

Wetland Processes and Restoration Opportunities in the Rodeo Lagoon Watershed,
Golden Gate National Recreation Area, Marin County, California

by

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		Date
		Date

University of California, Berkeley

Spring 2005

Wetland Processes and Restoration Opportunities in the Rodeo Lagoon Watershed

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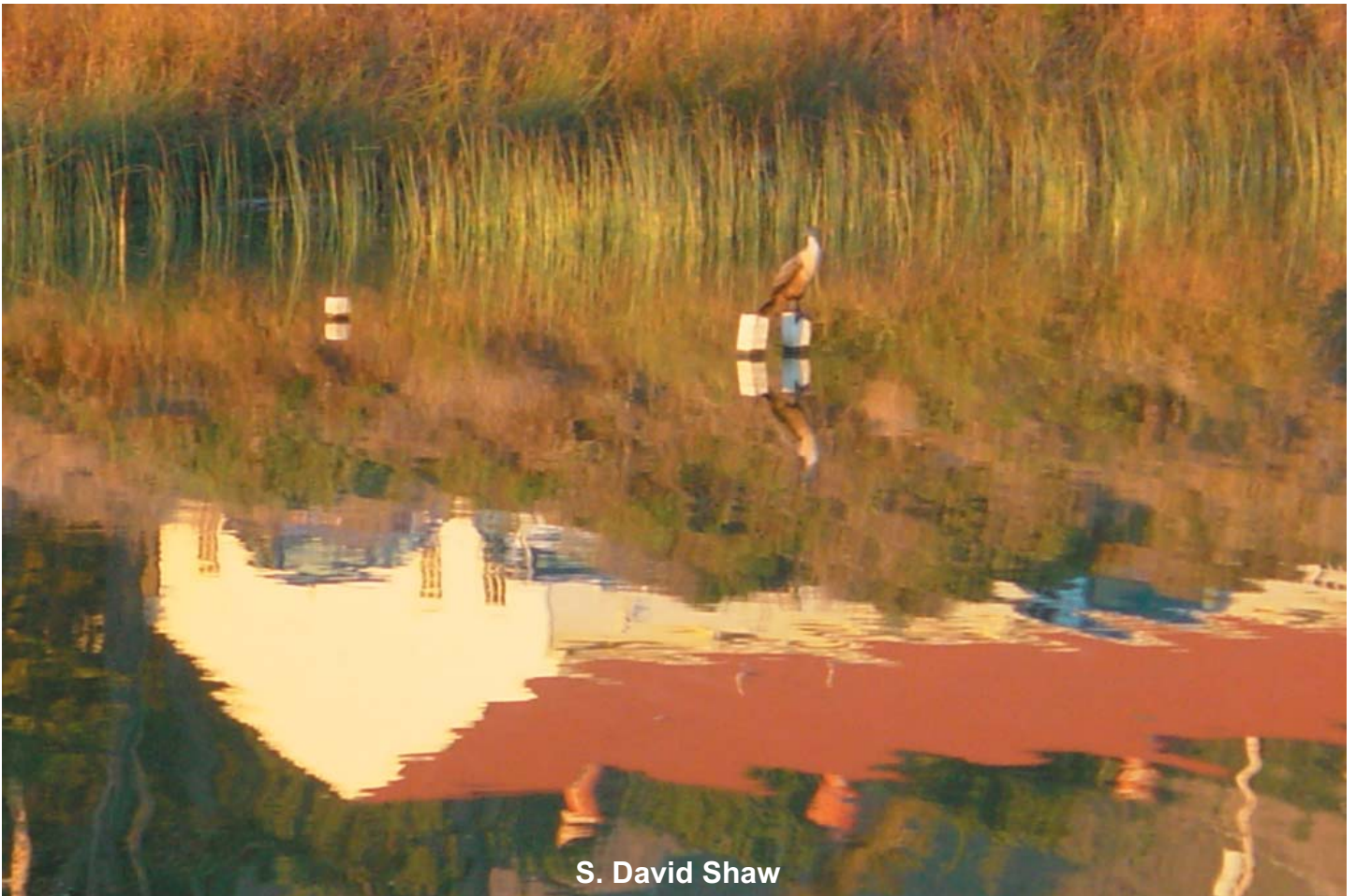
By

S. David Shaw

Wetland Processes and Opportunities for Restoration

Rodeo Lagoon Watershed

Golden Gate National Recreation Area Marin County, California



S. David Shaw

Acknowledgements

In completing the following work, I have relied on several individuals in numerous ways. Raymond Costantino, Erik Oerter, Kyla Burson, John Williams, Christine Waljewski, Jessie Levine, Kirk Klausmeyer, and Lissa MacVean chose to carry out various term projects in this watershed that have informed both my study and wetland restoration planning in general. Others simply volunteered to help me with field work on projects that I would have been unable to complete alone, including Chris Belnap, Alberto Rovira, and my parents, Jay and Carol Shaw. Barry Hecht and the staff of Balance Hydrologics kindly shared field equipment with me, accommodated my equipment and samples in their equipment room, and shared insight as I developed this study. Dan Zucker of the Marin Headlands Institute has provided me with nutritional support by sharing hot meals with me at the end of long field days.

