes the factors controlling water quality in the lower creek channel.



***Graphic 18**: Conceptual Model #4, describing the presence/absence of refuge scour pools in the lower creek channel.*

c. Summary of Contemporary Constraints for Enhancement

i. An aggraded, supratidal channel and floodplain that provides no geomorphic space for an extensive or deep beach-dammed backbarrier lagoon comprised of open water and marsh habitats

ii. Low creek flows within the channel that are rapidly lost to infiltration through the highly permeable coarse-grained beach along a long, attenuated bluff-toe channel

iii. High fluvial sediment loads that aggrade the channel bed and floodplain which would rapidly fill any off-channel pool habitats without significant engineered controls (e.g. gates) or regular maintenance (e.g. dredging)

iv. No residual brackish influence in wetlands or channel, which prevents the development of osmotic acclimation opportunities for salmonids

v. A large, mature dune system at the creek mouth which shelters willow woodland from the full impact of overwash and salt spray

vi. A dense willow thicket that stabilizes the position of the lower channel

vii. Elevated nutrient loads and poor water quality in backwater areas that favor high potential production of emergent marsh, filamentous algae, and riparian woodland

viii. Existing sensitive biological resource values in beach and riparian areas which could be subject to significant impacts from major coastal engineering activities

d. Summary of Opportunities for Enhancement

i. Enhancement of the backwater slough could provide potential rearing habitat for smolts though implementation and maintenance of any enhancement measures in this area would be very labor-intensive

ii. Manipulation of flows within Pilarcitos Creek could generate opportunities to maintain an open outlet for longer windows of time for inmigrating adults and outmigrating smolts

iii. Strategically placed LWD and other structures may promote scour and salmonid refuge pool formation in the non-cohesive sands within the bed of the lower channel downstream of Highway 1

iv. Limiting the northward drift of the outlet opening (to a location closer to the Pilarcitos mouth) may promote longer outlet opening duration and deeper outlet depths via a steepened hydraulic gradient

v. Planning for a catastrophic post-storm re-engineering opportunity (e.g. creek deflection structure installation) could provide a window of reduced potential impacts to a disturbed biological setting

vi. A new equestrian crossing designed to prevent or limit direct contact between horses and the channel/floodplain would help to reduce direct disturbance to the lower creek

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Personal communications:

Keith Mangold, local resident and former SFPUC employee.

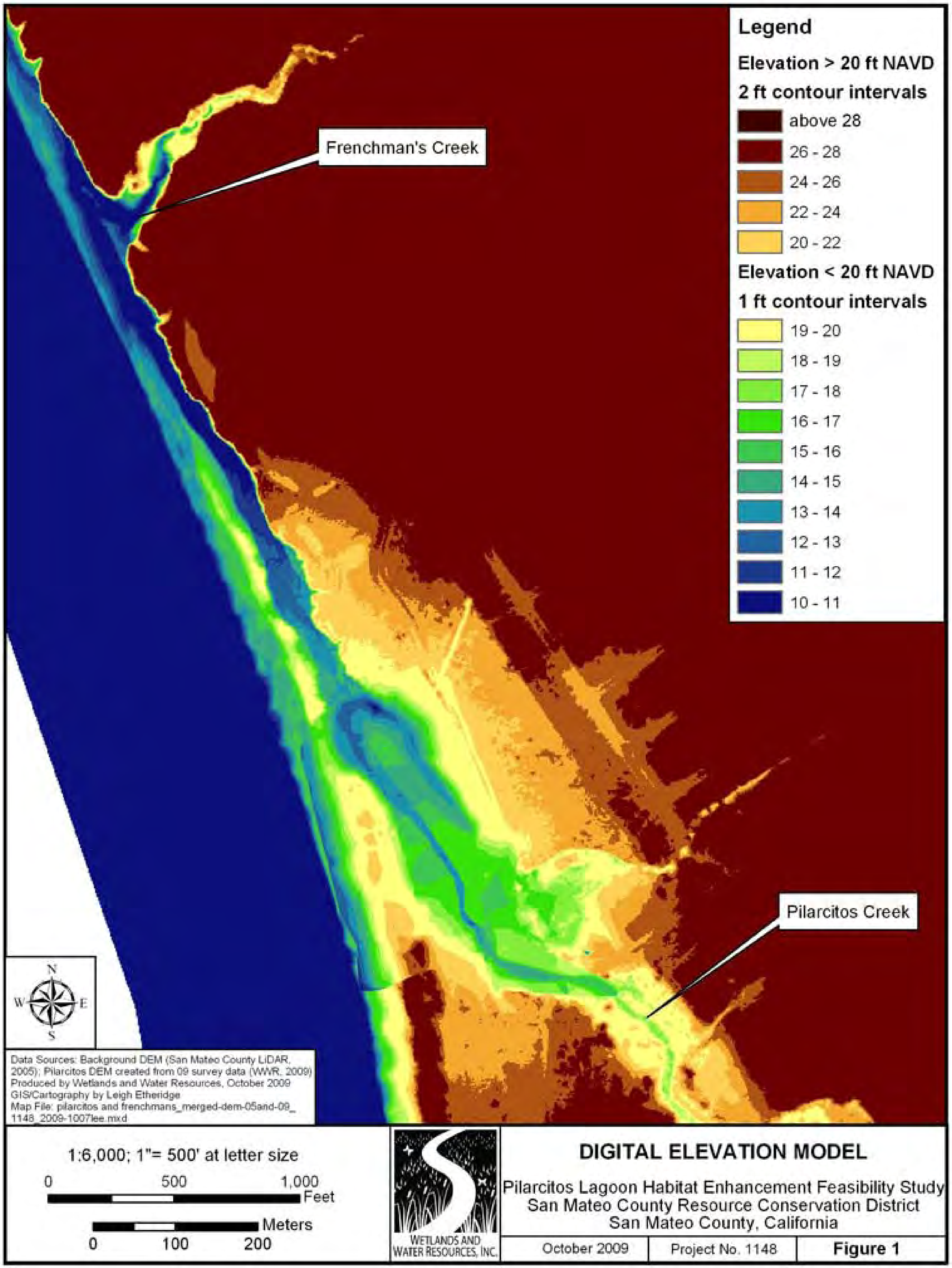
June Morrall, local resident and historian.

John Schmale, local resident and Ocean Shore Railroad historian.

John Vonderlin, local resident and historian.

Jerry Smith, Ph.D., San Jose State University, expert on lagoon habitats and morphodynamics along the Central California coast.

Figures



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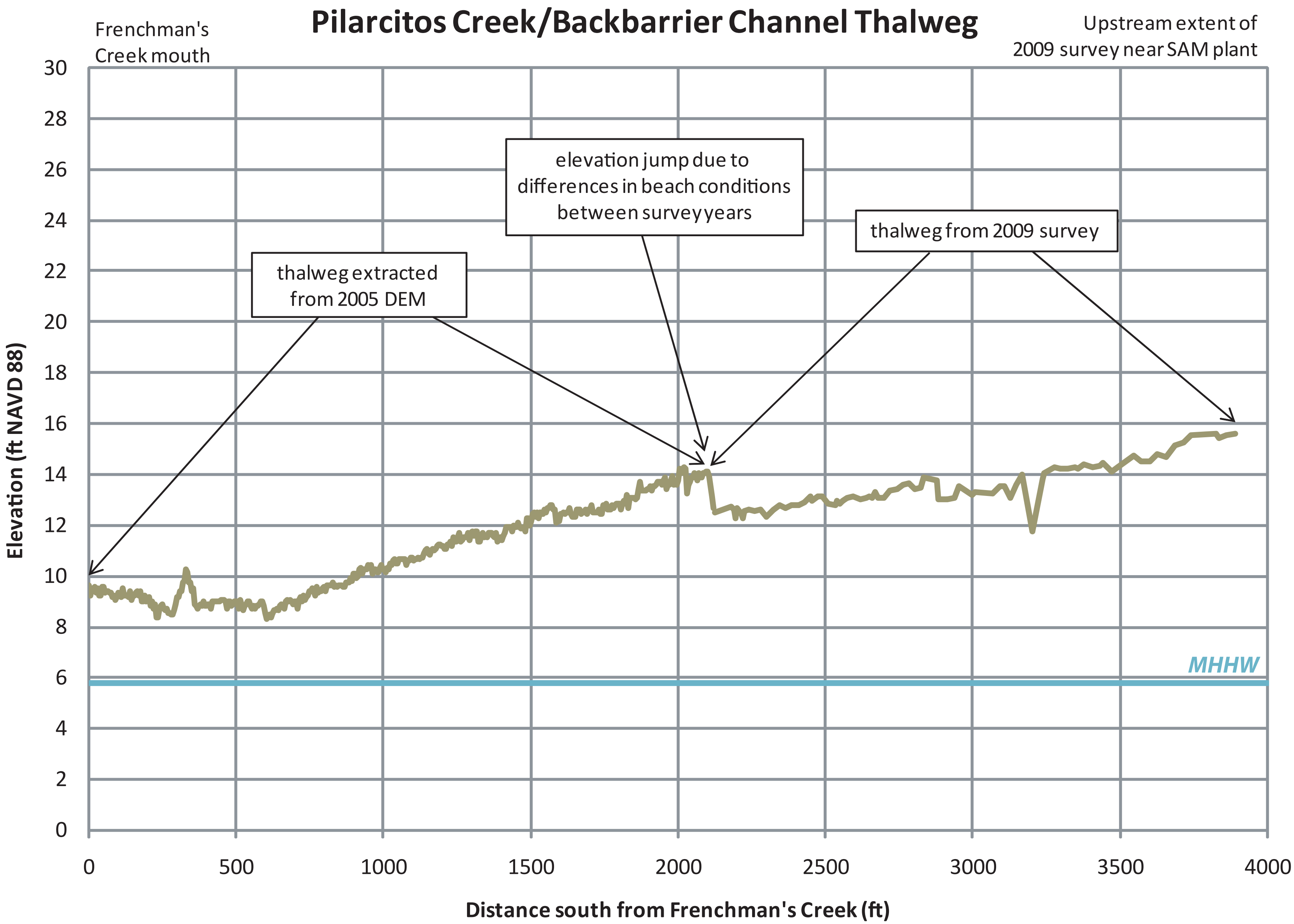
DIGITAL ELEVATION MODEL

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County Resource Conservation District
San Mateo County, California

October 2009	Project No. 1148	**Figure 1**



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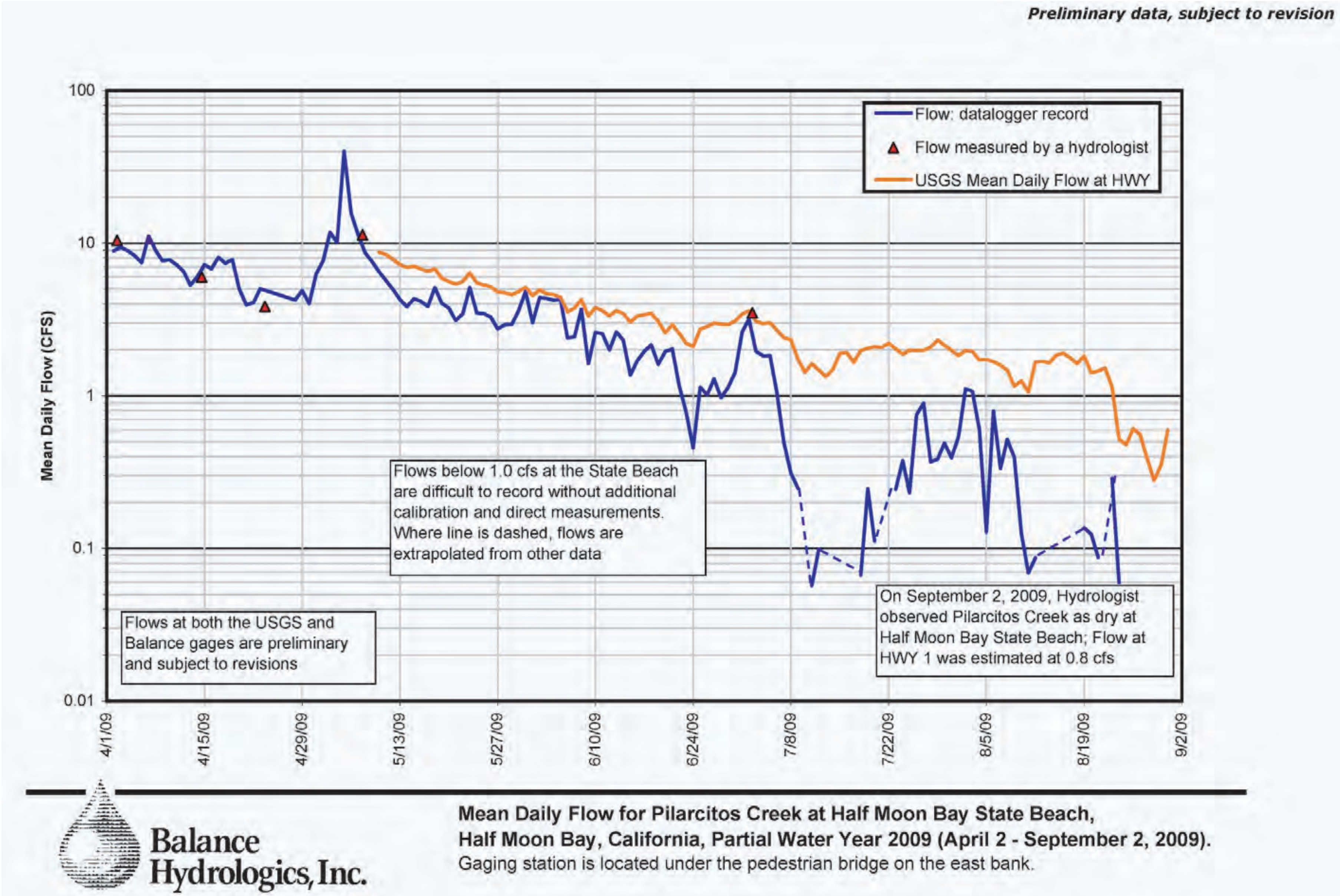
PILARCITOS CREEK
THALWEG PROFILE, 2009

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 2



Mean Daily Flow for Pilarcitos Creek at Half Moon Bay State Beach, Half Moon Bay, California, Partial Water Year 2009 (April 2 - September 2, 2009).
Gaging station is located under the pedestrian bridge on the east bank.

data source: Oct 6 TAC graphics_2009-1007ct.ppt
file source: 3.Pilarcitos Creek gage data _2009-1007lee.ai

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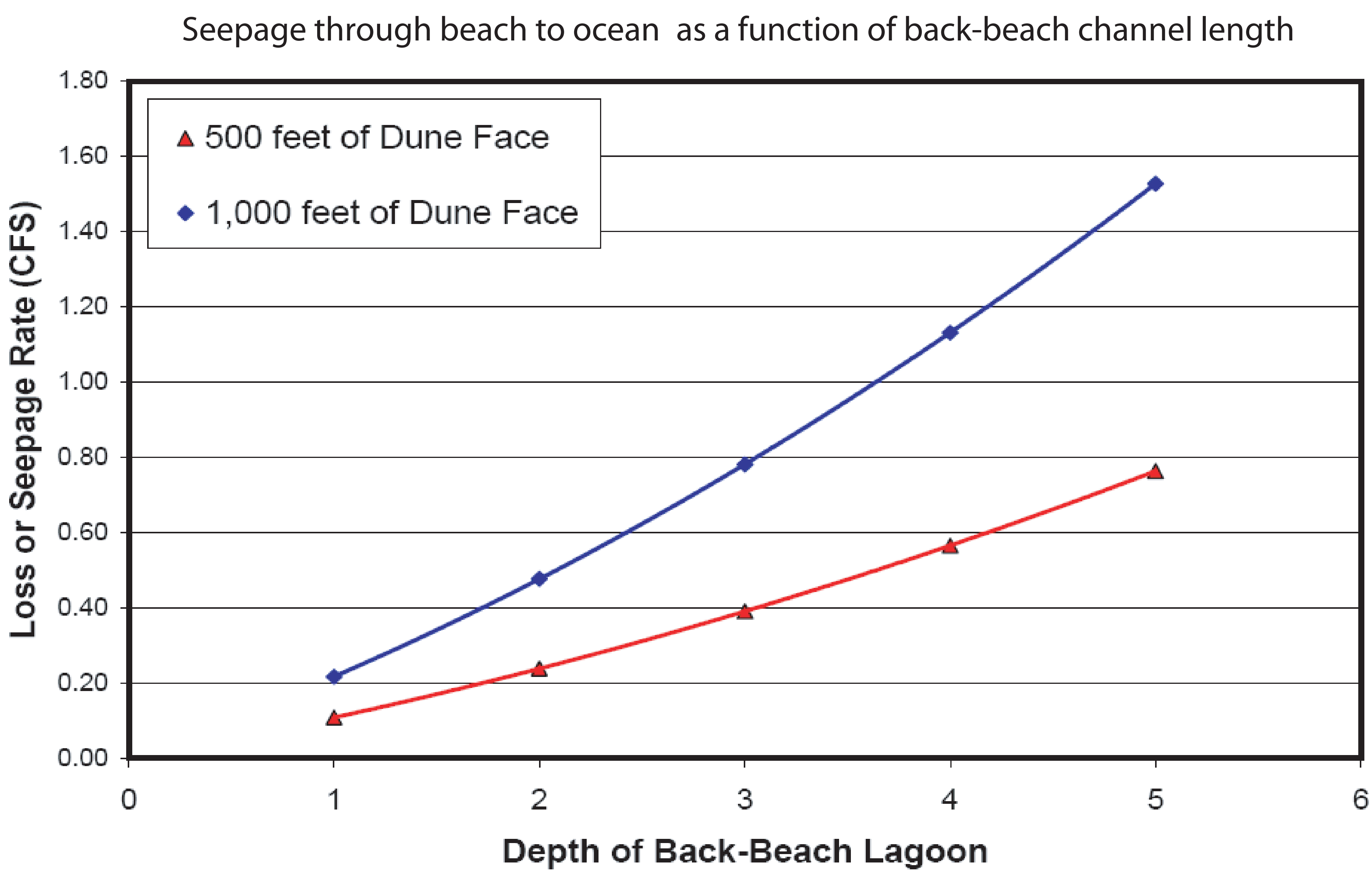
PILARCITOS CREEK GAGE DATA

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 3



data source: Balance Hydrologics, Oct 6 TAC graphics_2009-1007ct.ppt
file source: 4.estimated seepage rates through beach berm _2009-1007lee.ai

Balance Hydrologics, Inc.®

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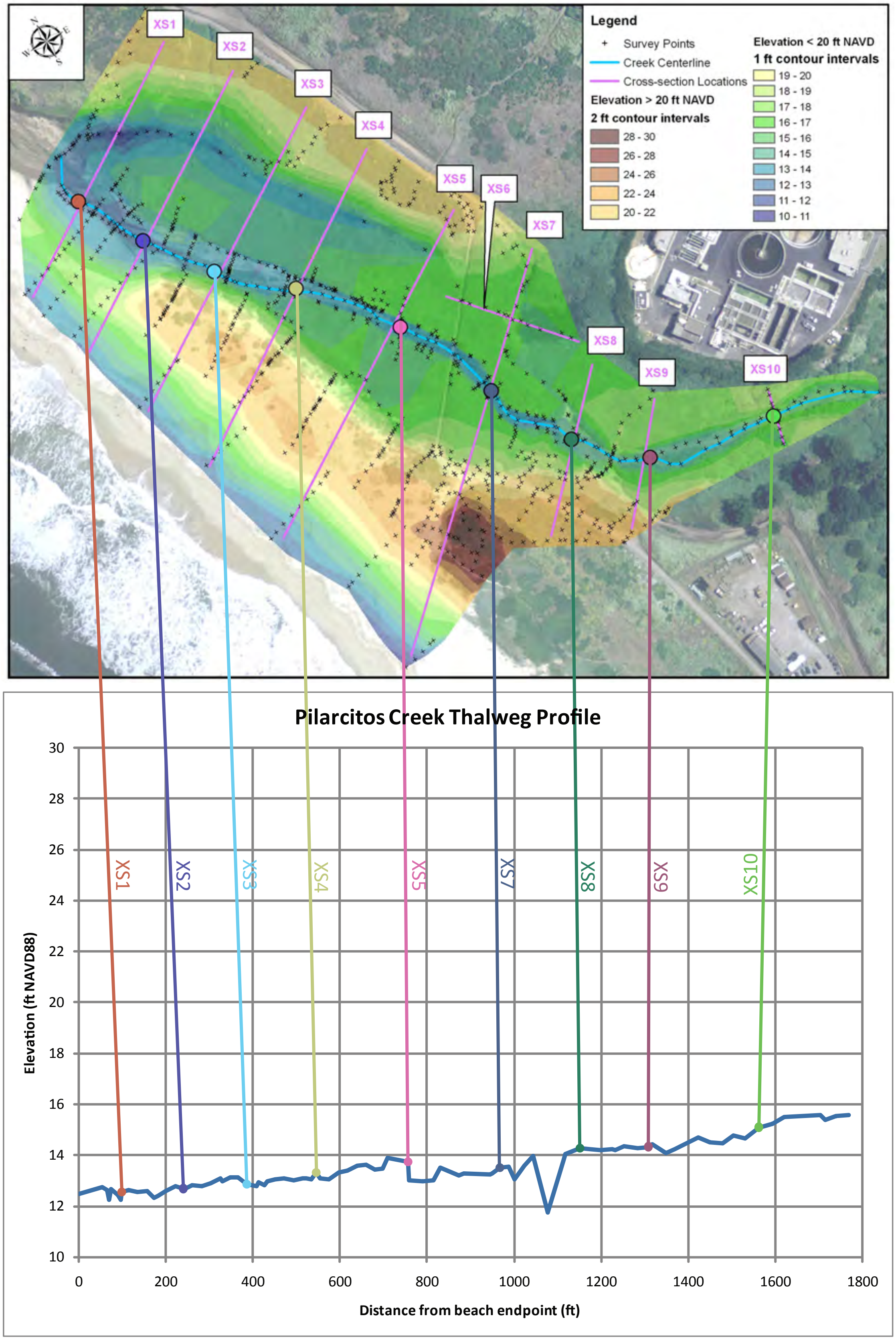
ESTIMATED SEEPAGE RATES THROUGH BEACH BERM

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 4



CROSS-SECTION LOCATIONS ALONG PILARCITOS CREEK THALWEG

Pilarcitos Lagoon Habitat Enhancement Feasibility Project
San Mateo County, California
San Mateo County Resource Conservation District

WETLANDS AND WATER RESOURCES

October 2009	Project No. 1148	Figure 5A

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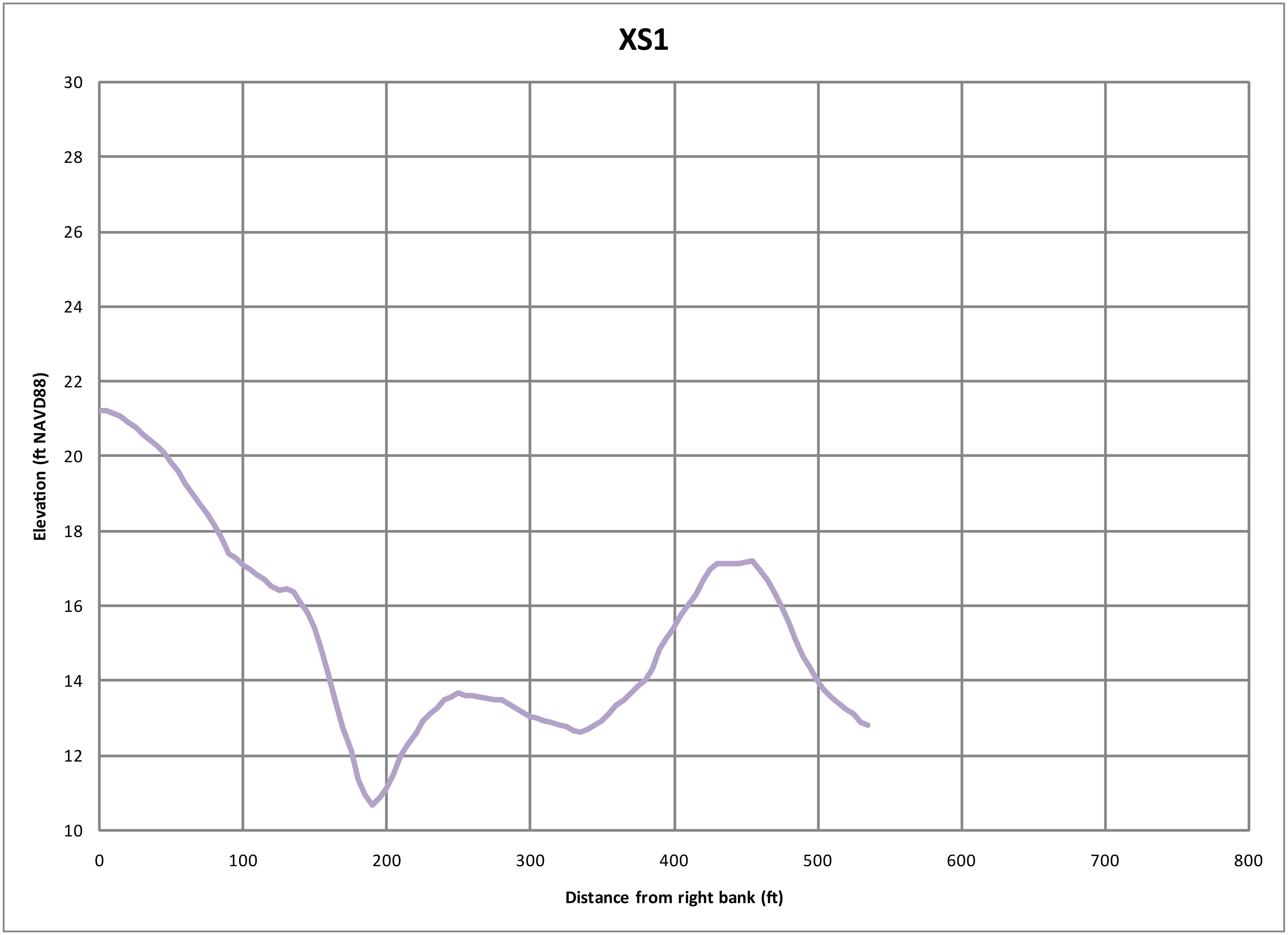
file source: thalweg profile_2009-1007ct.ai



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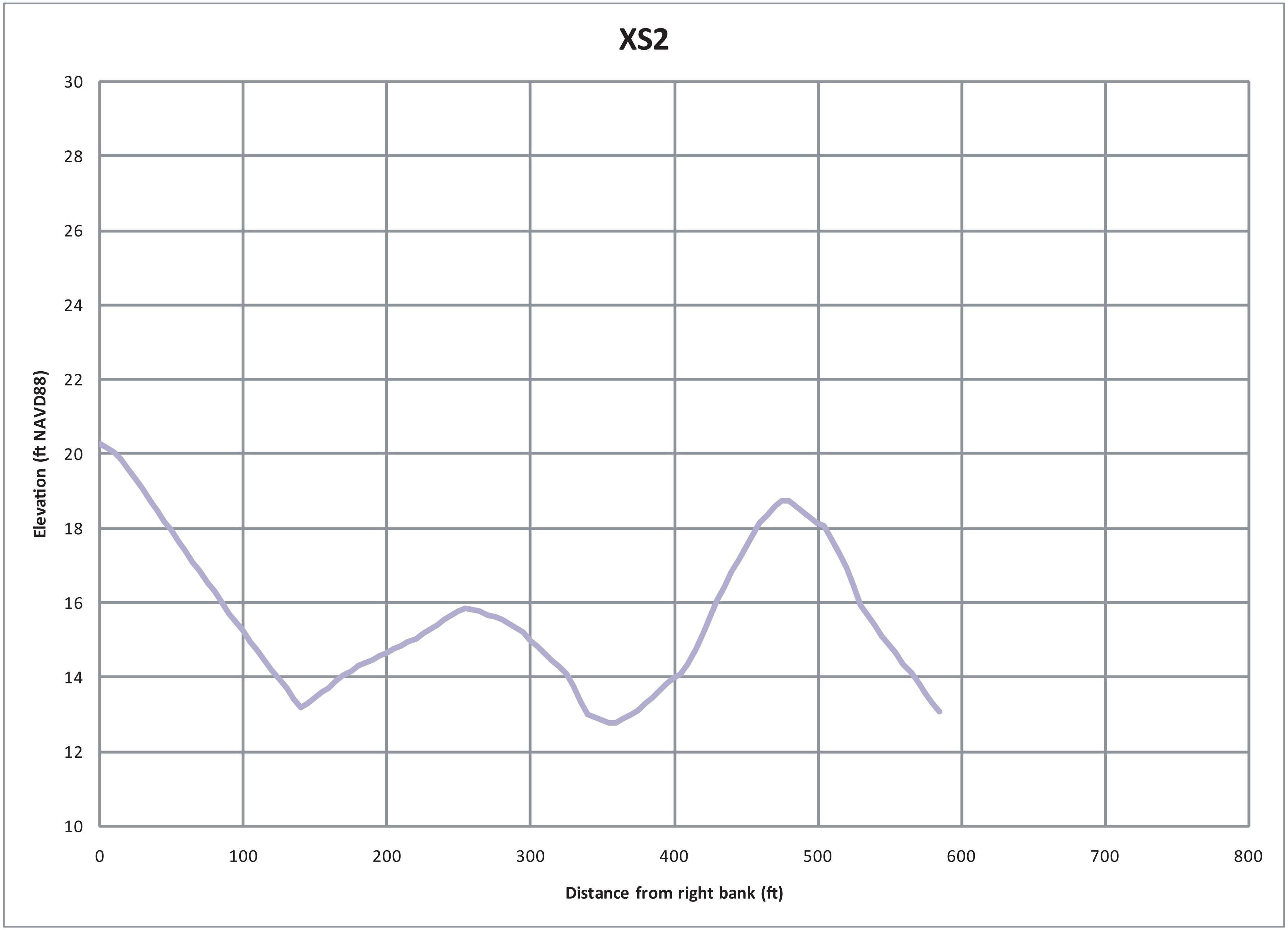
TOPOGRAPHIC CROSS-SECTIONS
XS1

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5B



TOPOGRAPHIC CROSS-SECTIONS
XS2

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5C

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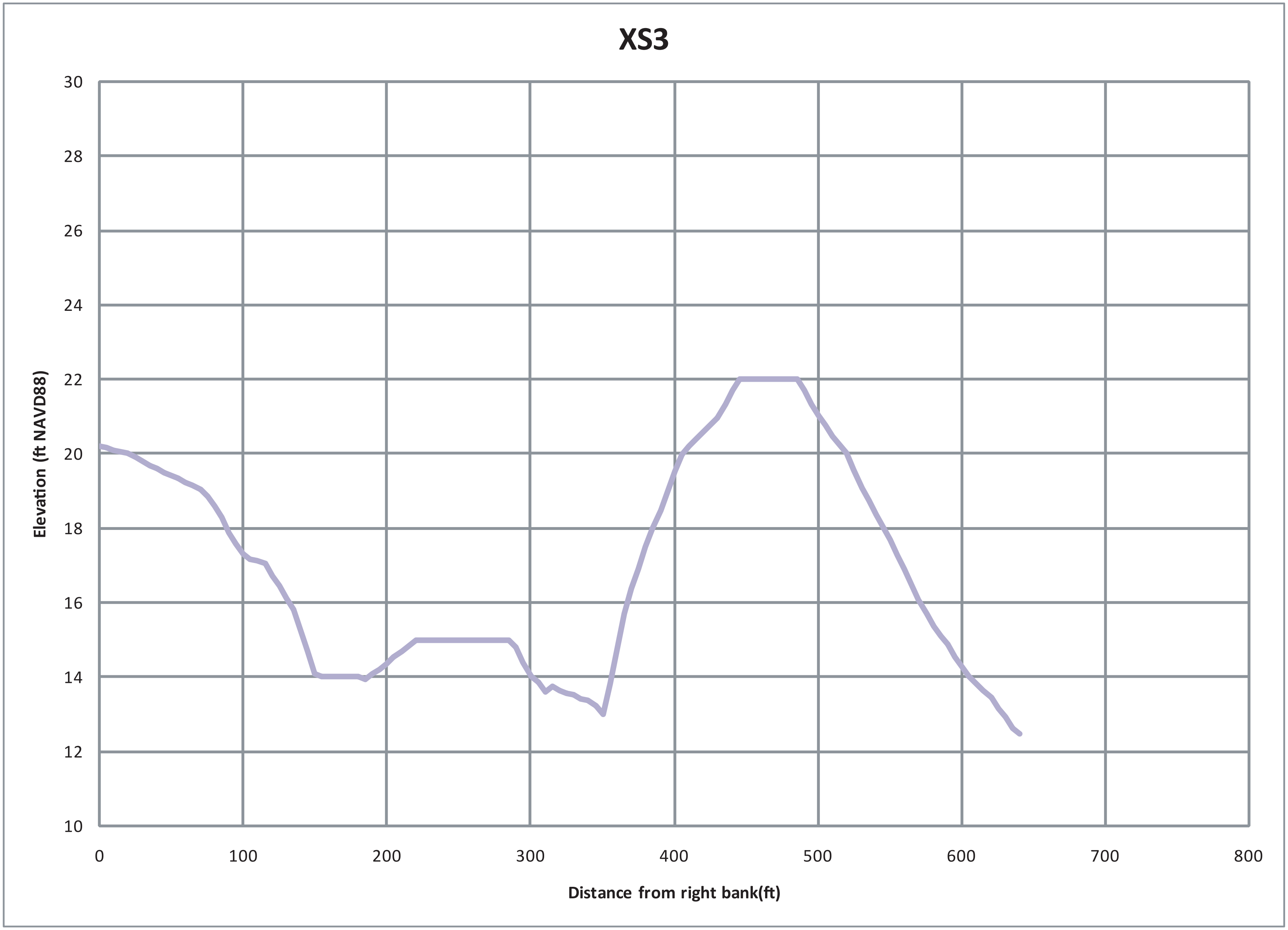
file source: 5C.XS2_2009-1007lee.ai



TOPOGRAPHIC CROSS-SECTIONS
XS3

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

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August 2009	Project No. 1148	Figure 5D

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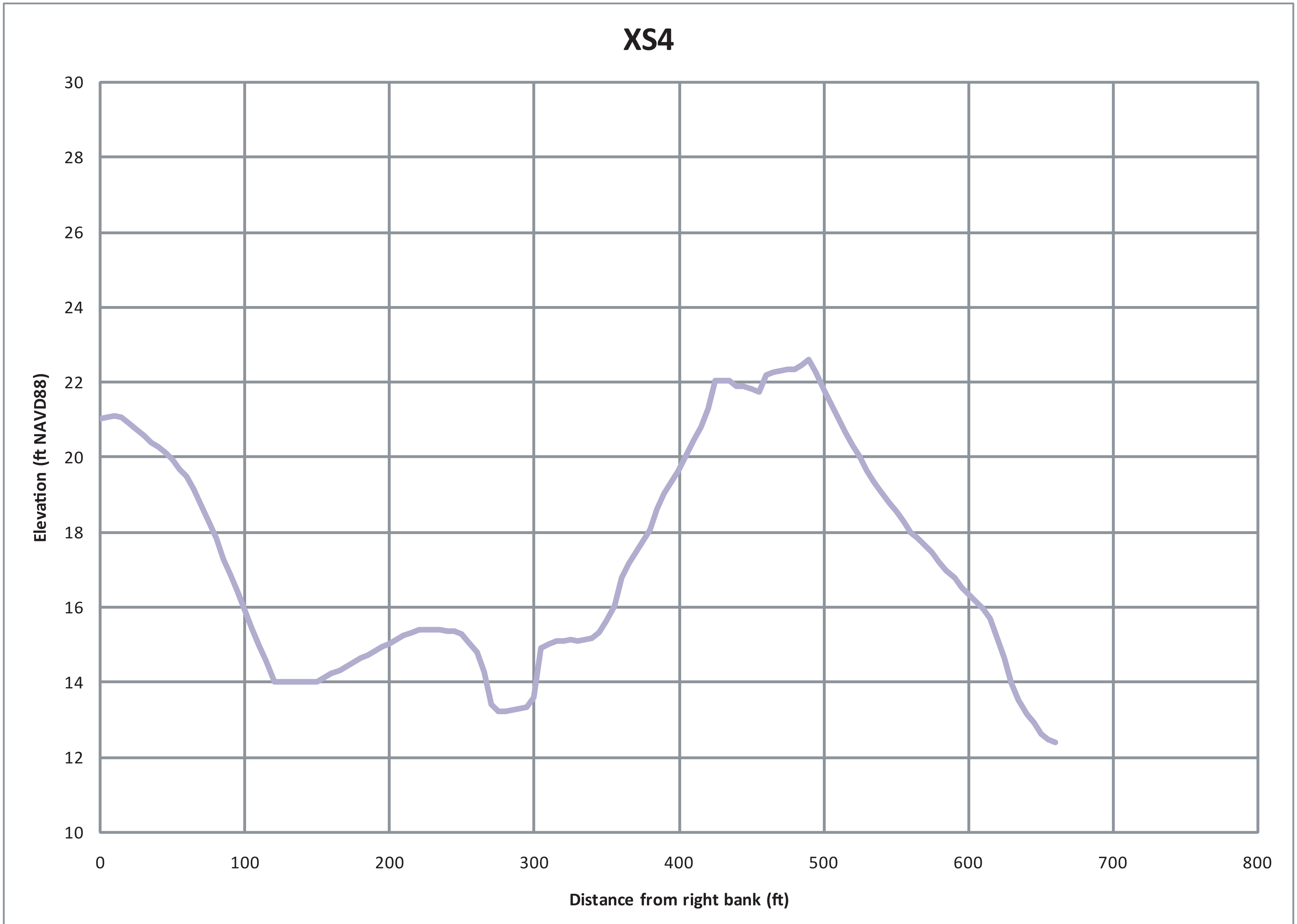

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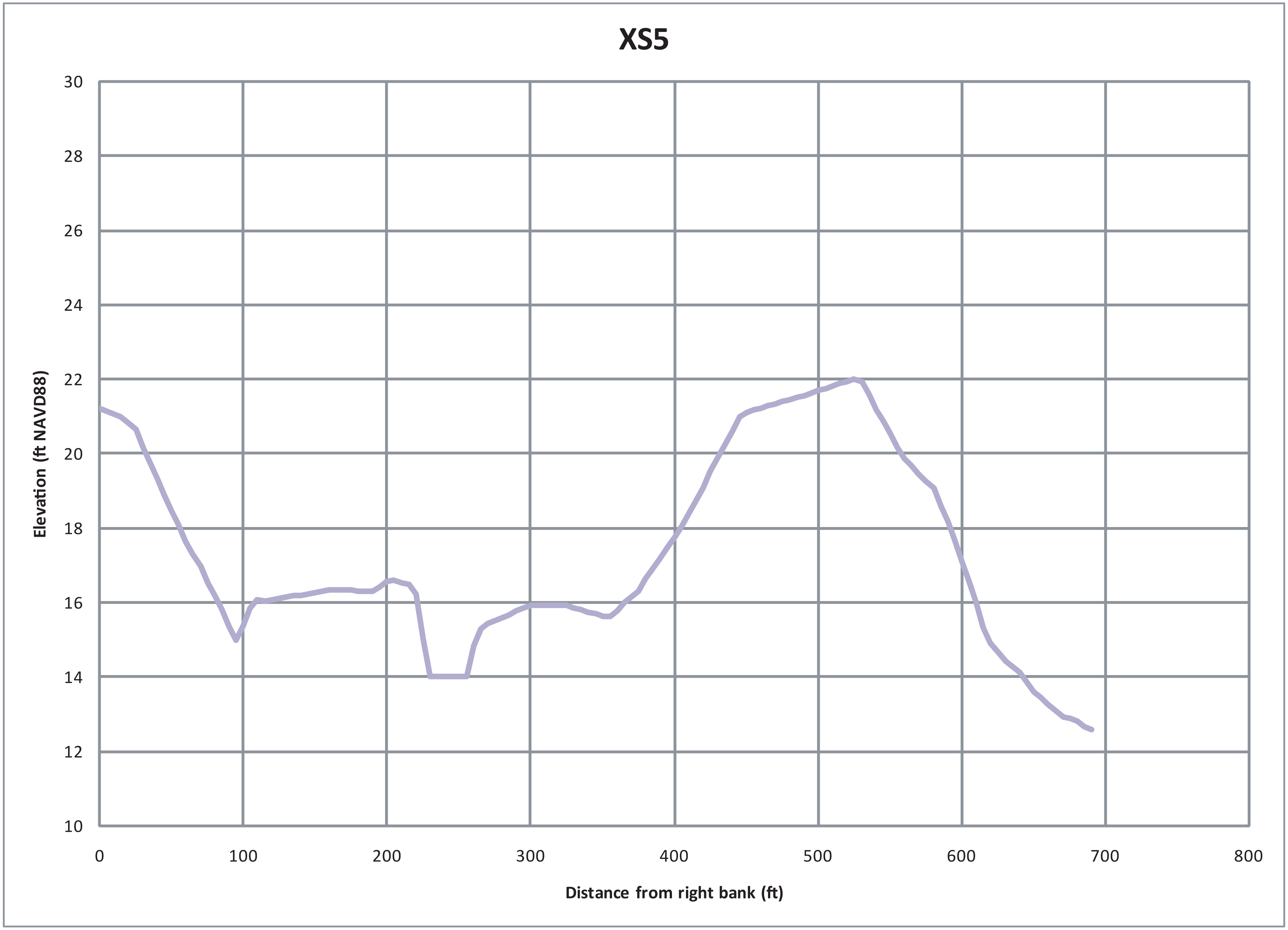
TOPOGRAPHIC CROSS-SECTIONS XS4 Pilarcitos Lagoon Habitat Enhancement Feasibility Study San Mateo County, California San Mateo County Resource Conservation District		
August 2009	Project No. 1148	Figure 5E