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Wetland processes in the Rodeo Lagoon Watershed:

A landscape investigation to inform site selection and design

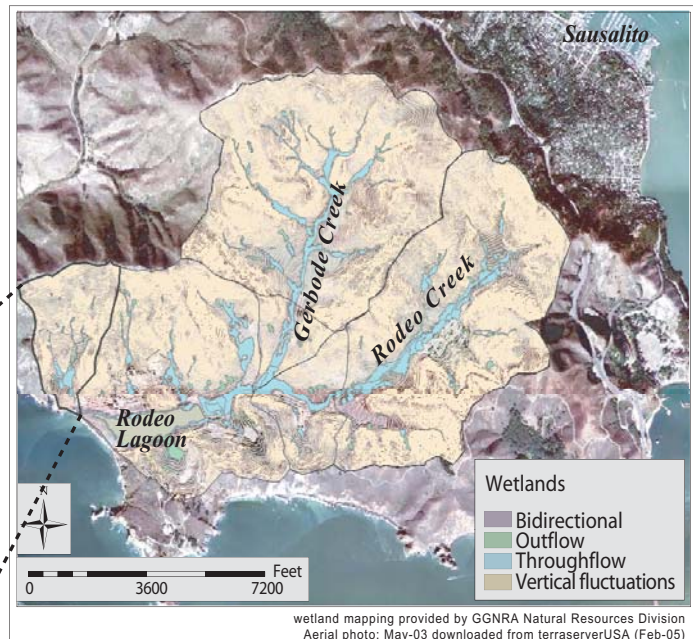
Executive Summary



Just north of San Francisco Bay's Golden Gate, the Marin Headlands are one of the most visited areas in the Golden Gate National Recreation Area.

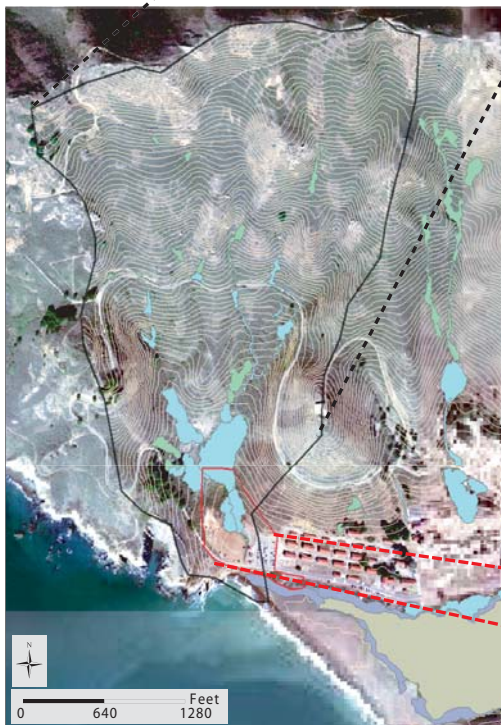
Years of cattle-grazing, road-building and military use have degraded the quality and area of wetland habitat in the watershed, so the National Park Service now seeks to enhance and restore habitat functions to former wetland areas, access to recreational open space, and access to historical resources.

Golden Gate National Recreation Area,
Marin County, California



Approach

1. Characterize hydrologic and geomorphic processes that affect wetlands throughout the watershed,
2. Identify potential restoration sites and strategies,
3. Investigate the highest priority site in detail, and
4. Design a restored wetland at the highest priority site.

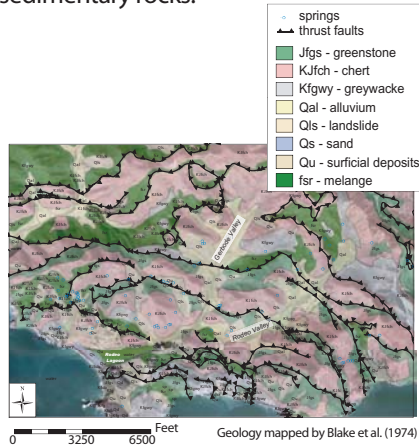


Watershed-wide processes

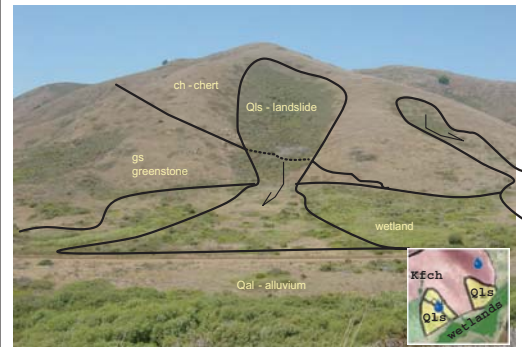
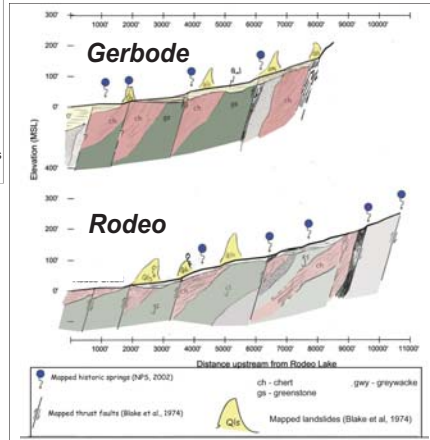
Executive Summary (cont.)