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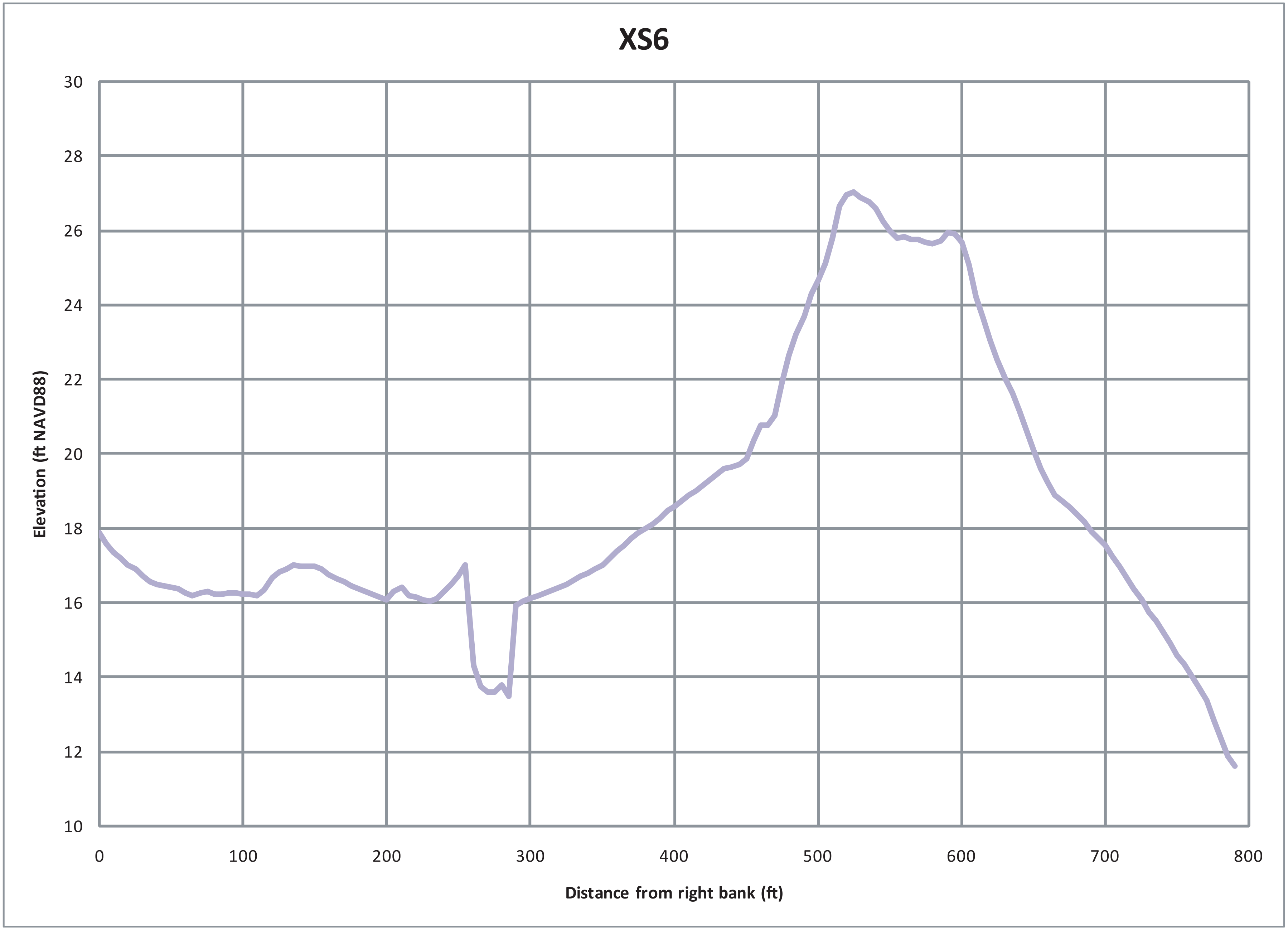
TOPOGRAPHIC CROSS-SECTIONS
XS5

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5F



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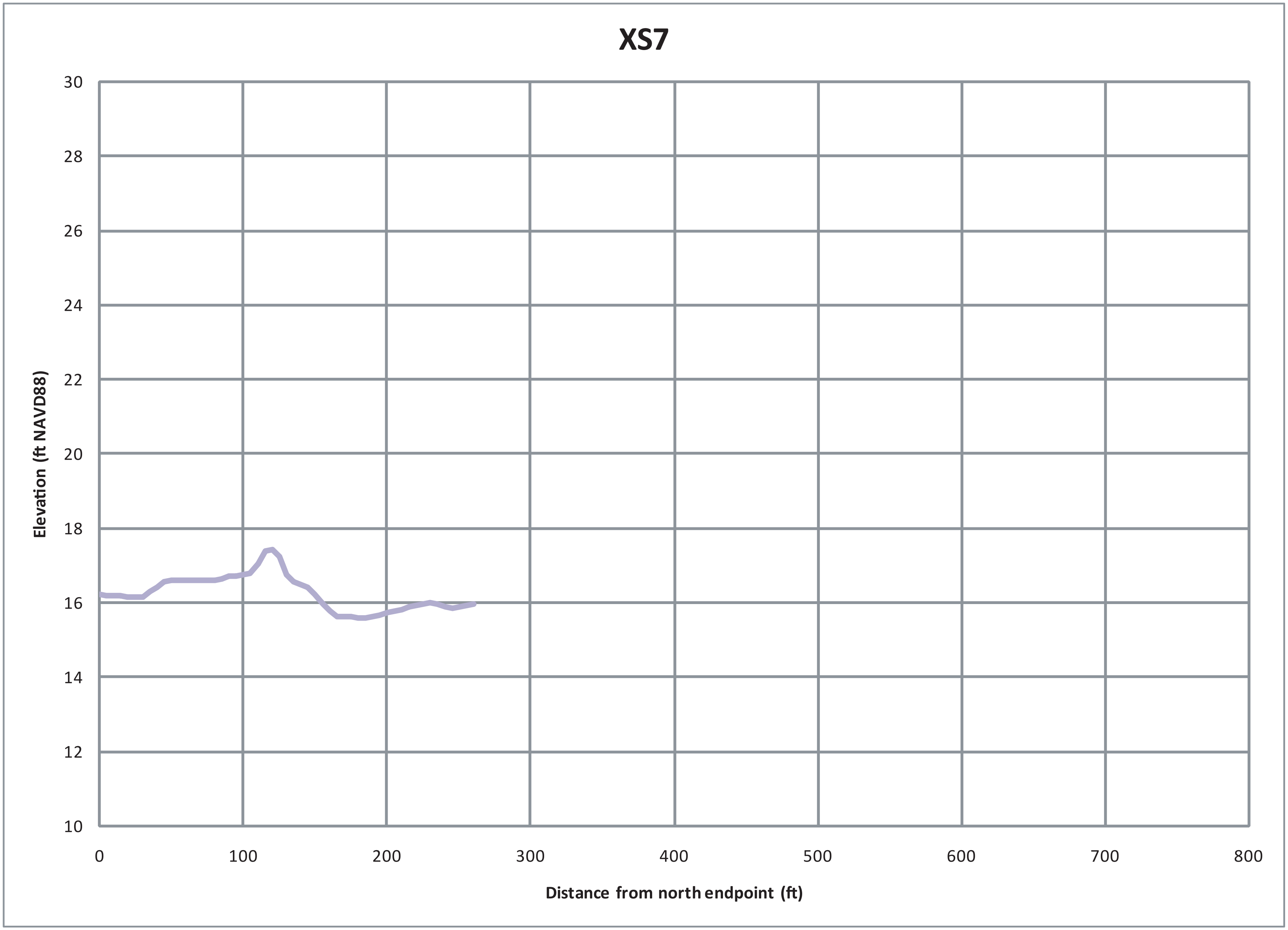
TOPOGRAPHIC CROSS-SECTIONS
XS6

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5G



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TOPOGRAPHIC CROSS-SECTIONS
XS7

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5H

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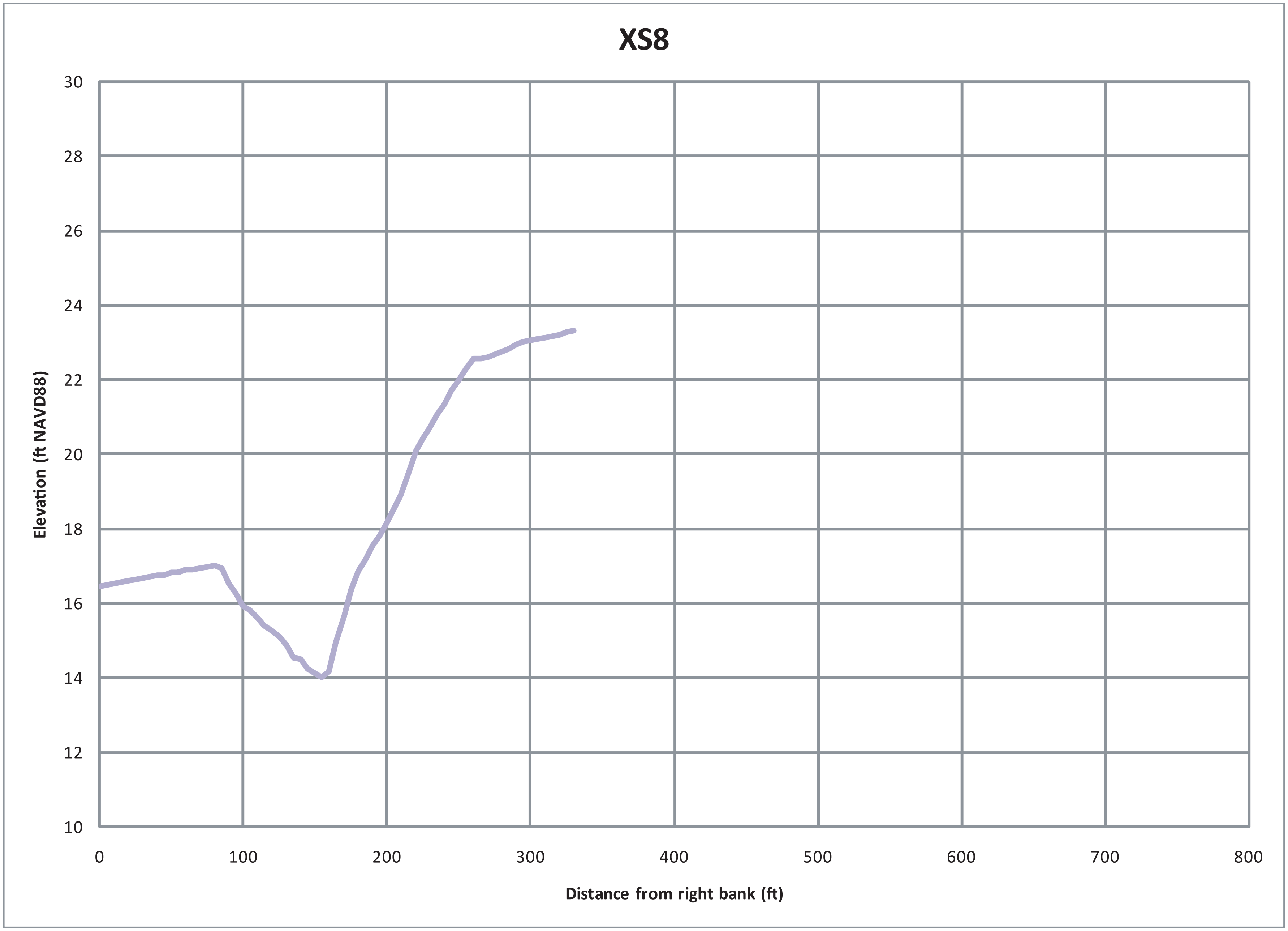

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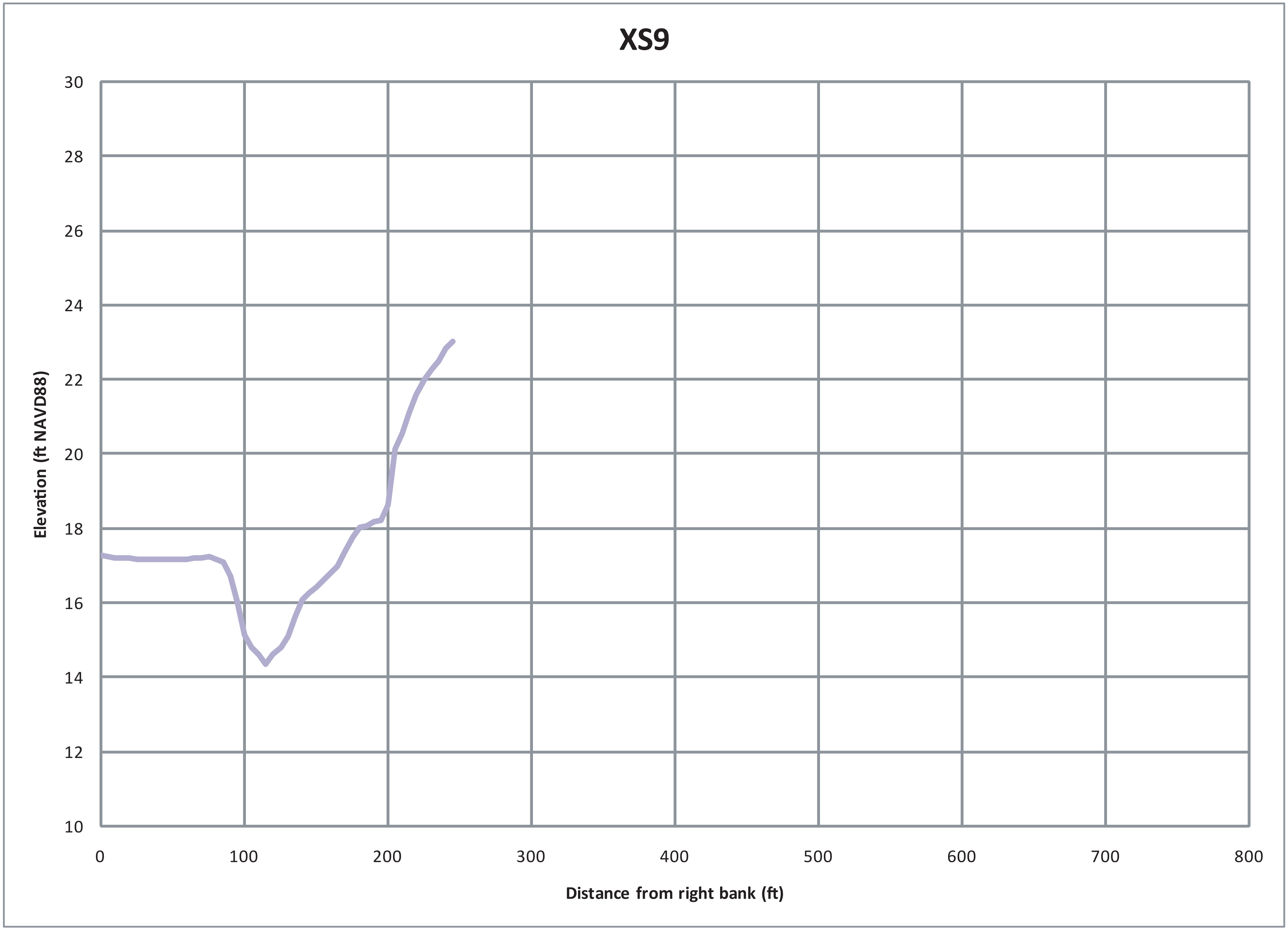
TOPOGRAPHIC CROSS-SECTIONS
XS8

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5I



TOPOGRAPHIC CROSS-SECTIONS
XS9

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5J

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data source: thalweg-and-cross-section-profiles_2009-0813lee.xls
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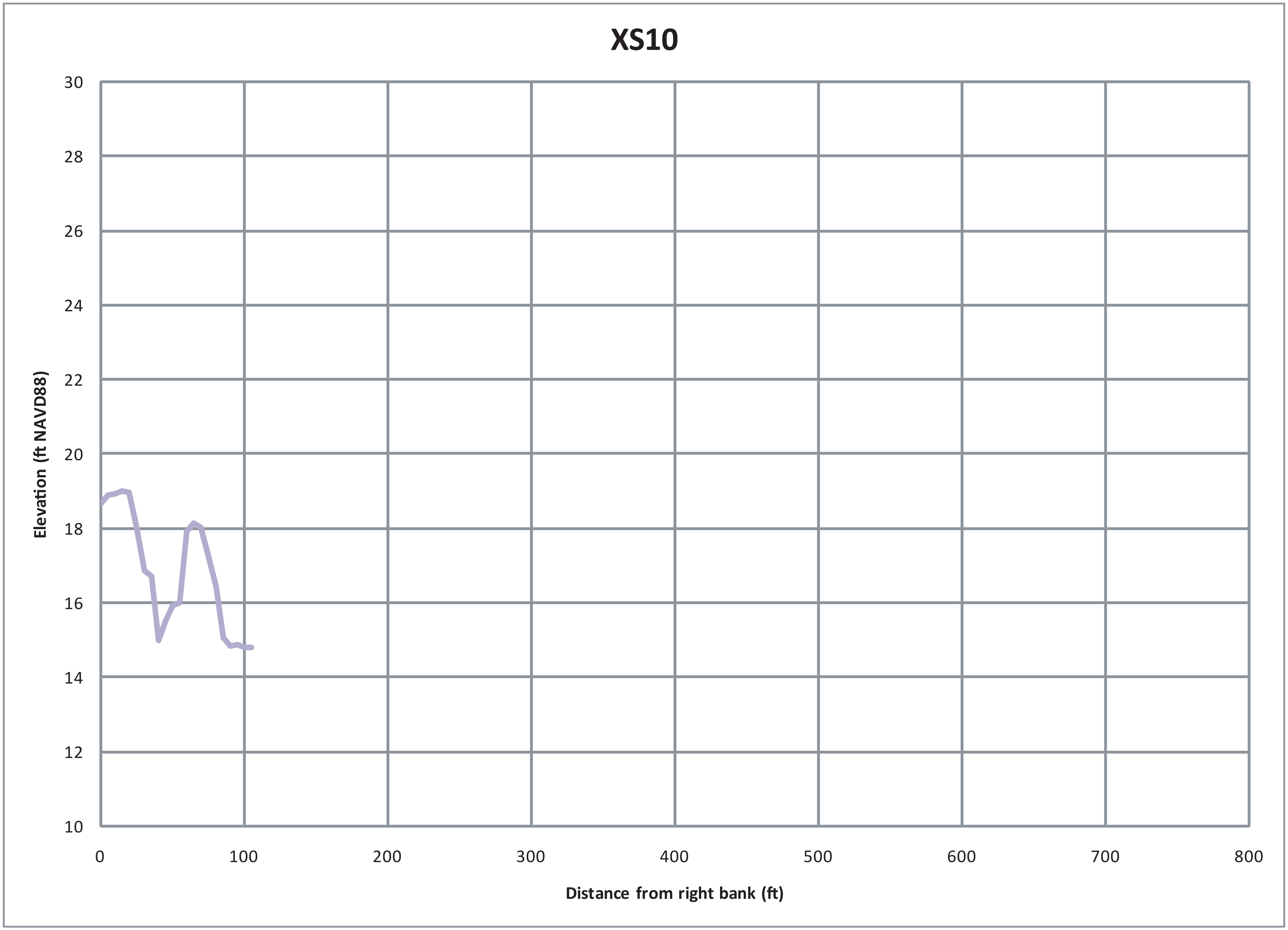