Landscape Evolution

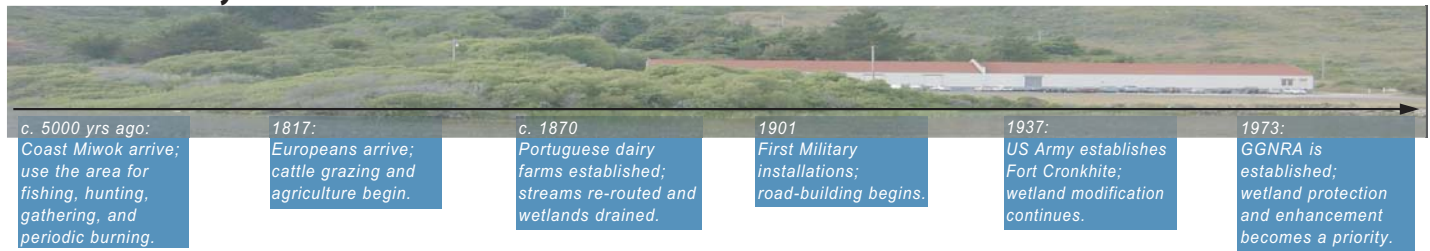
The Marin Headlands structural geology is characterized by a series of parallel thrust faults, which have sheared and displaced layers of near-shore marine sedimentary rocks.



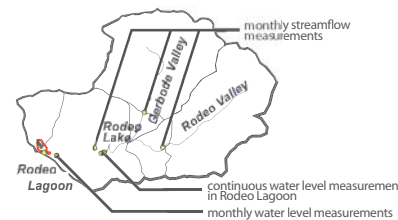
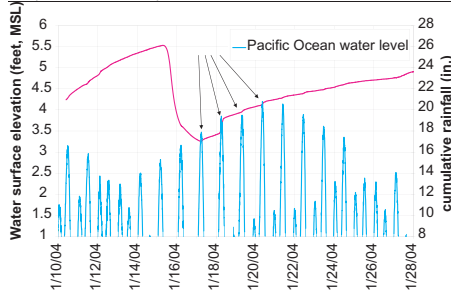
Springs, landslides, and the associated slope wetlands tend to occur along these faults, and at contacts between rock types. Slopes of the valley floors therefore resemble a stair-stepped pattern; wet meadows form where sediment and colluvium accumulates, and narrow riparian woodlands occur where valley slopes are steeper and incision occurs.



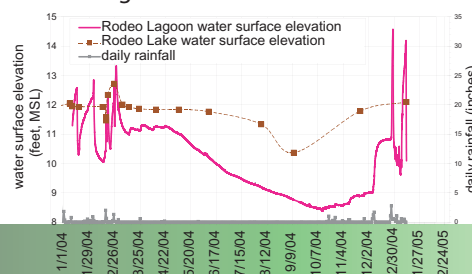
Human History



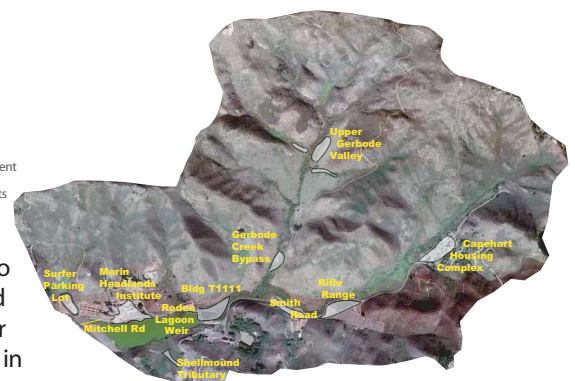
Hydrology



The hydrologic connection between Rodeo Lagoon and its watershed has been altered by a constructed bridge and weir at Bunker Road. The beach is overtopped frequently in the winter after Rodeo Lake has filled completely. The lagoon is filled by streamflow and high tides between breaching events.



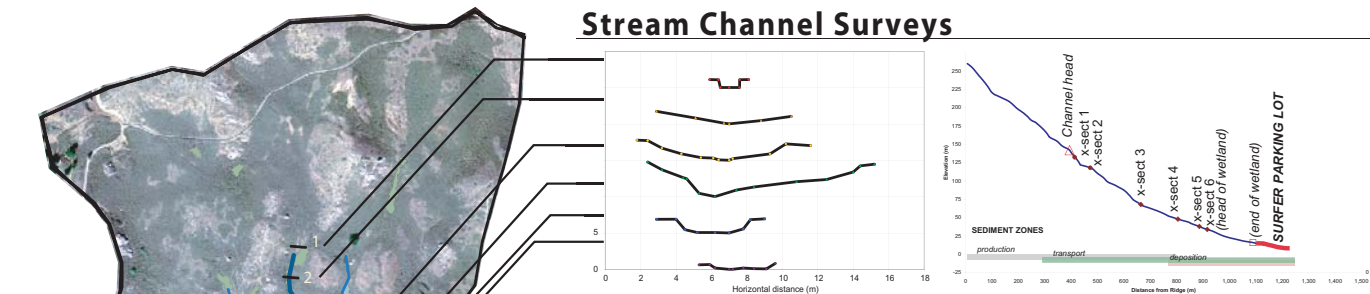
Potential Restoration Sites



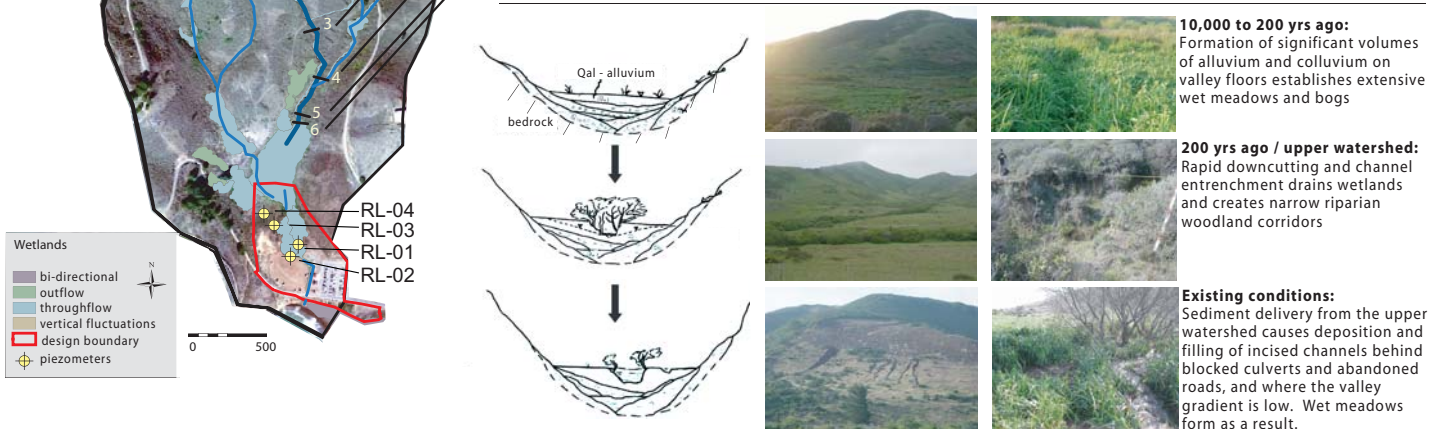
High-priority site investigation

Executive Summary (cont.)

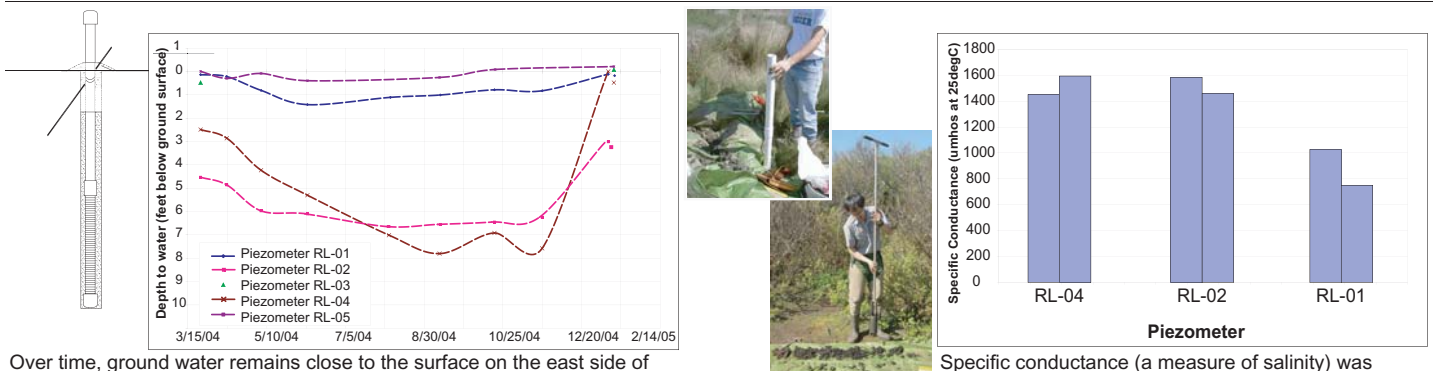
Stream Channel Surveys



Landscape and Wetland Evolution



Ground Water

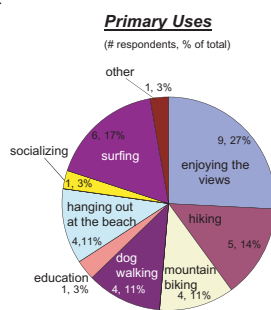


Use and Preference*

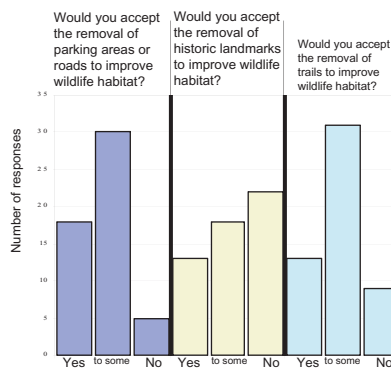
In general, people visit the Surfer Parking Lot and Rodeo Beach to enjoy the views, surf, hike, and mountain bike.