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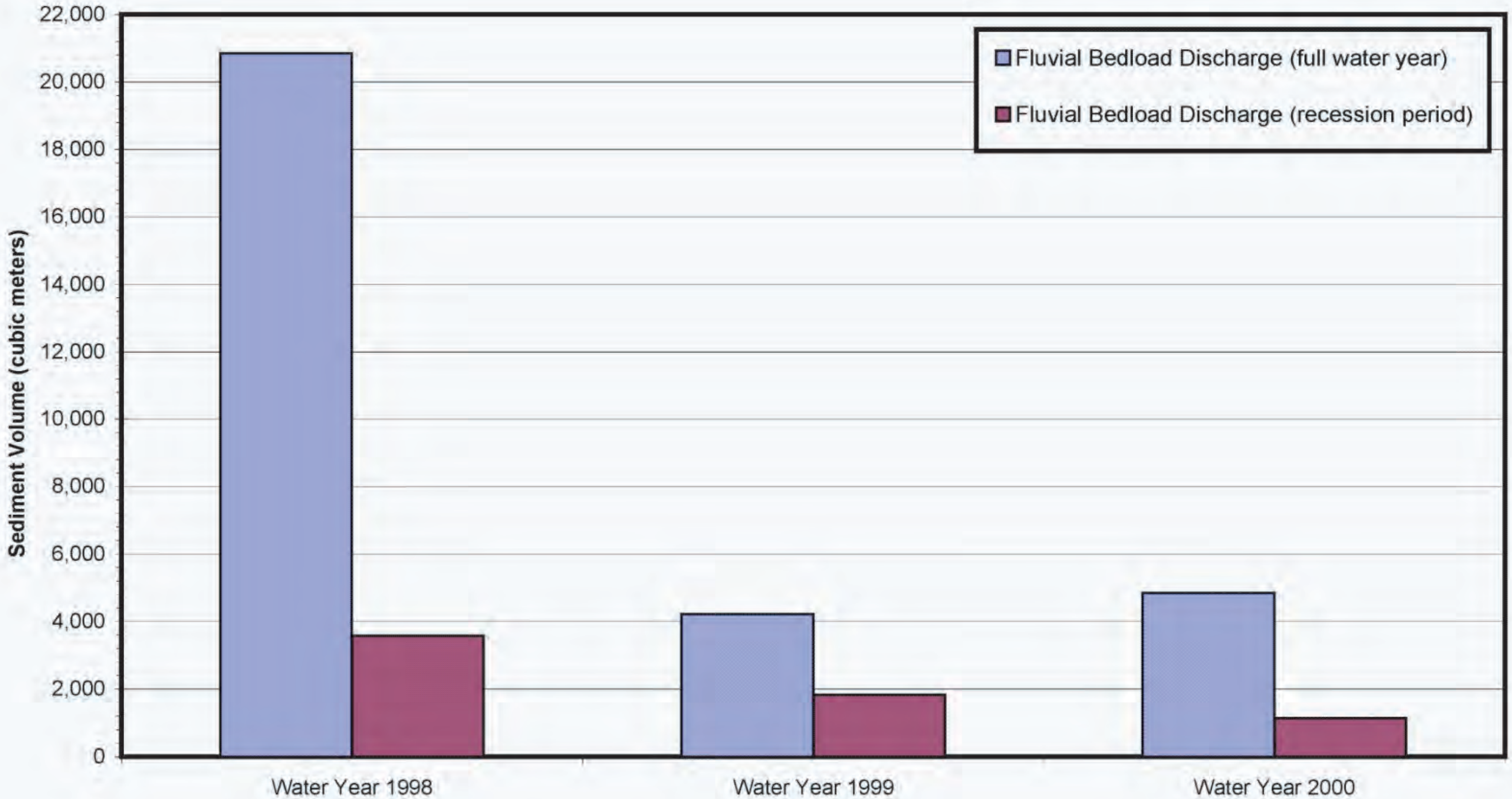
TOPOGRAPHIC CROSS-SECTIONS
XS10

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

August 2009	Project No. 1148	Figure 5K



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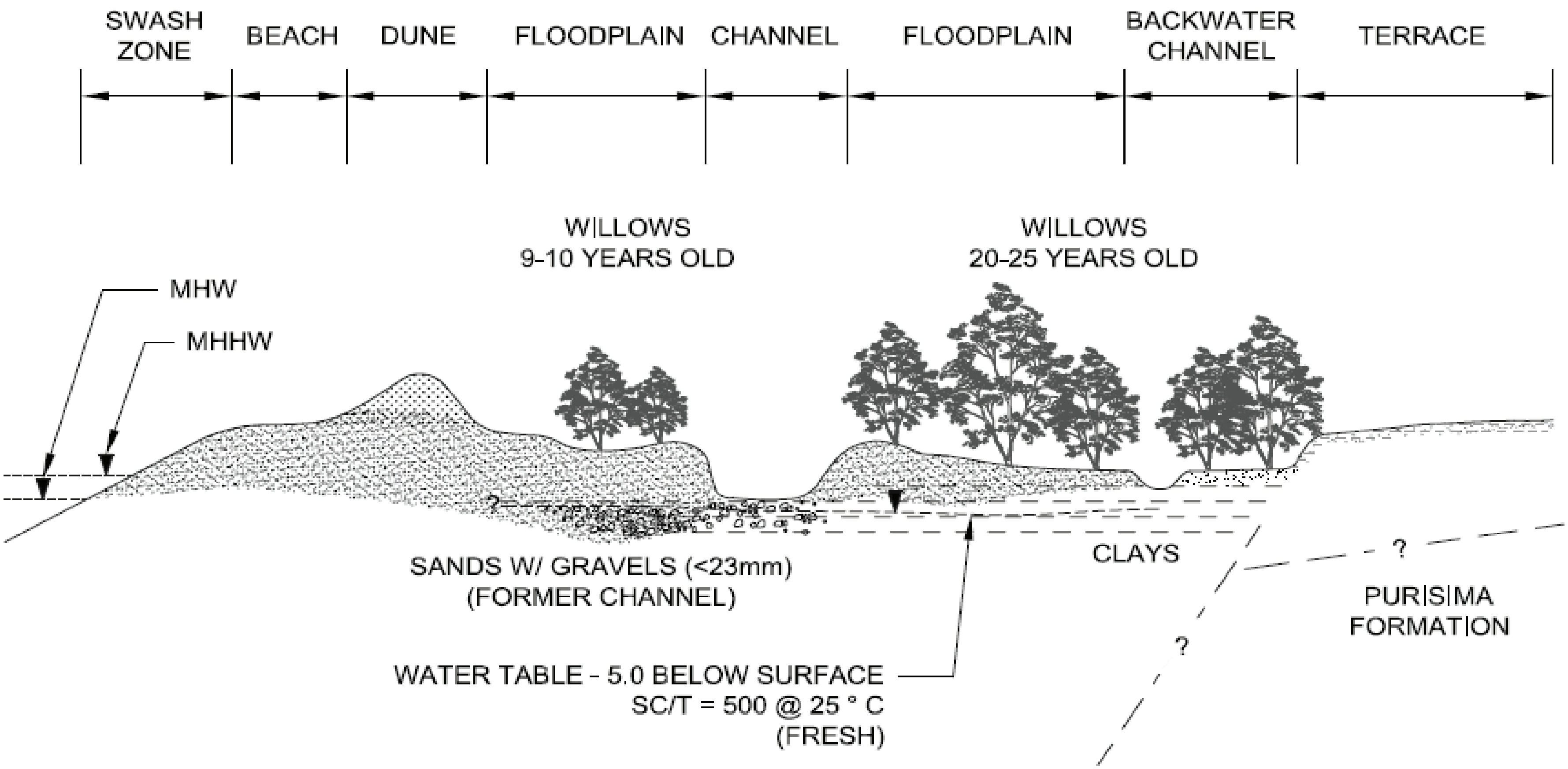
Estimated Lagoon Filling (Bedload Transport), Pilarcitos "Lagoon", Half Moon Bay, CA (average to wet water years). The graph shows bedload discharge over the entire water year, and bedload discharge during the recession period following the last large storm (which is most likely be trapped behind the beach dune rather than washing out of the creek mouth).

ESTIMATED SEDIMENT DELIVERY TO LAGOON Pilarcitos Lagoon Habitat Enhancement Feasibility Study San Mateo County, California San Mateo County Resource Conservation District		
October 2009	Project No. 1148	Figure 6

WETLANDS AND WATER RESOURCES, INC.

data source: Oct 6 TAC graphics_2009-1007ct.ppt
file source: 6.estimated sediment delivery to lagoon_2009-1007lee.ai



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Cross-section of shallow subsurface conditions, Pilarcitos Creek
Half Moon Bay State Beach, CA

Borings and water table recorded on September 3, 2009

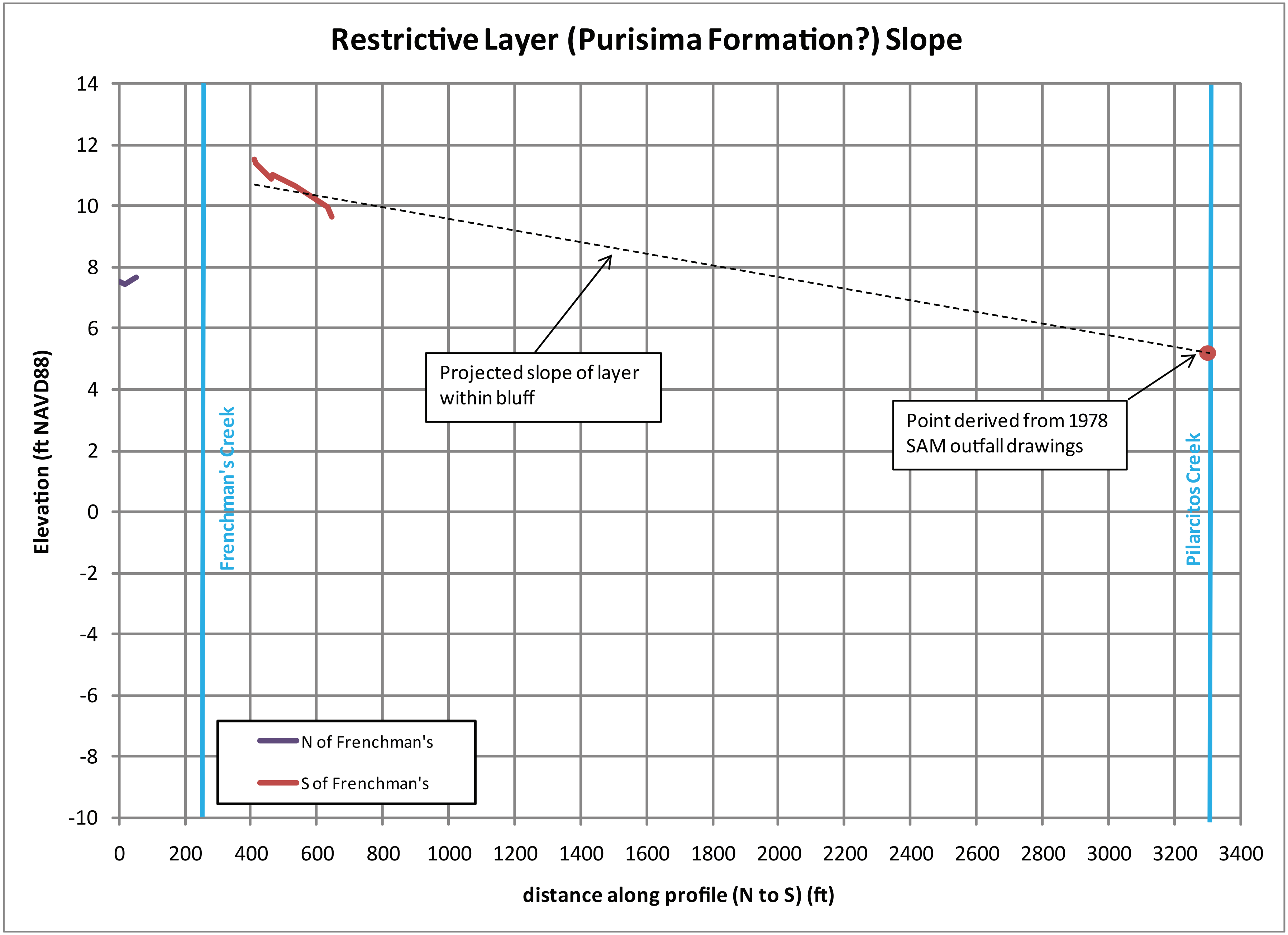
WETLANDS AND WATER RESOURCES, INC.

SUBSURFACE PROFILES

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 7

file source: 7.sediment coring data_2009-1007lee.ai



data source: Pilarcitos Rover 3Sept09_2009-1007ct
file source: Fig-08_restrictive layer_2009-1007ct.ai

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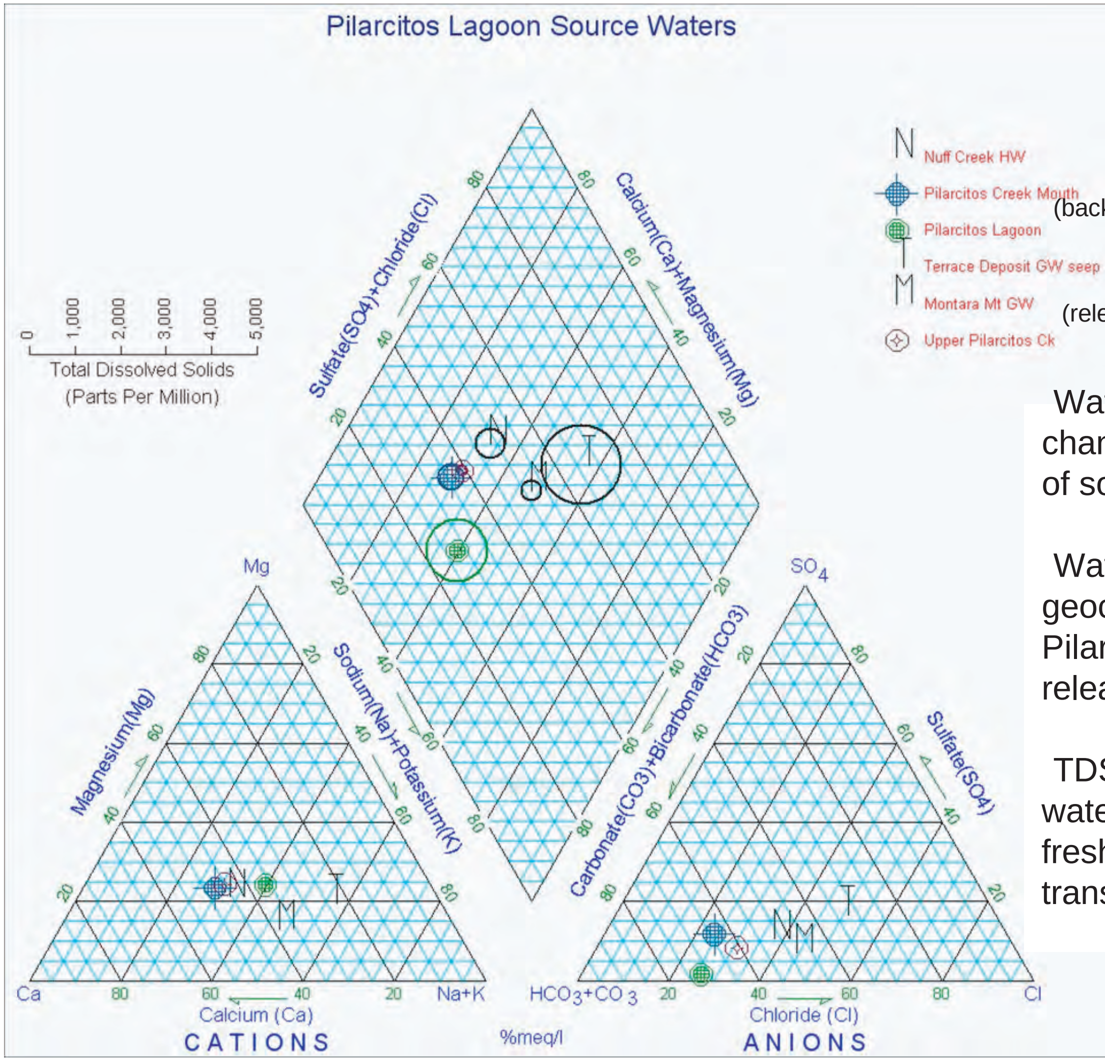
ESTIMATED SLOPE OF RESTRICTIVE LAYER IN MARINE TERRACE

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 8

Are waters in Pilarcitos Lagoon adequate to provide steelhead transitional habitat?



(backwater channel)

(releases from Stone Dam)

Waters in back-water ("lagoon") channel may be from a mixed number of sources

Waters released from Stone Dam are geochemically similar to waters at Pilarcitos mouth (suggesting low-flow releases make it to the mouth)

TDS values suggest waters in back-water "lagoon" or channel are mainly fresh and may not provide a brackish, transitional environment for steelhead.

data source: Balance Hydrologics, Oct 6 TAC graphics_2009-1007ct.ppt
file source: 9.chemical fingerprinting of source waters _2009-1007lee.ai

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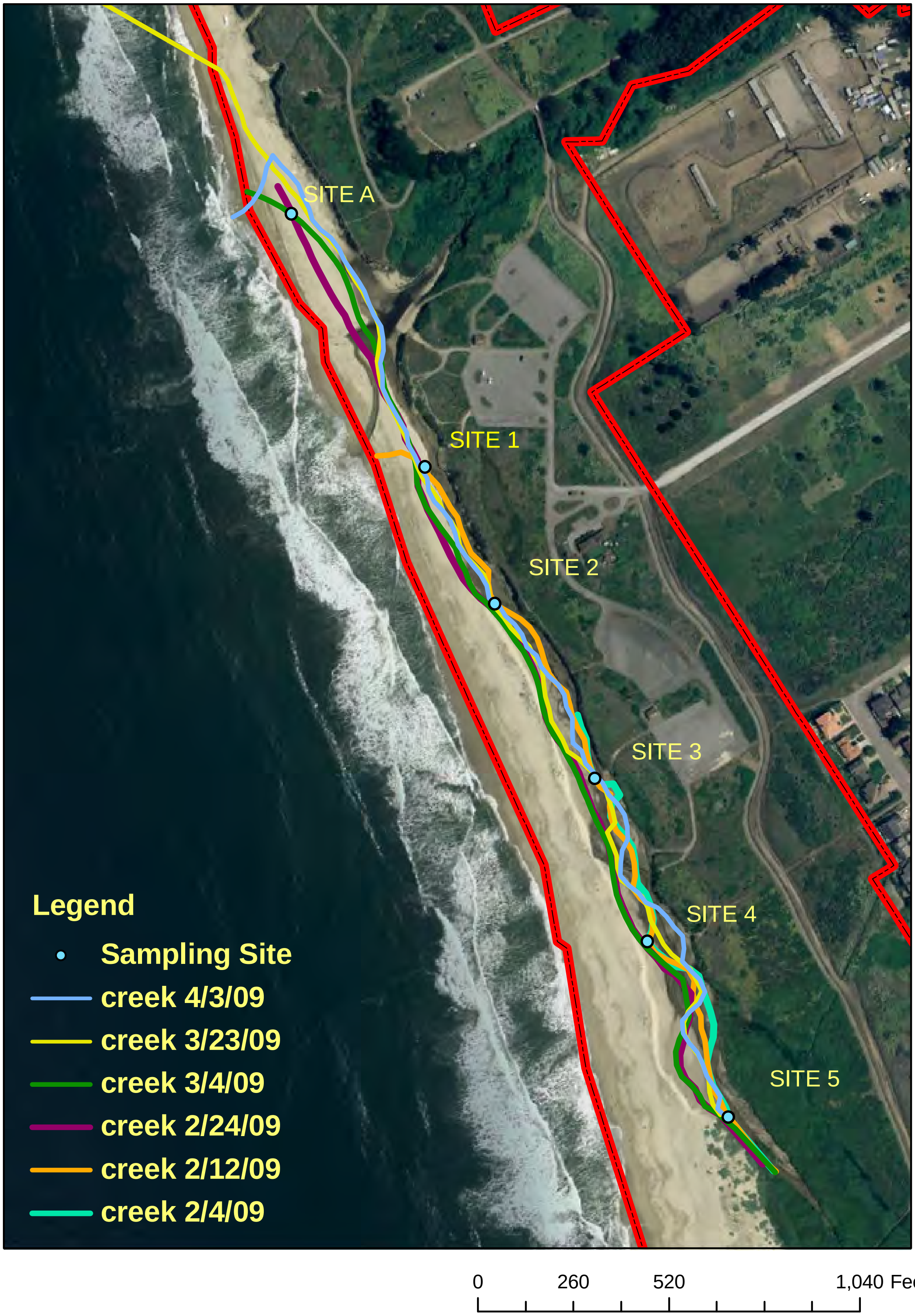
WETLANDS AND WATER RESOURCES, INC.