Visitors would like to see improvements to wildlife habitat, not parking.

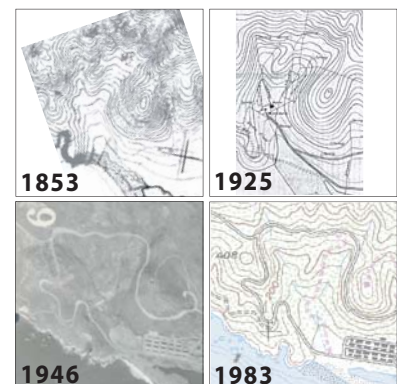
These improvements, however, should not take place at the expense of historic resources.



*based on Shaw (2004)

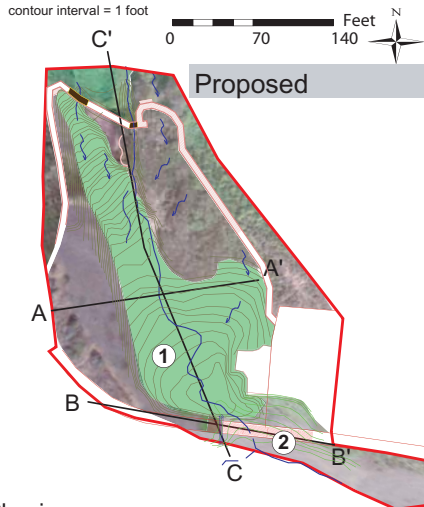
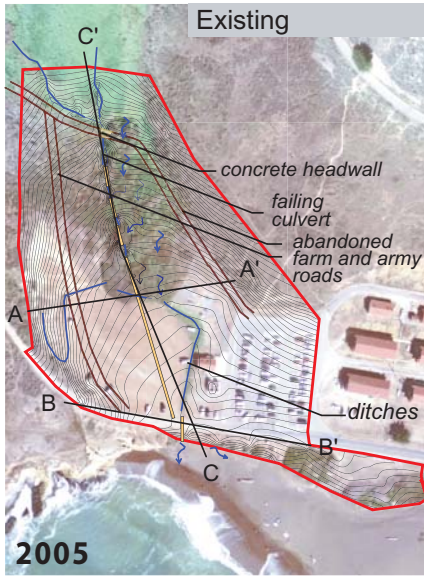


Site History



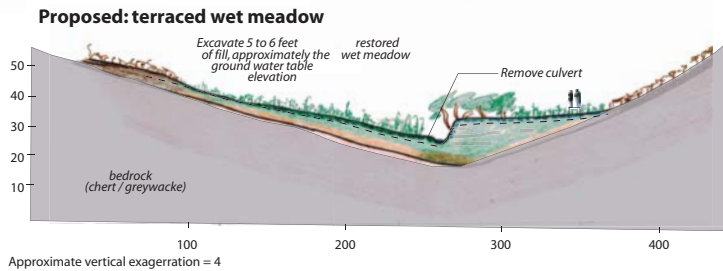
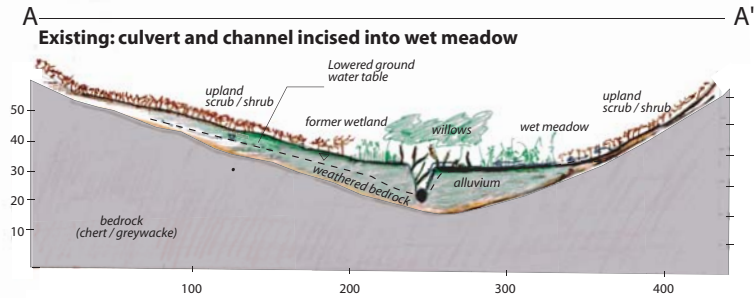
Wetland restoration design

Executive Summary (cont.)



Phasing:

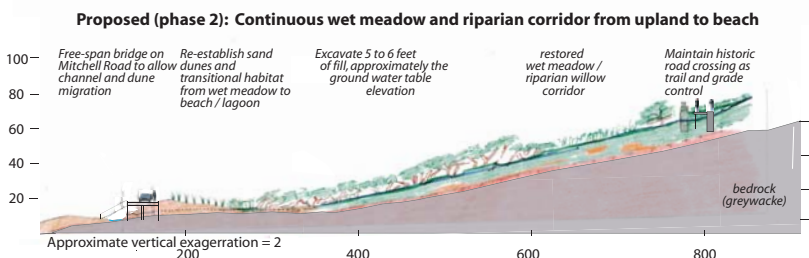
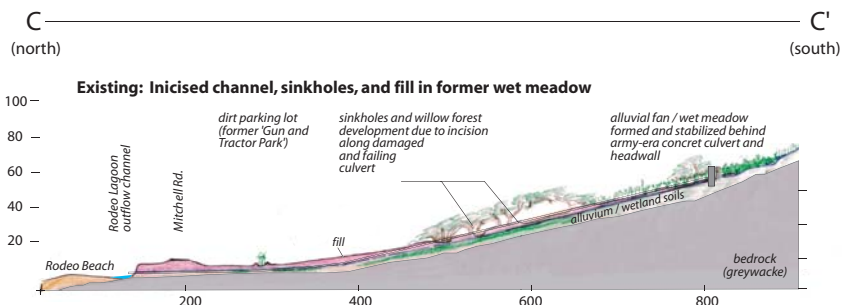
- ① - Re-occupy abandoned roads with interpretive history and habitat trail
 - Re-establish crossing of West Fork under abandoned road
 - Remove culvert
 - Excavate 4 to 5 feet on west side of valley
 - Remove fill from dirt parking area and excavate to the current existing water table
- ② - Replace culvert outfall on beach with free-span bridge
 - construct transitional dune zone between Rodeo Lagoon, Rodeo Beach, and freshwater wetland



Existing: double culvert in fill channels water underneath former wetland area, out of sight



Proposed: remove fill, construct bridge, restore wetland-dune-lagoon transition



1. Introduction and Overview

Rodeo Lagoon and its barrier beach are surrounded by rolling hills that give way to the dramatic steep cliffs and crashing surf of the Marin Headlands, just north of San Francisco Bay's Golden Gate. After several military installations were decommissioned in the 1960s and 70s, a group of citizens helped convince the federal government to permanently set this and the surrounding areas aside as the Golden Gate National Recreation Area (GGNRA), thereby protecting it from the sprawling development that consumes much of the region today. As a result of this and other similar actions, western Marin County now contains approximately 125,000 acres of contiguous public open space, and is one the largest urban open space preserves in the country.

Millions of people visit the parks each year for a variety of recreational purposes, with the Marin Headlands and Rodeo Beach as one of the most popular destinations (Nelson and Nygaard, 2002). In addition to taking in romantic vistas of San Francisco and the Golden Gate Bridge, they explore the natural environment and remnants of former military installations, agricultural tracts, and dairy farms. The National Park Service (NPS) is now the land-management agency, its primary responsibility being the protection of natural resources through maintenance, restoration, and enhancement, including remediation of damage to those resources from past activities. The Park Service is also responsible for maintaining the human component of this landscape through providing access to recreational, educational, and historical resources.

1.1 Purpose of this study

Various planning and infrastructure development activities are taking place in the Rodeo Watershed. The GGNRA Transportation Division has recently completed a regional transportation planning study, including re-design alternatives of portions of the Marin Headlands, while the Marin Headlands Institute, a non-profit environmental education center with facilities at Fort Cronkhite, is considering renovation alternatives of its facilities, located at Fort Cronkhite. National Park Management Transportation Policies (2001) explicitly state that park roads, infrastructure and uses "should be sensitive to natural and cultural resources..., with minimal or no impacts on natural resources," so it is necessary to identify where such resources are located and how they function, so that park planning can avoid impacts. This study focuses on wetland resources in particular, and evaluates the functions and processes that support wetlands in the Rodeo Watershed.

Historical activities in the Rodeo Watershed have altered stream and wetland functions in a variety of ways and locations. Water quality studies have consistently shown that Rodeo Lagoon and its tributaries are contaminated with heavy metals, nutrients, sediment, and pathogens (Madej, 1989; Podlech et al., 1993). Several streams appear to be actively incising, primarily due to higher flow velocities in

straightened channels and concentration of flow near roads and trails (Costantino, 2003). Although erosion and downcutting are natural geologic process along the Marin Coast, Haible (1980) has found that much of the present-day incision on Walker Creek, approximately 20 miles north of Rodeo Lagoon, has taken place in the 60 years prior to his study, probably in response to human activities and land management. Montgomery (1999) reached similar conclusions in Tennessee Valley, the adjacent watershed to the north of Rodeo Lagoon. Incision of this type may be an explanation for higher sedimentation rates and filling of coastal lagoons during and after European settlement, as observed by Mudie and Byrne (1980), and it is likely that alluvial wetlands have been largely de-watered due to more efficient draining. Physical re-alignment of channels for agriculture in several areas has also concentrated water and helped to drain wetlands. Finally, Rodeo Lagoon and associated fringe wetlands have been severely impacted due to road-building by the US Army, including areas of fill, as well as the construction of a causeway and weir at the east end of the lagoon. It is therefore necessary to identify and describe specific wetlands in the Rodeo Lagoon Watershed (shown in Figure 1) that have been disturbed or altered, and propose methods for either reversing negative trends like wetland draining and habitat loss, or encourage positive trends that lead to natural wetland recovery and re-development.