CHEMICAL "FINGERPRINTING" OF SOURCE WATERS
Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 9

Pilarcitos Creek



data source: CA State Parks/Don Alley 2009
file source: 10.thalweg movement during 2009 spring_2009-1007lee.ai

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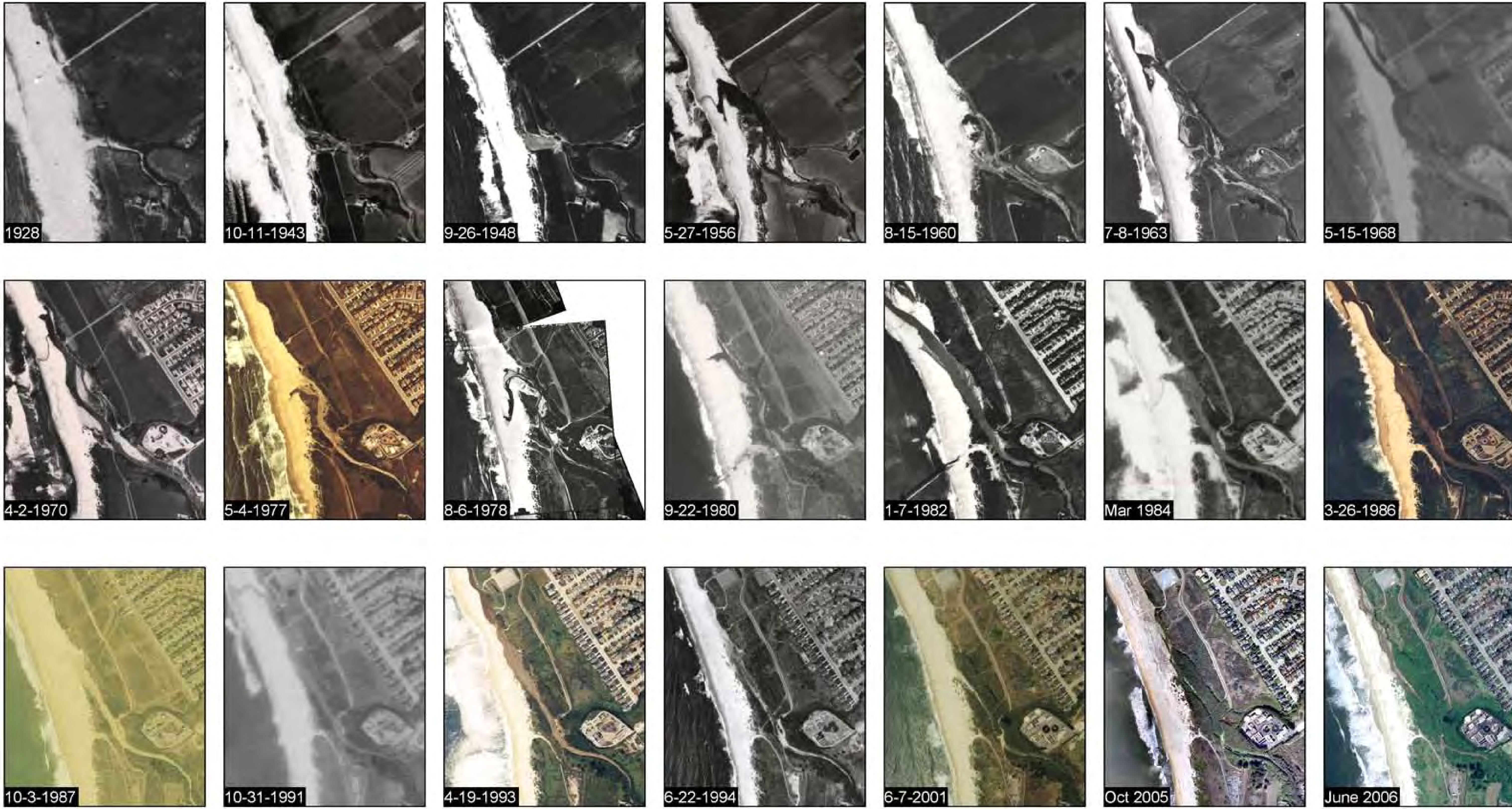
THALWEG MOVEMENT DURING 2009 SPRING

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 10



N
W E
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1:12,000; 1 inch = 1000 ft at B-size layout

0 500 1,000 2,000 3,000 4,000 Feet

0 150 300 600 900 1,200 Meters

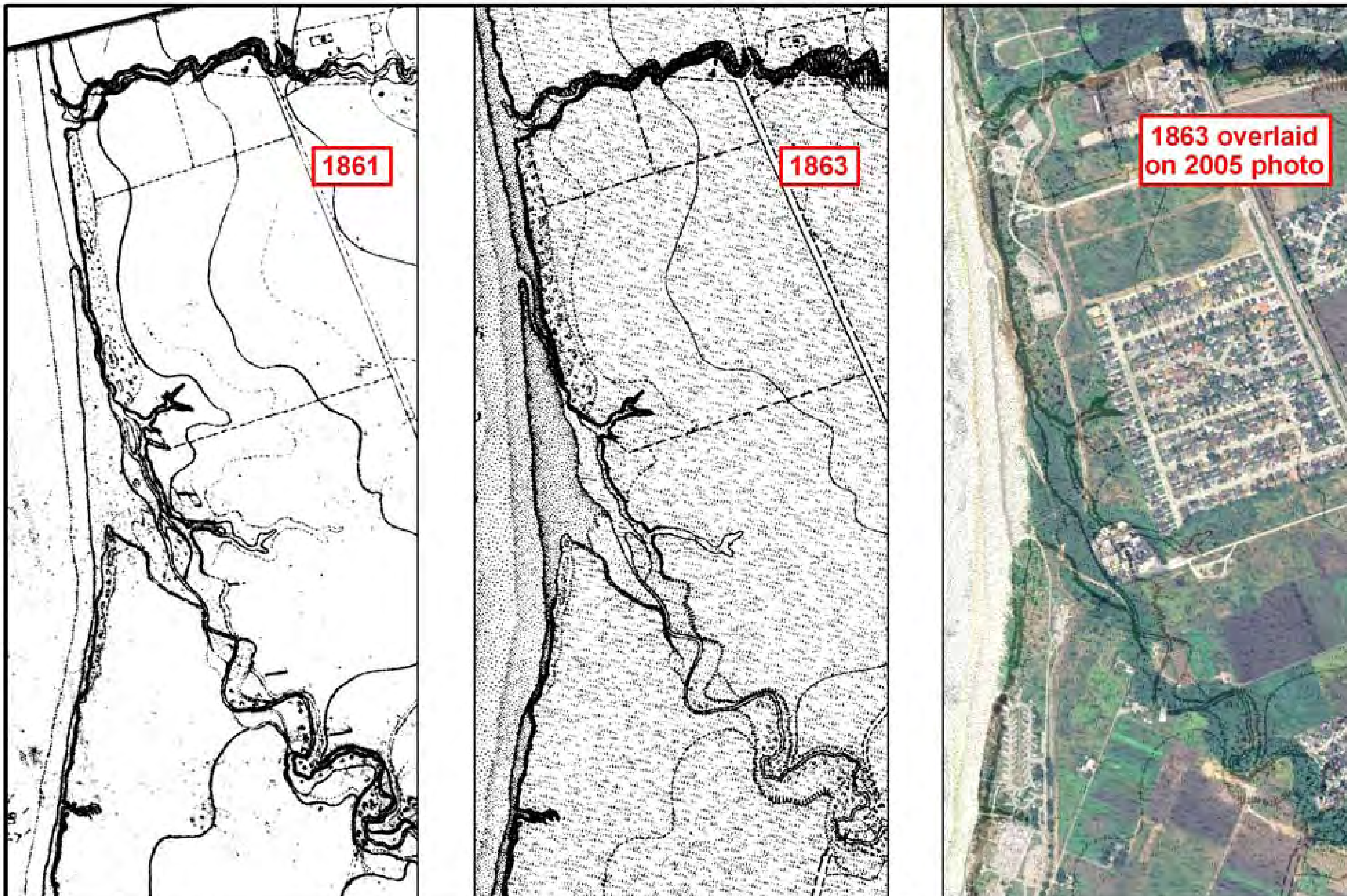
Data Sources: UCSC, USGS
Produced by: Wetlands and Water Resources, Inc., June 2009
Cartography/GIS by Christina Toms and Leigh Etheridge
Map File: 1148_air photo overlay_2009-0612ct.mxd
file source: 11 historic aerial photos 1928-2006_2009-1007lee

WETLANDS AND WATER RESOURCES, INC.

HISTORIC AERIAL PHOTOS: 1928 - 2006

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County Resource Conservation District
San Mateo County, California

June 2009	Project No. 1148	Figure 11

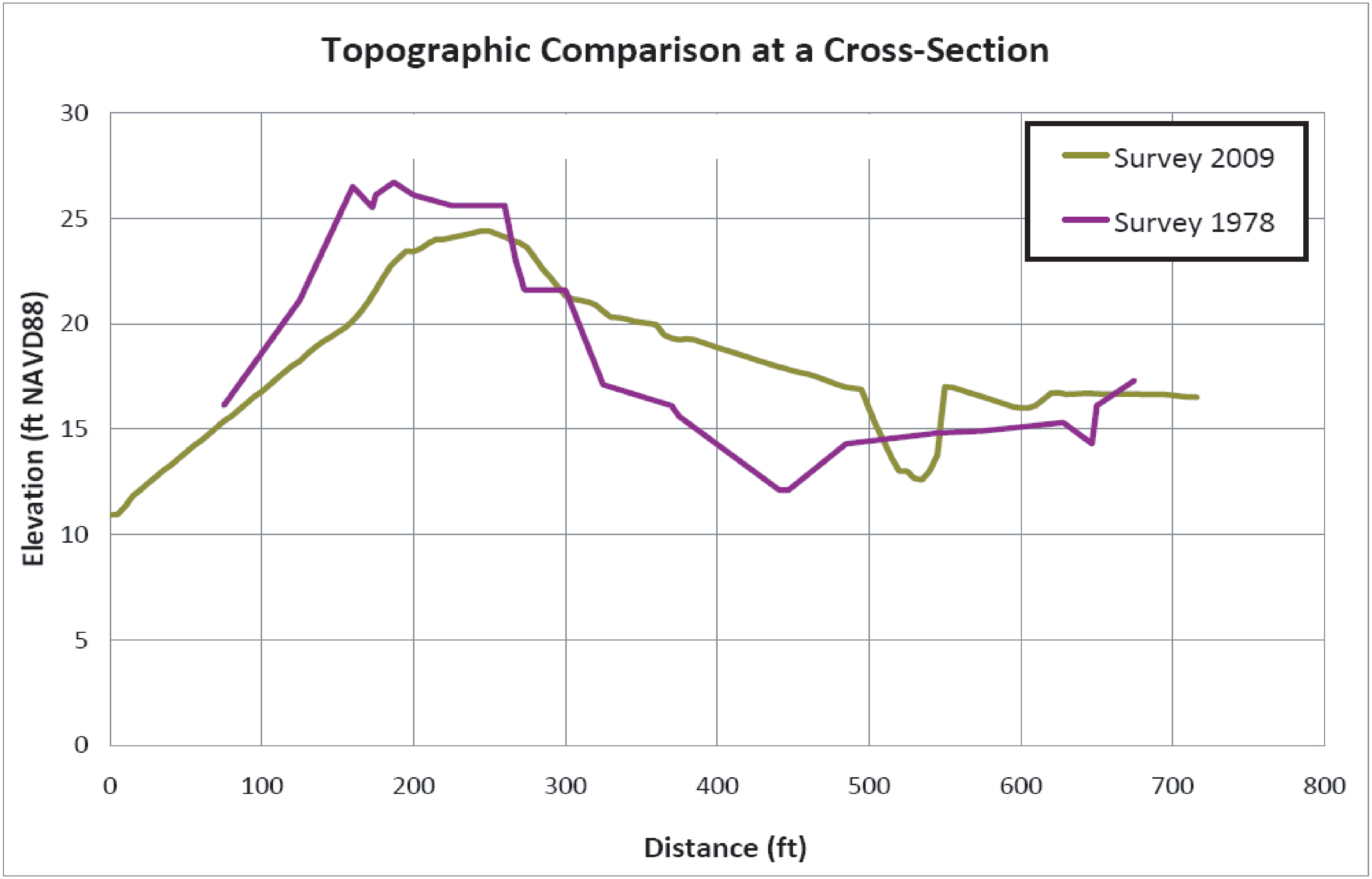


1861 AND 1863 US COAST SURVEY MAPS

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County Resource Conservation District
San Mateo County, California

May 2009	Project No. 1148	**Figure 13**

Map File: 1861-1863_coast-survey-maps_2009-0531ct.mxd
Data Sources: historic US Coast Survey maps:
UC-Berkeley (1861), Keith Mangold (1863)
2005 photo: USDA NAIP
Produced by Wetlands and Water Resources, Inc., May 2009
GIS/Cartography by Leigh Etheridge and Christina Toms



data source: Balance Hydrologics, Oct 6 TAC graphics_2009-1007ct.ppt
file source: 14.ground surface profile along SAM plant outfall _2009-1007lee.ai

Balance Hydrologics, Inc.®

WETLANDS AND WATER RESOURCES, INC.

GROUND SURFACE PROFILE ALONG SAM PLANT OUTFALL

Pilarcitos Lagoon Habitat Enhancement Feasibility Study
San Mateo County, California
San Mateo County Resource Conservation District

October 2009	Project No. 1148	Figure 14

Appendices

Appendix A

Technical Memorandum:
Technical Memo: Sources of beach sediment at Pilarcitos Lagoon

Memo

To: Wetlands and Water Resources, Inc. (WWR)
From: Brian Hastings, Barry Hecht, Jonathan Owens
Date: Sept. 15, 2009

Subject: Sources of beach sediment at Pilarcitos Lagoon

I. Introduction

Planning for management of the Pilarcitos Lagoon rests in part on an understanding of the sources of the sands forming the barrier bar, beach, and dunes. These appear to be a mix of sands originating from littoral and from terrestrial sources. This memo is a preliminary discussion of likely sources of beach materials, and how these sources may vary over decadal time.

When considering the types of sources of sand, it's important to differentiate amongst the different temporal and spatial scales. Temporally, sediment can be evaluated on an annual basis especially when we consider the littoral component—how much sand is supplied to Pilarcitos Lagoon over one calendar or water year? This memo is focused on the annual sediment sources and delivery. However, we define several other important scales to illuminate the geomorphic processes at work. For example, fluvial sediment on an annual scale may not be appropriate due to the complexities of fill and scour during multiple storm periods---a lagoon may fill during one storm, but scour during the subsequent event. The last major storm event may be the critical factor in filling a lagoon on an annual basis. Therefore, a temporal scale based on the recessional hydrology may be more appropriate for lagoon management. This is roughly the falling limb of the annual hydrograph from the last large storm until summer baseflows are observed (February thru August). Within this time period, we may also consider a smaller temporal and spatial scale that focuses on great habitat concerns such as fish passage or beach closure. Local geomorphic processes become more dominant—sediment sources such as longshore sediment transport and even wind transport become more important.

Again, this memo is solely focused on the larger or annual picture to understand the relative magnitude of sediment sources operating in Half Moon Bay. We begin this memo with an outline of our approach, and follow with a description of our analyses for calculating the annual sediment sources. Sediment yield values from several temporal scales are provided in Table 1. Figure 1 provides an illustration of the relative sediment yields from each of the described sources over an annual period. This memo concludes with a comparison and discussion of our findings for this topic.

II. Approach

We approach this analysis using multiple lines of evidence, which may be progressively refined as needed to address management questions:

A. Mineralogical composition

B. Estimates based on coastal sediment production rates based on bluff retreat

C. Estimates based on littoral transport based on conventional transport equations

D. Estimates based on sediment yields from terrestrial sources reported in the literature.

We then discuss some of the implications that may bracket management of the lagoon.

III. Mineralogical composition

We know of no quantitative assessment of beach-sand mineralogy for the coast near the mouth of Pilarcitos Creek. Early work by Stanford staff during the 1950s (c.f., Hutton, 1958; Spotts, 1959) described the mineralogy of sands in the Montara/Moss Beach area or the trace minerals originating from the Montara Mountain batholith. Corps of Engineers staff quantified the origin of sediments in Half Moon Bay (Wilde and others, 1973). We have not reviewed these older publications, in part because the sources of sediment have changed during the past half century. Our recollection of the literature is that local terrestrial sources – either fluvial or eroded from the terraces – comprised much or most of the beach deposits, with the substantial but subordinate contribution from longshore drift, presumably from San Francisco Bay but also include coastal-bluff material from south of the Golden Gate. Wong (2000) describes the heavy-mineral composition of sediment on the continental shelf a few miles of Devils Slide to be a combination of trace minerals of granitic origin and a pyroxene-rich suite of volcanic origin (including Purisima-derived sediments).

Based on brief inspection by hand lens for this study, beach sediment at Pilarcitos Lagoon is composed of a range of sizes, which seem to be predominantly medium sands. Sand mineralogy includes a large suite of subangular to subround material of apparent granitic sources, a second admixture of round to subround quartzose and 'purplish' lithic and yellowish (pyroxene?) sands of likely Purisima provenance, and a third component of indeterminate origin, which tends to be finer and rounder, may include elements of both primary sources plus other constituents including trace amounts of chert.

Both recollection of the older literature and our preliminary field viewing of samples from along the Pilarcitos/Frenchman beach front, we hypothesize that terrestrial and littoral sources each make up a large share of the beach material, probably in about subequal proportions. Additional contributions may originate –directly or indirectly -- from Franciscan sources, either those outcropping in the upper Pilarcitos watershed or further north along the coast. Alternatively, some of these materials may have been mobilized from sources below the wave base such as those described by Wong (2000).

IV. Sediment originating from coastal erosion

Sands originating most recently from coastal-bluff erosion include a combination of those transported from north of Pillar Point and those mobilized from bluffs with Half Moon Bay. We believe that the latter predominate, particularly since Pillar Point Harbor was constructed during the 1960s. The harbor likely deflects a large proportion of the sediment delivered from north of Pillar Point onto the continental shelf to the south. The harbor is thought to have depleted longshore drift sufficiently to induce bluff retreat in the Miramar area immediately to the south. Lajoie (in Weber and others, 1979) measured bluff retreat averaging 2.1-2.4 m per year during the 1970s in this segment of coast, with the rate attenuating southward. Subsequently, he noted a slowing of the observed rate during the 1980s.

We estimated bluff retreat at Miramar during the 1990s and more recently using historical aerial photography, concluding that a rate of 1.0 m -- or about half of the rate observed by Lajoie – may apply at present. A total of bluff-supply rate at Miramar beach of 980 cubic m per year of sand may be supplied by bluff retreat at present, assuming a height of 4.5 m, and a sand content of about 45 percent (based on the terrace-deposit model developed by Laduzinsky and others, 1987 using the stratigraphy reported in approximately 70 water wells developed in the El Granada coastal terrace). The USGS evaluated coastal erosion after the 1982-83 El Nino season along San Mateo County shoreline and concluded that significant coastal erosion occurred north of Pillar Point, while areas south of Pillar Point to Pilarcitos remained almost unchanged (LaJoie and Mathieson, 1998) with the exception of Miramar Beach—a direct result of dynamics around the constructed breakwater. The absence of coastal erosion during this very stormy period is evidence to suggest that Half Moon Bay coastal dynamics may provide some buffering during El Nino years or episodic events when evaluating the variability in coastal erosion. An evaluation of historical aerial photographs between 1940 and 2007 also suggests very little change in beach widths near Pilarcitos Creek.

V. Sediment originating from terrestrial sources

Sands originating from erosion of the coastal bluffs mix with those eroded from Montara Mountain, then delivered to the Half Moon Bay cell through the several coastal streams[1]. The longshore current (directed south in this region) then provides a delivery mechanism for these terrestrial sources to reach Pilarcitos. We calculated the annual sediment yields for these watersheds using unit yields of bedload sediment transport[2] measured in Apanolio Creek in 2000, an average precipitation year (Owens and others, 2001b). Arroyo de en Medio (approximately 1.0 square miles), and Frenchmans Creek (approximately 4 square miles) yield mean annual sediment totaling 425 cu m per year (see Table 1). During years following wildland fires, landslides, or other major episodic events, sediment yields are likely to be much higher, perhaps by a factor of 10 to 20 times in these steep granitic watersheds (see Table 1).

Balance Hydrologics gaged flow and sediment at many locations within the Pilarcitos Creek watershed, with a primary focus on developing a reconnaissance coarse-sediment budget. Flow was measured and gaged during water years 1998 to 2000 (Owens and others, 2001a); bedload and suspended-sediment discharge was gaged during water year 2000 (Owens and others, 2001b).

For this lagoon enhancement project we wanted to create a flow-to-sediment-discharge rating curve for the watershed as a whole. To do this we first created flow correlations between the USGS gage at Highway 1 and the 4 locations where Balance had measured sediment discharge (Pilarcitos Creek at the Sare residence, Corrinda Los Trancos at Hwy 92, Apanolio Creek at Hwy 92, and Arroyo Leon above Miramontes Street). This allowed us to apply the sediment-discharge rating curves from each individual location based on the flow at Highway 1. In addition, we added flow and sediment contributions for Madonna Creek and Nuff Creek that were not included in Balance's sediment study (based on measured creeks with similar geology and topography). Other small tributaries and some portion of the main stem of Pilarcitos Creek have not been accounted for as sources of sediment.

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[1] Denniston Creek and Deer Creek discharge to Pillar Point Harbor; therefore, we can assume terrestrial sediment from these drainages is trapped in the harbor and does not contribute to the longshore delivery.
[2] We identify two types of sediment transports: bedload and suspended load. Here we assume suspended load (~40% of total load) is transported through the system.

Based on these individual sediment rating curves and flow correlations we synthesized a combined sediment rating curve for Pilarcitos Creek at Highway 1.[3] Because of the timing of the current Pilaritos Lagoon enhancement project is during the low-flow season, the only direct sediment measurements that we made were April 2009 bedload measurements during low flow near the creek mouth (just upstream from the horse trail crossing). These low flow bedload measurements agreed with the combined sediment rating curve. Note that most local creeks do not transport bedload at such low flow, so the fact that bedload discharge persisted into July and was both visible and measureable highlights the extreme degree of sediment loads.

Using the combined sediment rating curve we calculated sediment discharge for water years 1998, 1999, and 2000, and also the recessional periods of those water years (period after the last large storm of the water year). As mentioned earlier in this memo, we think the recession period sediment total would be the most closely linked to lagoon filling, because sediment discharge prior to- and during large storms would not be obstructed by the beach berm. These totals are shown in Table 1.

We observed substantial accumulations of coarse, angular hornblende-rich (granitic-origin) sand throughout lower Pilarcitos Creek during the late 1990s and early 2000 decade. We, and others (c.f., PWA, 2008) infer that pulses of coarse sediment originating from the 1991 basin-breach event or from other events affecting the north-side streams were modulated and gradually flushed from lower Pilarcitos during the past 10 to 15 years. These observations are consistent with the aggradation and rapid fluctuations of bed elevation recorded at the USGS gage during this period. They help us approximate the time frame over which future pulses of sediment entering Pilarcitos Creek may also be attenuated and gradually delivered to the lagoon, a set of processes observed in many other coastal stream systems.

VI. First estimates for Longshore Sediment Transport

In the absence of dredging records at Pillar Point Harbor or other local studies, we used an empirical approach adopted from the USACE to calculate a rough value of longshore sediment transport between Pillar Point and Pilarcitos Creek. The approach is based on the Coastal Engineering Manual (USACE, 2002) using local variables measured from the Half Moon Bay Buoy (NOAA, Station ID 46012), wave approach geometry (using aerial photos), measured beach angles, and the mean sediment diameter along the swash component of the beach. We would emphasize that this calculation is an introductory exercise to evaluate the magnitude of sediment relative to terrestrial sources. We believe that the calculated value, shown in Table 1, is an overestimate based on the following observations or evidence: a) the complex dynamics of the Pillar Point breakwater—a constructed feature which interrupts the longshore current; b) uncertainty in rate or volume of sediment entering Half Moon Bay from north of Pillar Point; c) absence of measurable bluff retreat within Half Moon Bay during El Nino events (USGS, 1998); and, d) no significant change in beach widths between the period 1940 and 2007. Based on these points and our

[3] We note in passing that it might not have been feasible to obtain a representative set of sediment-transport measurements for Pilarcitos Creek at Highway 1, as the stream was visibly still flushing the pulse of coarse sediment which entered the stream with the landfill pond breach during 1991. Other anthropogenic events which may have affected the increased sediment yields during this period include the incision of Corrinda los Trancos (arrested by a restoration project emplaced subsequent to 1998 and diminution of the effects of the late 1980s road-construction and drilling program in the upper Apanolio drainage (marked reductions in bed sedimentation observed between 2000 and 2004).

observations along the shore over the last decade, it would be reasonable to assume that longshore sediment transport is nearly equal to terrestrial sources.

VII. Comparison and discussion

Beach sands in other settings along the central California coast appear to be subequal mixtures of fluvial and coastal-bluff erosion. Perg and others (2003) found that the beaches of the Santa Cruz littoral cell (south of Pilarcitos) were comprised primarily of a mixture of sands delivered from local streams and from 'coastal bluffs eroding at rates of 10 cm per year. Their study is of particular interest in that it used cosmogenically-altered sands to partition the origin to bluffs and streams; the cosmogenic alteration does not affect submarine sands, which were not found in abundance. Hence, it is reasonable that in the relatively more-sheltered setting of Half Moon Bay, the two sources would be less diluted with material of neritic or longshore origin. Coarse-sediment inputs from terrestrial sources – and Pilarcitos Creek in particular – will have an important role in shaping the beach sediment supply, as well as the filling of pools, the lagoon, and other quieter-water settings.

The lagoon configuration is likely affected by a broad range of sediment delivery from either marine or terrestrial sources. Sands reaching the beach from the north can increase, sometimes abruptly, during years of magnified storms, such as the cycle of beach erosion noted during 1982-3, compounded by episodic fluvial contributions from local streams. Coarse sediment delivery from Pilarcitos Creek is expected to vary with episodic events and with anthropogenic sediment inputs. Delivery to the beach may be best seen as fluctuating at a decadal scale, recognizing that the substantial coarse-sediment storage in lower Pilarcitos Creek may elongate the rate at which this material reaches the lagoon. Management of the lagoon should recognize that the rate of coarse-sediment inputs from the creek may increase and decrease over periods of 5 to 10 years, with related filling of storage sites upstream and within the lagoon reach. Sediment delivery late in the season, which may have particularly importance for filling of pools and lagoons affecting summer habitat conditions, may be expected to be greatest at times when coarse-sediment delivery is heaviest.

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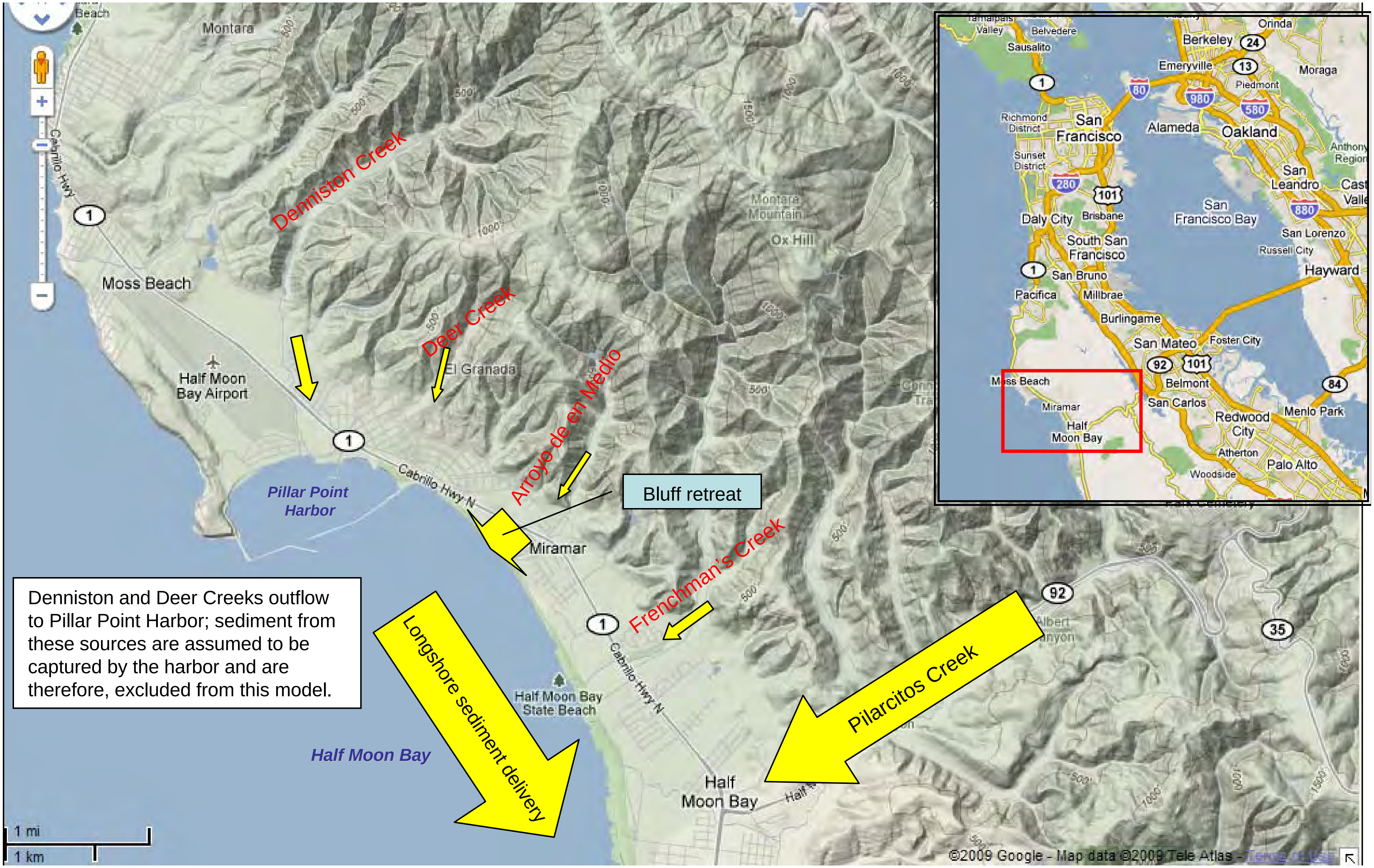
Table 1.0 Initial estimates of shore and stream sediment delivery, Pilarcitos Lagoon

Delivery from	Source	Shoreline	Drainage area [2]	Unit mean yield [3]	Seasonal yield [4]	Mean Annual yield	El Nino yield [5]	Episodic Max [6]	Remarks
		(mi)	*(sq. mi.)*	*(m3/sq mi/yr)*	*(m3/yr)*	*(m3/yr)*	*(m3/yr)*		
Coastal Erosion									
	Bluff retreat[7]	2.1	--	--	--	**983**	--	9,828	Measured from historical aerial photos
North Shore [1]									
	Denniston Creek[8]	--	1.5	84	62	**126**	591	936	Based on measured sediment yields in Apanolio Creek
	Deer Creek[8]	--	0.91	84	38	**76**	358	568	Based on measured sediment yields in Apanolio Creek
	Arroyo de en Medio	--	1.01	84	42	**85**	398	630	Based on measured sediment yields in Apanolio Creek
	Frenchmans Creek	--	4.05	84	169	**340**	1,595	2,528	Based on measured sediment yields in Apanolio Creek
	Wind (aeolian)	0.5	--	--		Important on a smaller spatial scale			Important along 0.5 mi of creek along bluff
		sum:			*211*	***425***	*1,992*	*3,158*	Sum of North Shore excludes Denniston and Deer Creeks
Pilarcitos Creek									
	Pilarcitos Creek[9]		29	28	826	**4,875**	3,011	12,390	Owens and others, 2001
Potential Longshore Sediment Transport [10]									
	USACE: Coastal Engineering Manual: Sediment Processes and Geology				66,079	**132,157**	--	--	USACE, 2002

Notes

1. Excludes bluff retreat from north of Pillar Point Harbor
2. Area contributing coarse sediment load only; excludes areas upstream of major impounding facilities such as Denniston Dam and Stone Dam
3. Unit mean sediment yield is based on direct measurements in WY2000 for Apanolio Creek a 1.99 sq. mi watershed in similar geology (Owens and others, 2001); annual unit mean
4. Seasonal sediment yields are based on direct measurements in WY2000 for Apanolio Creek--an average year; and equivalent to the seasonal recession (February through September); assumes earlier storms fill and scour
5. El Nino yields based on measured sediment rates in WY1998 for Apanolio Creek (Owens and others, 2001);and equivalent to the seasonal recession (February through September); assumes earlier storms fill and scour
6. Assumes maximum annual delivery following a fire, landslide or other major event of 15x (streams), 10x (bluff retreat) and 2x (wind) the average coarse-sediment yield
7. Based on an analysis of average annual bluff retreat at Miramar Beach 1991-2007; compared with K. LaJoie (USGS, 1971)
8. Denniston and Deer Creeks drain to Pillar Point Harbor; assume terrestrial sediment from these watersheds are trapped in the harbor. Denniston Dam also provides sediment storage.
9. Includes approximately 29 square miles downstream of Stone Dam on Pilarcitos Creek
10. The values calculated for this component are emperical and purely theoretical; observations of unchanged beach width over the years and minor coastal retreat during El Nino years may suggest this value is much lower.
11. Values presented in this table may not be accurate to more than 1 or 2 significant figures; any additional figures presented are purely result of calculation



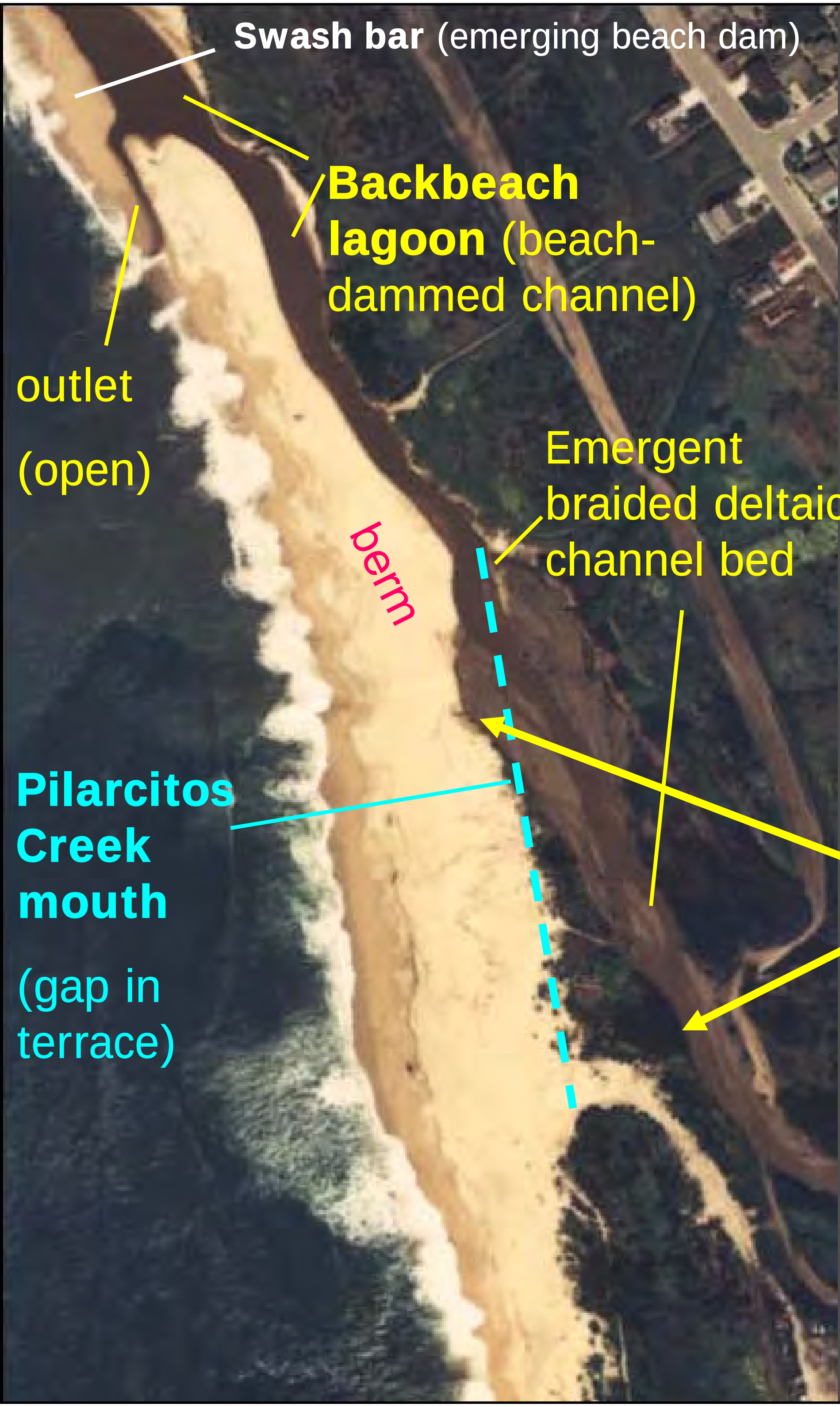
Balance Hydrologics, Inc.

Figure 1. **Conceptual Model of Mean Annual, Coarse Sediment Delivery, Half Moon Bay, San Mateo County, California.** Longshore sediment Delivery is assumed to be nearly equal to terrestrial inputs, based on recent literature, And a decade of observations along the coast.

209013 Initial Estimates of shore and sediment delivery.ppt

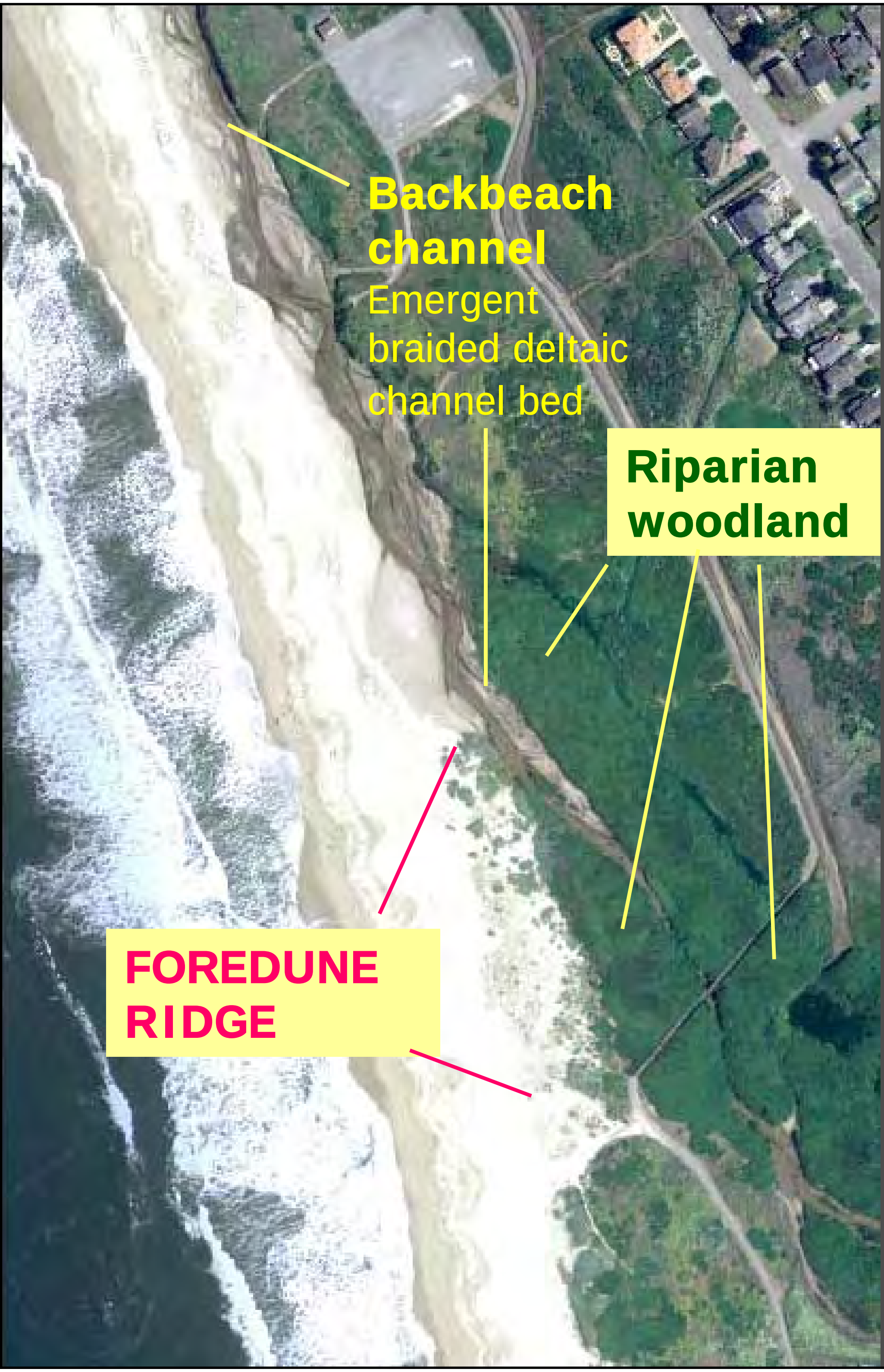
Appendix B

Evolution of Pilarcitos Creek mouth, 1986-2006



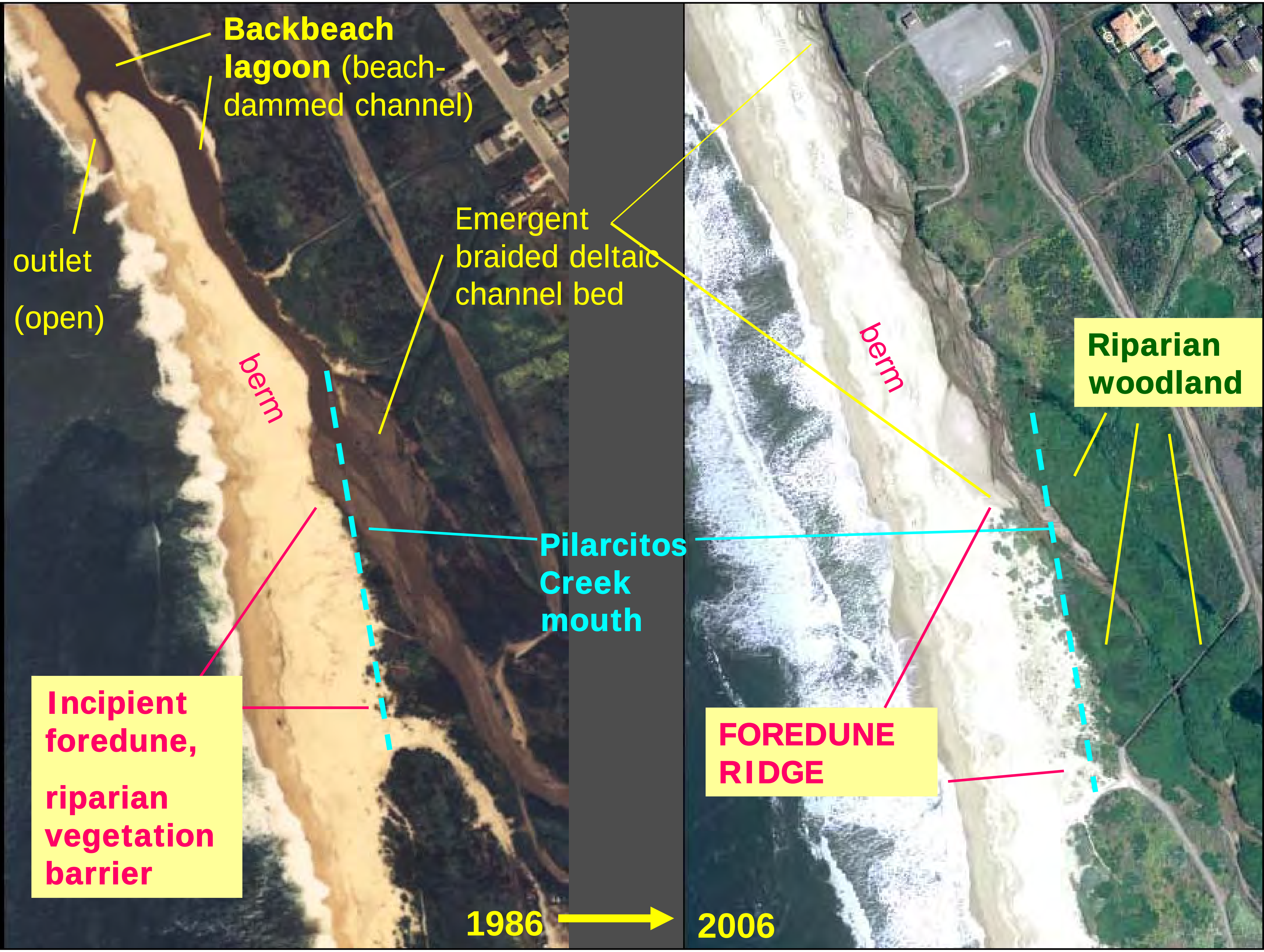
PILARCITOS CREEK MOUTH – lagoon phase, 1986

- All lagoon formation in backbeach zone (backshore runnel morphology)
- Deltaic channel bed at mouth aggraded above tidal range; no basin, no brackish mixing
- No lagoon formation within or above mouth, or in floodplain backwaters
- **Mouth shielded, channel "steered" northwest by incipient, expanding riparian vegetation and foredune barrier complex – continued growth through 2009**



PILARCITOS CREEK MOUTH – 2006

- Deltaic channel bed prograded northwest
- No lagoon formation within or above mouth, or in floodplain backwaters
- Mouth filled with riparian woodland and freshwater marsh, aggraded watershed sediment (sand, silt)
- Foredune ridge and fringing riparian woodland form barrier across mouth – relatively stable deflect channel NW
- **Extensive shore-parallel channel = beach seepage surface area**



Backbeach lagoon (beach-dammed channel)
outlet
(open)
berm
Emergent braided deltaic channel bed
Pilarcitos Creek mouth
Incipient foredune,
riparian vegetation barrier
1986
2006
berm
Riparian woodland
FOREDUNE RIDGE

Appendix B

Results of Vascular Plant Surveys at the Pilarcitos Creek Mouth

Appendix B
Riparian, Beach and Dune Vegetation of Pilarcitos Creek Mouth, Halfmoon Bay, San Mateo County

Introduction

The vegetation at Pilarcitos Creek mouth consists of two main formations related to sedimentary depositional environments and hydrology: the **beach-foredune vegetation** (strand vegetation) of wind-deposited and wave-deposited well-drained sand (groundwater estimated at more than 2 m depth below ground surface), and **riparian vegetation** (streambed, stream-side and floodplain vegetation: channel bed, bank, and overbank deposits composed of fluvial silts and sands with perennial saturation or inundation less than 1 m depth below ground surface, or submerged ground surface). The two formations intergrade at the landward edge of the foredune zone, where wind-blown sand and overwash sediment overlap. The riparian vegetation also intergrades with disturbed (former agriculture) terrestrial vegetation of the adjacent marine terrace, which would have supported coastal scrub and grassland prior to agricultural conversion.