The NPS is addressing these goals by working with the University of California, Berkeley Center for Environmental Design Research (UCB) and the San Francisco Estuary Institute (SFEI). GGNRA Natural Resources Division staff has completed background wetland mapping and classification, and SFEI has

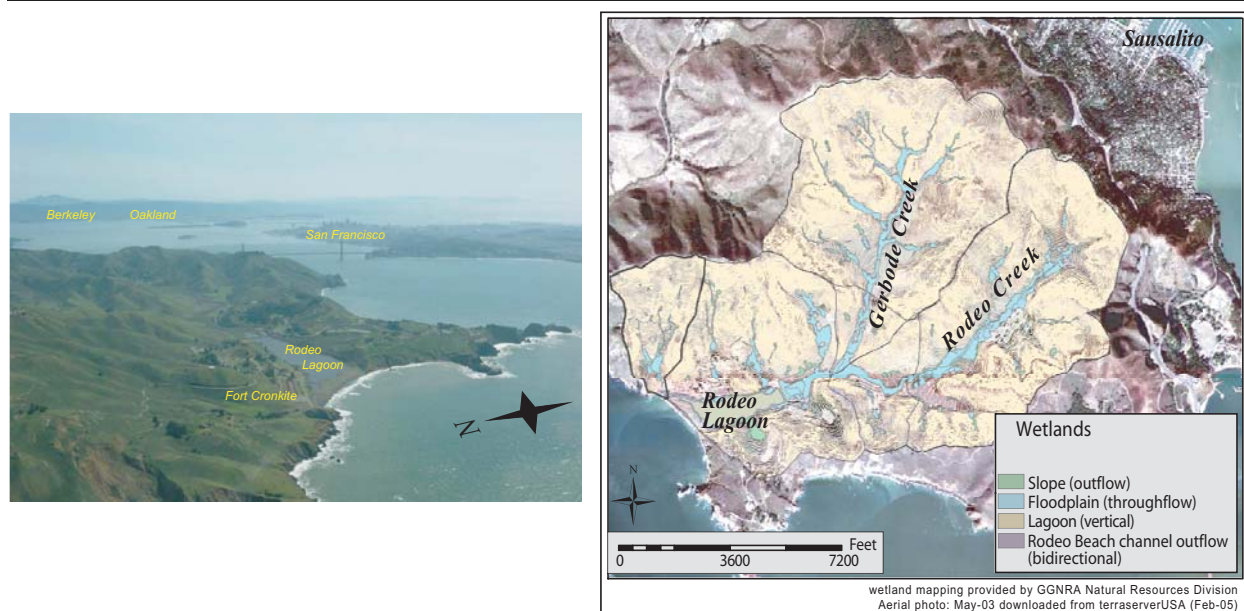


Figure 1. Regional setting of the Rodeo Lagoon Watershed. Just north of San Francisco Bay's Golden Gate, the Marin Headlands are one of the most visited areas in the Golden Gate National Recreation Area. Years of cattle-grazing, road-building and military use have degraded the quality and area of wetland habitat in the watershed, so the National Park Service now seeks to enhance and restore habitat functions to former wetland areas, access to recreational open space, and access to historical resources.

recently completed a historical landscape analysis of the watershed (Striplen et al., 2004), highlighting major changes in wetland areas over the past 150 years. In cooperation with the individuals who carried out those studies, I have undertaken this project in order to:

1. Characterize the hydrology of wetlands in the Rodeo Watershed,
2. Identify specific potential restoration sites and strategies,
3. Rank these potential sites according to priority, and
4. Provide a conceptual design for the highest priority restoration site.

I have achieved these goals by:

1. Observing and measuring surface and ground water conditions,
2. Developing a list of conditions that should be weighed and considered when planning restoration projects,
3. Evaluating the opportunities and constraints of potential wetland projects in terms of such conditions, and
4. Conducting a detailed investigation of the highest priority site, so that restoration designs are consistent with the natural dynamics of this location.

1.2 What this study is not trying to achieve

This study is intended to be a comprehensive evaluation of wetland functioning and restoration opportunities from a hydrologic and landscape evolution perspective. Other considerations, such as social frameworks, vegetation type and distribution, and water quality conditions are also important factors in this regard, but are addressed only in terms of prior analyses that have been carried out in the watershed. I have not produced quantitative vegetation analyses or mapping, so site-specific restoration designs include only very general planting recommendations. The GGNRA Native Plant Nursery is located in the Rodeo Watershed, and will evaluate historic wetland soils and buried plant material, in order to provide planting recommendations and plants that are appropriate for the wetland types described in Chapter 6.

Although water quality is impaired in Rodeo Lagoon, Rodeo Creek, and Gerbode Creek (Podlech, 1993; Madej, 1989; Leach, 1997) and likely imposes a restriction on a range of habitat types within the watershed, I did not carry out extensive water quality analyses, or attempt to define point or non-point sources of impairment. The San Francisco Bay Regional Water Quality Control Board (RWQCB) is, however, currently establishing water quality monitoring stations on these water bodies as part of its Surface Water Ambient Monitoring Program (SWAMP). Furthermore, staff from the Marin Headlands Institute have been collecting water quality data on a monthly basis from several locations in the watershed, some of which were established as hydrologic monitoring stations for this study.

Finally, this project is not intended to serve as a complete inventory of wetlands in the watershed; NPS staff has already carried out this task (National Park Service, 2003, Figure 1). Instead, I have attempted to identify particular wetlands that have been either directly or indirectly impacted by construction activities and/or land use decisions over the past 200 years (since European settlement of the area).