The riparian vegetation is complex. It is composed of some assemblages that are relatively stable in composition (willow thickets with freshwater marsh understory; multiple freshwater marsh assemblages) as well as unstable, early-succession assemblages of freshwater marsh and immature willow thickets on recently deposited sediments. The riparian assemblages are distinguished by dominant species in the overstory and ground layers of the vegetation. The beach-foredune vegetation is less diverse in structure and dominant species composition, but includes some assemblages with distinctive habitat value.

Methods

The survey area covered the vegetation of the riparian floodplain complex, and adjacent beach-foredune vegetation at the mouth of Pilarcitos Creek, Half Moon Bay, San Mateo County. Wandering transects across the entire area were performed on May 18 and June 22, 2009. Releves were recorded for each stand within riparian or foredune formations that represented new dominant or subdominant species, along with the relative abundance of associated vascular plant species within the stand, physiognomy (life-form, vegetation structure) and qualitative depositional environment (landscape position, sediment type, landform). Representative stands were photographed. Vegetation units were classified based on dominant species (single-species or mixed stands) in each layer of vegetation (ground layer, shrub, subcanopy, canopy). Only riparian woodland (willow thicket) had complex, multilayered vegetation structure

The geographic scope of the surveys was limited to vegetation developed on either fluvial/floodplain sediments (alluvium; creek bed, bar, and overbank deposits of sand, silty sand, and silt), beach sand (deposited by waves) and dune sand (deposited by wind). The survey area included trails within or bordering riparian (floodplain) vegetation, and coastal bluffs (marine terrace) bordering riparian vegetation or the backbeach channel. The upstream limit of the survey area was the sewage treatment plant facility.

Results

Most of the vegetation of the mouth is dominated by closed-canopy riparian woodland dominated by arroyo willow (*Salix lasiolepis*) with a low salt spray/wind-sheared closed canopy approximately 3 to 5 m high. A small proportion of the canopy includes scattered alder (*Alnus rubra*) and shining willow (*Salix lucida*), primarily along channel banks, but these are not currently locally dominant or subdominant species. Dominant understory vegetation of the riparian woodland varies from California blackberry (*Rubus ursinus*, most abundant near bank edges and higher floodplains) to shaded freshwater sedge marsh (small-fruited sedge, *Scirpus microcarpus* water-parsley, *Oenanthe sarmentosa*, and marsh hedge-nettle, *Stachys chamissonis*), but also includes large subcanopy and ground-layer dominant stands of invasive non-native Cape ivy (*Delairea odorata*), an herbaceous perennial climbing forb.

Open freshwater marsh vegetation types lacking a woody overstory are limited to a few backwater slough and pond depressions , and the active channel banks and mid-channel bars. Freshwater marsh dominants of backwater slough and pond areas include the species of the shaded understory marsh (but at higher density), in addition to shade-intolerant emergent graminoid species including *Sparganium eurycarpum* (bur-reed), cattail (*Typha latifolia*), hardstem tule (*Scirpus acutus*). The remaining freshwater marsh dominants are associated with disturbed, recently deposited unconsodated sediment (mixed beach sand and fluvial sediments) of channel bars, banks, and braided channel beds of the distal end of the mouth, grading towards the backbeach channel bordering coastal bluffs. These include local near-monotypic stands of watercress (*Rorippa nasturtium-aquatica*), mixed stands of watercress and water parsley, and bulrush marsh narrowly distributed along backbeach channel banks at the toe of the coastal bluff (*Schoenoplectus pungens*), in monotypic stands or co-dominant with silverweed (*Argentina egedii*). Small, local stands of co-dominant western dock and silverweed (*Rumex occidentalis-Argentina egedii*) are also present in a narrow fringe at the back of the beach. The latter assemblages are the only marsh types that qualify as potentially “brackish marsh” vegetation. The only other salt-tolerant species present (not dominant) is non-native brass-buttons (*Cotula coronopifolia*) on wet flats of the emergent braided backbeach channel bed, but in close proximity with salt-intolerant species such as watercress, brooklime (Veronica americana), and willow-herb (*Epilobium ciliatum*), indicating that it does not reflect local brackish marsh gradients.

Distinctive native elements of the riparian vegetation include arroyo willow with a sparse ground layer of a native clonal stream orchid, *Epipactis gigantea*, spreading over extensive areas behind the beach. This orchid is not reported from other coastal stream mouths in central and northern California, and is not otherwise known from the Pilarcitos Creek watershed. Noxious invasive non-native species spreading in the shaded riparian understory include upright veldtgrass (*Ehrharta erecta*) and Cape ivy (*Delairea odorata*). These species threaten to displace native understory vegetation.

The majority of the seaward half of foredune vegetation consists of sparse stands of beach morning-glory flats (*Calystegia soldanella*) occupying a low foredune terrace (less than 0.5 m above wave-deposited coarse beach sediment), interspersed with sea-rocket (*Cakile maritima*) among low foredune mounds (less that 1 m high) formed by silvery beach pea (*Lathyrus* *littoralis*) and beach-bur (*Ambrosia chamissonis*). The latter mound-forming foredune species dominate the foredunes at the southern and landward portions of the foredune zone. North of the perennial foredune vegetation, which terminates at the north end of the willow riparian vegetation, *Cakile maritima* alone occurs landward of the beach crest. A very small area of stabilized backdune scrub, extending from the dunes south of Pilarcitos Creek mouth, occurs at the south end of the foredunes; it is dominated by the procumbent form of coyote-brush (*Baccharis pilularis*). The ecotone between foredune and riparian woodland is dominated by iceplant (*Carpobrotus edulis* x *chilense*) at the foredune end of the ecotone, and blackberry (*Rubus ursinus*) at the riparian end. The iceplant is being removed by State Parks. Opportunisic weeds such as sow-thistle (*Sonchus* spp.) colonize the iceplat-cleared areas, but native perennials that may be potential dominants are also colonizing the gaps, including creeping wildrye (*Leymus triticoides*).

The overall pattern of vegetation types indicates that infrequently flooded freshwater vegetation dominates the riparian wetlands of the mouth, and that no persistent areas of brackish marsh (seawater/freshwater mixing influencing plant growth) occur outside of the bluff toe/backbeach channel area. The few areas with persistent flooding during the growing season (backwater ponds and sloughs) are dominated by dense herbaceous freshwater marsh vegetation with dominant species that indicate submergence depths significantly less than 1 m during the growing season.

Discussion and conclusions

The ecological significance of the vegetation types present at Pilarcitos Creek mouth, from the perspective of ecological restoration and management, is what they reveal about recent past and current environmental conditions. Plant species vary significantly in their environmental tolerances to variables such as depth and duration of flooding, soil salinity in the root zone during the growing season, and the duration of episodes of dryness, drainage, salt spray, or pulses of marine salinity in winter (storm overwash flooding). The affinities (overall environmental associations and regional limits of environmental tolerance) of distinct vegetation types found at Pilarcitos Creek mouth are identified, and are used to reach qualitative conclusions about wetland conditions relevant to lagoon and wetland habitats relevant to salmonid habitat restoration and management.

The types of riparian and beach-foredune vegetation are listed below, based on dominant species in one or more vegetation layers. The classification is at the level of local, individual vegetation stands (patches) within a narrowly confined study area. The resolution of vegetation patches is thus at a finer scale than that used for statewide classifications (Sawyer, Keeler-Wolf and Evans, 2008), but is consistent with the broader classification used for the state as a whole. The regional environmental affinities of distinct vegetation types are provided, based on background observations of coastal lagoons and stream mouths from Mendocino County to Monterey County southern North Coast, northern Central Coast).

The following major interpretations about the vegetation of Pilarcitos Creek mouth are based on comprehensive inventory of vegetation present, and are directly relevant to evaluation of the status of lagoon, estuarine, or related fish habitats.

- **Halophyte-dominated vegetation stands are absent through most of Pilarcitos Creek mouth**. No extensive stands of halophyte-dominated vegetation (salt-tolerant species characteristic of brackish marsh or salt marsh with chronically or periodically elevated soil salinity during the growing season) are present in the vicinity of the mouth. Very small and narrow stands of perennial brackish-tolerant vegetation, typical of fresh-brackish seasonal salinity fluctuations (0 to 18 ppt range), such as threesquare (*Schoenoplectus pungens*) and silverweed (*Argentina egedii*) are present locally in narrow marsh fringes between the bluff toe and the backbeach channel at the extreme north end of the mouth, where the channel is deflected northward against the bluffs. This supports the hypothesis estuarine circulation (mixing of marine and fluvial discharge) is negligible and marginal to the mouth.

- **Submerged aquatic vegetation** (pondweeds) **is absent**. The characteristic vegetation of submerged fresh to brackish coastal lagoon beds in the region, submerged aquatic vegetation (chiefly pondweeds *Potamogeton pusillus*, *Stuckenia pectinatus*; sometimes *Ruppia maritima* in brackish to haline lagoons), is entirely absent at Pilarcitos Creek mouth. This supports the hypothesis that shallow to deep standing water or bed stability (or both) are insufficient to support aquatic lagoon habitat for pondweeds. Channel beds or pools scoured during winter flows, and permanently flooded backwater ponds, typically provide pondweed habitats in the lagoons of the region.

- **Freshwater-dependent, salt-intolerant emergent marsh vegetation and riparian vegetation dominate the wetlands of the mouth.** Woody and herbaceous freshwater plants with negligible tolerance to soil salinity not only dominate the riparian vegetation at the mouth, they exhibit high vigor and a lack of typical symptoms of salinity stress (foliar necrosis at the leaf tip, pale or discolored leaves, inhibited growth, prematurely senescent older leaves). This supports the hypothesis that groundwater and stream flows influencing riparian wetland vegetation are consistently nonsaline or at least oligohaline (less than 1 to 2 ppt) throughout the growing season. Only salt spray impacts, evident as defoliation and wind-flagging of the upper willow canopy, were evident in the vegetation.

The dominance of salt-intolerant riparian woodland and freshwater marsh species in most of the creek mouth wetland areas indicates a long-term prevalence of freshwater hydrologic regimes and net deposition of fine sediment. Much of the riparian woodland has developed over formerly wide, braided channel beds and bars colonized by hardstem tule, which was still common near the pedestrian bridge in the 1990s (P. Baye, pers. observ.). The rapid succession, spread, and maturation of salt-intolerant riparian vegetation directly behind the foredune, and the extreme scarcity of marsh types that are marginally tolerant of brackish soil, indicates that long-term environmental trends have not included brackish estuarine wetland conditions in the mouth. This is consistent with the observed absence of any submerged aquatic vegetation typical of coastal lagoons along the central coast.

There is no evidence that even vestigial or marginal coastal lagoon vegetation exists at the modern Pilarcitos Creek mouth. No species tolerant or typical of long periods of deep seasonal submergence in brackish to fresh lagoon conditions, including *Potamogeton pusillus, Stuckenia* *pectinata,Zannichellia palustris,* and *Ruppia maritima*, or species typical of emerngent brackish or fresh-brackish marsh bordering lagoons, such as *Ludwigia peploides, Hydrocotyle* spp., or *Juncus lescurii*, were detected.

Table 1. Vegetation, formations and assemblages, Pilarcitos Creek Mouth

1.0 Formation: Beach and foredune and beach (strand)

1.1. Landform and landscape position: Foredune (Map symbol: FD)

Depositional environment: wind-blown sand accretion, deflation; relatively thin annual deposits, thinnest in prostrate *Calystegia soldanella* stands.

Calystegia soldanella (monotypic, low-density stands)
Calystegia soldanella-Cakile maritima
Calystegia soldanella- Lathyrus littoralis
Calystegia soldanella-Ambrosia chamissonis

1.2. Landform and landscape position: Washover and beach (Map symbol: W-B)

*Cakile maritima (*sparse patches*)*

1.3. Landform and landscape position: Backdune/riparian ecotone (Map symbol: B/R-E)

Carpobrotus edulis x *chilensis*
Rubus ursinus-Baccharis pilularis
Artemisia douglasiana

2.0 Formation: Riparian vegetation (floodplain and channel vegetation)

2.1. Riparian woodland and scrub assemblages (Map symbol: RW)

Rubus ursinus
Rubus ursinus-Scirpus microcarpus
Salix lasiolepis-Rubus ursinus
Salix lasiolepis-Scirpus microcarpus
Salix lasiolepis- Epipactis gigantea
Salix lasiolepis-Stachys chamissonis
Salix lasiolepis-Delairea odorata

2.2. Freshwater emergent marsh assemblages (Map symbol: FM)

Scirpus microcarpus-Oenanthe sarmentosa

Oenanthe sarmentosa-Rorippa nasturtium-aquatica
Rorippa nasturtium-aquatica-Schoenoplectus pungens
Argentina egedii-Schoenoplectus pungens
Argentina egedii-Rumex occidentalis
Sparganium eurycarpum-Scirpus microcarpus
Scirpus microcarpus-Raphanus sativa
Schoenoplectus acutus

3.0 Backbeach channel (Map symbol: BC. Braided bed of backbeach channel of mouth; wet emergent sand flats during the growing season; undifferentiated pioneer sere of freshwater marsh or riparian woodland). No dominant species based on cover; very low absolute cover. Frequent species:

Agrostis stolonifera
Epilobium ciliatum watsonii
Gnaphalium spp.
Juncus bufonius
Rorippa nasturtium-aquatica (juvenile and seedling)
Rumex conglomerata
Salix lasiolepis (juvenile and seedling)

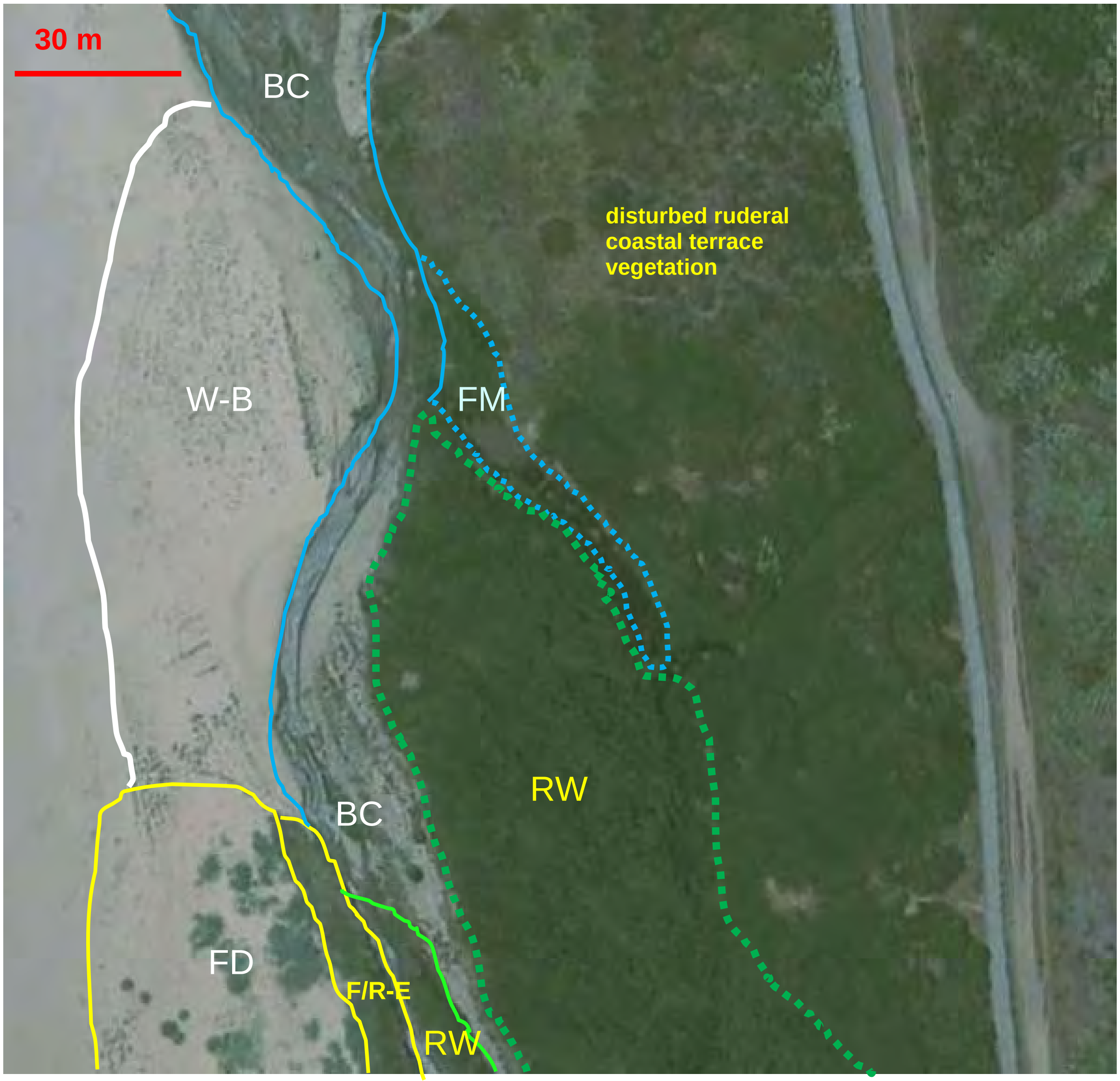


Figure B-1. Northern section, delineation of major vegetation units of Pilarcitos Creek mouth. Baseline aerial photo: Google Earth, June 2007. Bar scale: approximately 30 m.

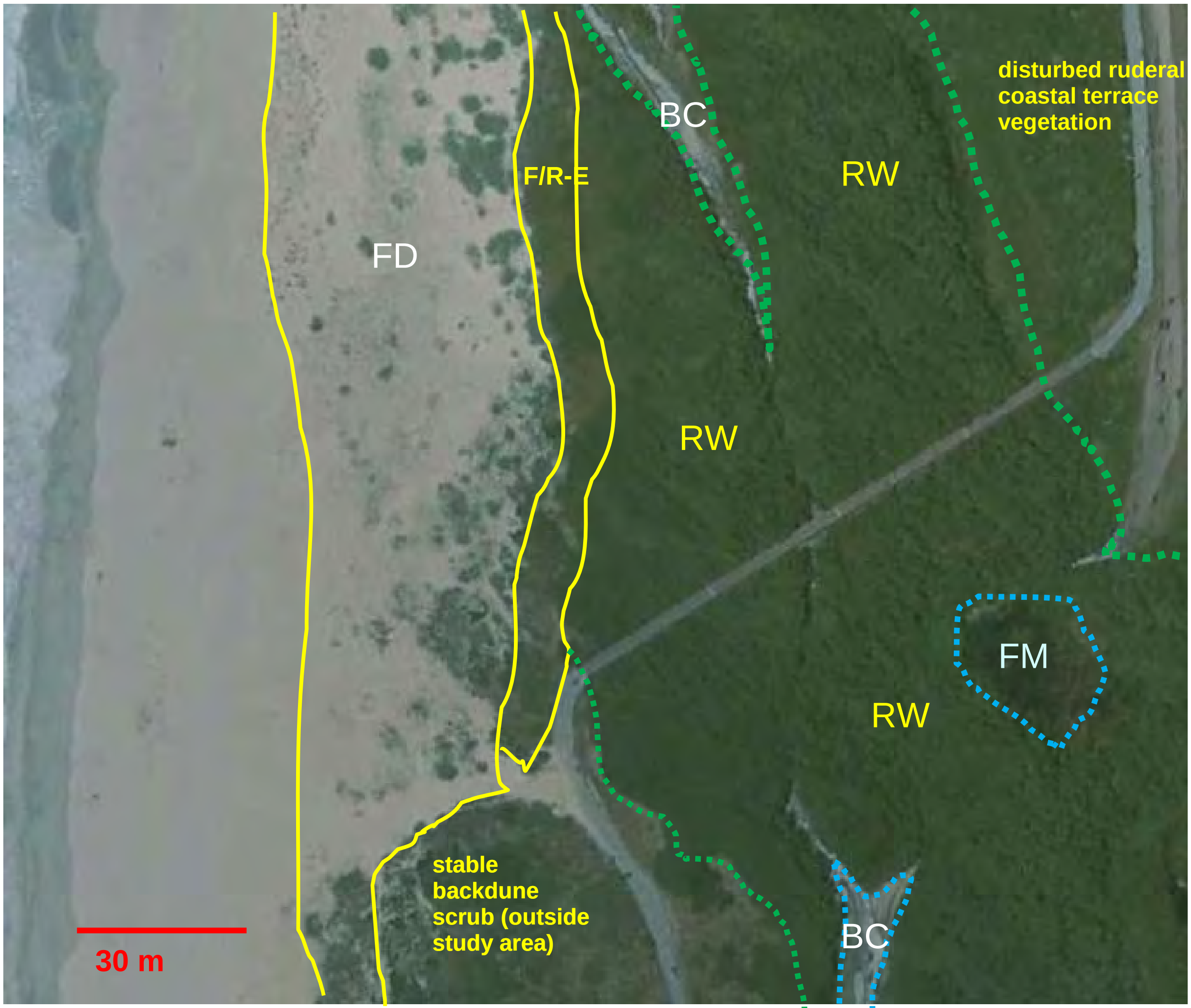


Figure B-2. Southern section, delineation of major vegetation units of Pilarcitos Creek mouth. Baseline aerial photo: Google Earth, June 2007. Bar scale: approximately 30 m.

Vascular Plant Species at
Pilarcitos Creek Mouth, Halfmoon Bay, San Mateo County
Riparian, Beach and Dune Vegetation

The vegetation of the riparian wetland complex and adjacent foredune and beach at the mouth of Pilarcitos Creek, Half Moon Bay, San Mateo County, was surveyed on May 18 and June 22, 2009.

The geographic scope of the surveys was limited to vegetated developed either on fluvial and floodplain sediments (alluvium; creek bed, bar, and overbank deposits of sand, silty sand, and silt) beach sand (deposited by waves) and dune sand (deposited by wind), trails within or bordering riparian (floodplain) vegetation, and coastal bluffs (marine terrace) bordering riparian vegetation or the backbeach channel. The upstream limit of the survey area was the sewage treatment plant facility.

The vegetation surveyed included riparian scrub and woodland of the floodplain and channel bars (willow-blackberry, willow, and willow-alder stands), freshwater marsh (sedge, bur-reed, cattail, and tule stands of creek banks and off-channel backwater depressions), and beach/foredune (strand vegetation of beach and dune sands landward of the high tide line).

Nomenclature and taxonomy follow Flora of North America (http://www.efloras.org/flora_page.aspx?flora_id=1) for taxa covered by FNA in 2009; other taxa not covered in FNP follow Jepson Manual revisions published in the Jepson Interchange (http://ucjeps.berkeley.edu/interchange.html), or the USDA Plants Database (http://plants.usda.gov/).

EQUISETACEAE Horsetail Family

1. Equisetum telmateia ssp. *braunii* Giant horsetail

Locally common in colonies in freshwater marsh and emergent channel bars of the backbeach channel and creek banks; occasionally persisting in shade of willow thickets.

2. Equisetum arvense common horsetail

Infrequent in small colonies in freshwater marsh edges and emergent channel bars of the creek and backbeach channel.

CUPRESSACEAE Cypress Family

3. †*Callitropsis macrocarpa* (syn. *Cupressus macrocarpa)* Monterey cypress
Infrequent; spreading from plantings of cultivated trees in upland edges of riparian woodland.

CYPERACEAE Sedge Family

4. Cyperus eragrostis nutsedge

Infrequent in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh

5. Bolboschoenus maritimus Alkali-bulrush, salt marsh bulrush

A single clonal colony near the mouth of the backwater slough at the channel mouth/beach edge

6. Isolepis cernuus Dwarf clubrush

Infrequent in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

7. Schoenoplectus acutus Hardstem tule

Locally abundant but infrequent, occurring in small dense stands in backwater slough freshwater marsh (backbeach channel and floodplain).

8. Schoenoplectus pungens Common threesquare

Locally abundant clonal stands, monotypic or co-dominant with *Argentina egedii* in fringing marsh along banks of backbeach channel, deltaic deposits between channel and bluff or floodplain.

LEMNACEAE Duckweed Family

9. Lemna gibba Duckweed

Infrequent and variable in seasonal abundance, in channel and shallow ponded water in backwater slough.

JUNCACEAE Rush Family

10. Juncus bufonius Toad rush

Common but not abundant in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh

11. Juncus effusus Soft Rush

Infrequent in freshwater marsh bordering unshaded or partly shaded channel banks

12. Juncus xiphioides Iris-leaf rush

Isolated individual patches in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

ORCHIDACEAE Orchid Family

13. Epipactis gigantea Stream orchid, giant helleborine

Frequent locally in shaded floodplain understory of willow, in young, thick silt deposits landward of foredunes. Associated with sparse cover of *Oenanthe sarmentosa*, *Scirpus microcarpus*. Uncommon in San Mateo County (no records in Consortium of California Herbaria; reported as “Infrequentin moist places among rocks” historically from Pescadero Creek by Thomas (1961). Noteworthy occurrence.

POACEAE Grass Family

14. †*Agrostis stolonifera* Creeping bentgrass

Infrequentspreading clonal patches in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

15. †*Agrostis semiverticillata* Water bentgrass

Infrequentpatches in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

16. Distichlis spicata Saltgrass

Infrequent, sparse clonal patches, backdune/riparian ecotone.

17. †*Ehrharta erecta* Panic veldtgrass

Locally abundant and spreading, in shaded understory of willow. Noxious invasive species, capable of dominating riparian woodland ground layer.

18. Glyceria pauciflora Mannagrass

Infrequent, shallow ponded water in backwater slough. (Identification of species tentative; browsed vegetative plants).

19. †*Lolium* x *multiflorum* Italian ryegrass

Infrequent in disturbed upland ecotone of riparian woodland and coastal bluffs.

20. †*Polypogon monspeliensis* Rabbit’s-foot grass

Infrequent patches in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

21. Leymus triticoides Creeping wildrye

Infrequent clonal patches in stabilized ecotone between riparian scrub and foredune.

22. †*Vulpia bromoides* Brome fescue

Locally common in stabilized ecotone between riparian scrub and foredune.

SPARGANIACEAE Bur-reed family

23. Sparganium eurycarpum Bur-reed

Locally abundant to dominant in freshwater marsh of backwater slough and pond; Infrequentin channel bank marsh. Associated with tule, cattail.

TYPHACEAE Cattail Family

24. Typha latifolia Broadleaf cattail

Locally dominant in portions of backwater marsh areas in the floodplain landward of the mouth; also present sporadically in young, disturbed freshwater marsh vegetation in emergent muddy sand point bars and mid-channel bars at the mouth and riparian banks. Possibly including *Typha* x *glauca* intermediates.

AIZOACEAE Carpetweed Family

25. †*Carpobrotus edulis* x *chilensis* Iceplant

Locally dominant to abundant in ecotone betweed stabilized foredune and seaward edge of riparian scrub. Undergoing removal/eradication by State Parks.

26. †*Tetragonia expansa* New Zealand Spinach

Infrequent in disturbed high flood deposits of backbeach channel banks

APIACEAE Carrot or Parsley Family

27. †*Conium maculatum* Poison-hemlock

Locally common in ruderal vegetation of upland edges in riparian woodland.

28. Oenanthe sarmentosa Water-parsley

Widespread and abundant to dominant in freshwater marsh and riparian woodland ground layer.

ASTERACEAE Aster Family

29. Ambrosia chamissonis Beach-bur

Locally common or abundant in foredunes, but not dominant.

30. †*Anthemis cotula* Mayweed, dog-fennel

Infrequent in disturbed upland edges of riparian woodland.

31. Artemisia douglasiana California mugwort

Infrequent but locally abundant clonal patches in high marsh banks bordering foredune and riparian woodland.

32. Baccharis pilularis Coyote-brush

Locally common to abundant in landward stabilized zone of foredune and ecotone with riparian scrub.

33. †*Cirsium vulgare* Bull thistle

Infrequent in disturbed upland edges of riparian woodland and channel deposits bordering coastal bluff.

34. †*Carduus pycnocephala* Italian thistle

Infrequent but locally abundant, disturbed upland edges of riparian woodland and channel deposits bordering coastal bluff.

35. †*Conyza canadensis* Horseweed

Infrequent, disturbed upland edges of riparian woodland and channel deposits bordering coastal bluff.

36. †*Cotula coronopifoli*a Brass-buttons

Common small patches in disturbed wet sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

37. †*Delairea odorata* Cape ivy, German Ivy

Widespread, abundant to dominant vegetative stands in shaded ground layer and through canopy of willow woodland; noxious invasive riparian weed, spreading. Flowering in canopy gaps or canopy surface where it intercepts direct sunlight.

38. Eriophyllum staechadifolium Lizard-tail

Infrequent and local in ecotone between foredune and riparian woodland or freshwater marsh banks.

39. †*Filago gallica* Narrow-leaf filago

Common small patches in disturbed moist sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

40. Gnaphalium stramineum Cudweed

Common small patches in disturbed moist sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

41. Gnaphalium palustre Lowland cudweed

Common small patches in disturbed sediment of backbeach delta and channel bar deposits, early succession stages of freshwater marsh.

42. Madia sativa Coast tarweed

Infrequent in disturbed upland edges of riparian woodland and coastal bluffs bordering coastal bluff.

43. †*Picris echioides* Bristly ox-tongue

Infrequent, disturbed upland edges of riparian woodland and coastal bluffs.

44. †*Senecio elegans* Purple ragweed

Infrequent in stabilized landward edge of foredune scrub.

45. †*Silybum marianum* Milk thistle

Infrequent in disturbed upland edges of riparian woodland .

46. Symphyotrichum chilense Common aster

Infrequent clonal colonies in ecotone between foredune and riparian woodland or coastal terrace.

47. †*Sonchus oleraceus* Sow-thistle

Infrequent in disturbed upland edges of riparian woodland and channel deposits; locally abundant in areas of icepalnt removal.

48. †*Sonchus asper* Prickly sow-thistle

Infrequent in disturbed upland edges of riparian woodland and channel deposits; locally abundant in areas of icepalnt removal.

BETULACEAE Birch Family

49. Alnus rubra Alder

Infrequent but widespread in riparian woodland landward of the terminal bend at the creek mouth; tree height is limited due to wind-flagging by salt spray. No seedlings or saplings were observed in or near the backbeach channel, in contrast with willow recruitment patterns.

BORAGINACEAE Borage Family

50. Heliotropium curassavicum salt heliotrope

Uncommon in weakly consolidated sandstone bluff seeps above the backbeach channel, mostly near Frenchman's Creek mouth.

BRASSICACEAE Mustard Family

51. †*Brassica oleraceus* Wild cabbage

    Escaped from cultivation, reverted to wild type; locally common in flood-deposited sediments silt below unconsolidated bluffs above the backbeach channel.

52. †*Cakile maritima* Sea-rocket

    Infrequent to common on high beach, washover, and outer foredunes.

53. †*Corynopus didymus* Wart-cress

    Infrequent, disturbed upland edges of riparian woodland and channel deposits.

54. †*Brassica nigra* Black mustard

    Infrequent, disturbed upland edges of riparian woodland and channel deposits

55. †*Brassica rapa* Field mustard

    Infrequent, disturbed upland edges of riparian woodland and channel deposits

56. †*Raphanus sativa* Wild Radish

    Common in disturbed flood deposits within freshwater marsh, channel banks, and emergent sediment bars, except in shade

57. Rorippa plantago-aquatica Watercress

    Luxuriant, tall monotypic stands occur at edges of shallow flowing water of wide, braided channel beds in the channel reach behind the south end of the foredunes; scarce in shade.

CHENOPODIACEAE Goosefoot Family

58. †*Atriplex prostrata* Spearscale; fat-hen

    Infrequentin disturbed moist flood deposited sediment and emergent sediment bars north of the foredunes.

59. †*Dysphania ambrosioides (*syn. *Chenopodium ambrosioides)* Mexican-tea; goosefoot

    Infrequent in disturbed flood deposits and emergent sediment bars north of the foredunes.

CONVOLVULACEAE Morning-glory Family

60. Calystegia soldanella Beach morning-glory

Widespread dominant single-species sparse, prostrate stands in low foredune terrace; also associated with sparse foredune mounds of *Ambrosia chamissonis* and *Lathyrus littoralis*.
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CUCURBITACEAE Cucumber Family

61. Marah fabaceus Marah, wild cucumber

Present at ecotone between riparian woodland and coastal bluff scrub.

FABACEAE Pea or Legume Family

62. Lathyrus littoralis Silvery beach pea

Common to co-dominant at south end of foredunes across the creek mouth.

63. Lupinus arboreus Bush lupine

A few individuals occur at the landward edge of foredunes at the south end of the mouth; more common and abundant immediately south in stabilized backdunes. Yellow-flowered fragrant form only.

64. †*Melilotus indicus* Yellow sweet-clover

Infrequent in disturbed flood deposits, emergent sediment bars, and disturbed coastal bluff vegetation bordering riparian woodland.

GERANIACEAE Geranium family

65. †*Erodium cicutarium* Filaree

Infrequent to locally common in disturbed coastal bluff vegetation bordering riparian woodland.

LAMIACEAE Mint Family

66. Stachys chamissonis Marsh hedge-nettle

Common and locally abundant in ground layer of riparian woodland, Infrequentin freshwater marsh along creek banks.

67. †*Mentha pulegium* Pennyroyal

Infrequent to common in disturbed moist or wet sediment on emergent bed of backbeach channel and channel bar deposits, early succession stages of freshwater marsh.

LYTHRACEAE Loosestrife Family

68. †*Lythrum hyssopifolium* Hyssop-leaf loosestrife

Common in disturbed moist or wet sediment on emergent bed of backbeach channel and channel bar deposits, early successional stages of freshwater marsh.

MALVACEAE Mallow Family

69. †*Lavatera arborea* Tree mallow

Local, infrequent in disturbed coastal bluffs

NYCTAGINACEAE Four o'clock Family

70. Abronia latifolia yellow sand-verbena

Abundant in foredunes at south end of mouth, uncommon in barrier foredunes opposite (west) of the creek mouth.

ONAGRACEAE Evening-primrose Family

71. Camissonia cheiranthifolia ssp. *cherianthifolia* beach evening-primrose

Locally common in stabilized sand at landward end of foredune zone.

72. Epilobium ciliatum ssp. *watsonii* Willow-herb

Infrequent to locally common in edges of freshwater marsh, moist to wet sediment of channel bars and emergent bed of backbeach channel.

73. Oenothera elata ssp*. hookeri* Evening-primrose

Occasional in disturbed coastal bluffs bordering the backbeach channel, trail edges.

PLANTAGINACEAE Plantain Family

74. †*Plantago major* English plantain

Locally common in trail edges, moist sediment of channel bars, disturbed coastal bluff soils.

75. †*Plantago coronopus* Buck's-horn or rat-tail plantain

Common in moist to wet sediment of channel bars and emergent bed of backbeach channel, trail edges, moist coastal bluff slopes.

POLYGONACEAE Buckwheat Family

*76. Persicaria punctatum (*syn. *Polygonum punctatum)* Dotted smartweed

Infrequent, freshwater marsh moist to wet sediment of channel bars and emergent bed of backbeach channel.

77. †*Persicaria maculosa (*syn. *Polgonum persicaria)* Lady's thumb, spotted smartweed

Infrequent, freshwater marsh.

78. †*Polygonum aviculare* ssp. *depressum* Dooryard knotweed

Infrequent in disturbed soils of trail edges, moist sediment of emergent bed of backbeach channel.

79. Rumex crassus Coast dock

Infrequent, moist coastal bluff toe and moist sediment of channel bars and emergent bed of backbeach channel.

80. Rumex occidentalis Western dock

Local in edges of freshwater marsh banks of the backbeach channel.

81. †*Rumex conglomerates* Dock

Infrequent, moist coastal bluff toe and moist sediment of channel bars and emergent bed of backbeach channel.

PRIMULACEAE Primrose family

82. †*Anagallis arvensis* Scarlet pimpernel

Infrequent but locally common in disturbed flood deposits, emergent sediment bars, and disturbed coastal bluff vegetation, trail edges.

ROSACEAE Rose Family

83. Achillea millefolium yarrow

Infrequent colonies in ecotone between stabilized foredune and riparian scrub. upland edges of riparian woodland, coastal bluffs.

*84. Argentina egedii (*syn. *Potentilla anserina* ssp. *pacifica)* Pacific silverweed

Locally common, dominant or co-dominant with *Schoenoplectus pungens* in freshwater to fresh-brackish marsh bordering the backbeach channel.

85. Fragaria chiloensis Beach strawberry

Infrequent colonies in stabilized foredunes and coastal bluffs.

86. Rubus ursinus California blackberry

Widespread, common, occurring either in monotypic stands along channel banks and ecotone between riparian woodland and stabilized foredune, mixed stands (co-dominant with *Salix lasiolepis* or *Scirpus microcarpus*) along channel banks, or dominating the shrub layer in shaded understory of *Salix lasiolepis*.

SALICACEAE Willow Family

87. Salix lasiolepis Arroyo willow

Widespread dominant of riparian woodland of floodplain, channel banks, and much of the salt spray wind-flagged ecotone between foredune and riparian woodland. Widespread, abundant seedlings occur seasonally in moist sediment of emergent bed of backbeach channel, and persisting in channel bars deposited around rapidly growing, robust juvenile willow stands. Willows exhibit high vigor despite dieback of shoot tips and canopies due to salt spray even in the backbeach channel.

88. Salix lucida ssp. *lasiandra* Shining willow

Infrequent in channel banks and riparian woodland.

SCROPHULARIACEAE Snapdragon Family

89. Scrophularia californica California bee-plant

Infrequent in high channel banks and terrestrial edges of riparian woodland.

90. Mimulus guttatus Monkey-flower

Infrequent in freshwater marsh of channel banks and channel bars, and emergent bed of backbeach channel in early stages of freshwater marsh succession.

91. Veronica americana American speedwell

Infrequent in freshwater marsh of channel banks and channel bars, and emergent bed of backbeach channel in early stages of freshwater marsh succession.

SOLANACEAE Nightshade family

92.Solanum americanum Nightshade

Infrequent in disturbed moist sediment of channel bars.

TROPAEOLACEAE Nasturtium family

93. †*Tropaeolum majus* Garden nasturtium

Infrequent but locally abundant in shaded edges of riparian woodland along trails.

URTICACEAE Nettle Family

94. Urtica dioica ssp. *holosericea* Nettle

Infrequent to locally common in landward end of riparian woodland bordering trails and channel banks.

Floristic analysis

- Number of families: 34
- Number of species (richness) 94
- Native species richness 53
- % non-native species: 44% (41/94)
- Uncommon or noteworthy species in subregion: *Epipactis gigantea.* No rare, threatened or endangered species were expected or detected.
- Brackish tolerant species: 11 (*Argentina egedii, Atriplex prostrata, Cotula coronopifolia, Bolboschoenus maritimus*, *Distichlis spicata, Heliotropium curassavicum, Plantago coronopus, Polypogon monspeliensis, Rumex crassus, Rumex occidentalis, Schoenoplectus pungens*)
- Brackish tolerant species widespread and at least abundant: 0
- Brackish tolerant species at least locally common or locally abundant: 2 (*Argentina egedii, Schoenoplectus pungens)*
- Submerged aquatic vegetation species: 0