1.3 Summary and organization of this report

The format of this report generally follows the chronological process by which I evaluated wetland restoration opportunities in the Rodeo Watershed. During the first year of the two-year project, I reviewed reports and studies of ecological systems in this and neighboring watersheds. At the same time, the San Francisco Estuary Institute (SFEI) conducted an in-depth analysis of historical watershed conditions (Striplen et al., 2004). Results of these general background analyses are used to describe the area in the context of planning for wetland restoration in the Rodeo Watershed. I also conducted a review of literature that describes general ecological restoration principles during the initial stages of the project, with a focus on ecological systems in recreation areas. Knowledge gained from this literature review is used and presented as the basis for incorporating the human dimension into the final restoration design for this project.

Chapter 2 summarizes the watershed-wide hydrologic monitoring program that was developed at the beginning of water year¹ 2004. During this time, graduate students enrolled in Hydrology for Planners and/or Restoration of Streams and Rivers courses at UC Berkeley conducted several sub-studies relating to the goals of this project. Five projects were conducted that ranged from evaluating incision along streams to measuring the rate of subsurface flow through Rodeo Beach. The monitoring program and studies were developed in order to evaluate and describe in detail the processes that govern the occurrence of wetland systems in the Rodeo Watershed. This information, along with information from the historical analysis was used to identify impaired wetlands and develop very basic approaches to restoring those areas. A decision-making matrix was developed during this time, where potential opportunities and constraints associated with each project could be considered in order to develop a prioritized list of potential restoration sites.

Twelve sites were identified during the background phase of the project as potential wetland restoration projects. In October 2005, background information and the twelve potential sites were presented to NPS staff and park partners (non-profit groups with offices and facilities at Fort Cronkhite), along with a list of potential opportunities and constraints associated with each site (Chapters 2 and 3). From these lists, staff and park partners identified the 'Rodeo Beach Parking Lot' as the highest-priority site, as discussed in Chapter 4. During water year 2005, I conducted a more detailed geomorphic and hydrologic

investigation of this site in order appropriately design a conceptual wetland restoration project for the area. The decision-making process and results of the detailed field investigation are presented in Chapter 5.

Finally, I have developed a conceptual restoration plan and site design for the Rodeo Beach Parking Lot at the end of Mitchell Road. The design calls for removal of road fill and dirt associated with US Army activities during the early 1940's, and replacement with wet meadow, sand dunes, and transitional lagoon fringe habitat. Fort Cronkhite construction documents (Meyer Construction Company, 1941) indicate that approximately 3 acres was converted in this location for the establishment of a 'gun and tractor' area. The proposed restoration plan, as described in Chapter 6, outlines an approach by which the area can be converted back to wetland conditions, while maintaining recreational access to coastal and historical areas.

¹ The term 'water year' refers to the period between October 1 and September 30. For example, water year 2004 means the period from October 1, 2000 to September 30, 2001.

2. Setting and Background

The Rodeo Lagoon watershed is located just north of the Golden Gate, in southwest Marin County about 5 miles from San Francisco, as shown in Figure 1. The watershed is part of the Coast Ranges Geomorphic Province, and consists of rolling hills with grasses, shrubs, or exposed rock in the upper elevations, and riparian woodland corridors, separated in places by expanses of wet meadow and occasional road or trail crossings in the lower elevations. Rodeo Lagoon has a 4.43-square mile watershed, ranging in elevation from sea level to just over 1100 feet.

Rodeo and Gerbode Creeks are the two major tributaries to Rodeo Lagoon, and account for about 70 percent of its watershed area. Although they have nearly equal drainage areas (1.5 and 1.61 square miles, respectively), they have experienced different land use histories and today exhibit distinct characteristics. Wetlands are well developed and continuous along the floor of Rodeo Valley, while the floor of Gerbode Valley is largely dry, consisting of upland vegetation in most place with a relatively narrow riparian woodland immediately surrounding the channel. Early maps of the area refer to Rodeo Creek as ‘Dry Creek’, and the USGS has mapped it as an ephemeral channel, but year-round flow was observed during several summer periods (Lehre, 1974; Podlech, 1993). Several unnamed tributaries flow into Rodeo and Gerbode Creeks, as well as Rodeo Lake and Lagoon, many of these on a year-round basis as well. During the Army’s development of the area, the eastern portion of Rodeo Lagoon was dammed and cut off from the western portion to create Rodeo Lake, now a freshwater wetland.

2.1 Climate and hydrology

The climate of the San Francisco Bay Area is Mediterranean, characterized by wet winters and cool, dry summers, with most of the annual rainfall typically occurring between October and April. Figure 2 shows a cyclic pattern of annual rainfall that has occurred over the past century, likely related to temperature oscillations in the Southern Pacific Ocean, and it is not uncommon for the region to experience prolonged wet or dry periods, which typically last from 7 to 10 years. As such, wetland areas can be expected to expand, contract, and shift accordingly. Stream corridors and wetland functions in this region are dominated by episodicity (Hecht, 1994), as infrequent, sudden pulses of sediment and debris during floods, after wildfires, and after droughts cause major changes.

During winter storms, precipitation is enhanced as moist air from the Pacific encounters the coastal mountains, rises, and water condenses. As a result, mean annual rainfall is higher at the upper elevations, and ranges from about 22 inches near the coast to 28 inches at ridges in the east end of the watershed (Rantz, 1971). Orographic effects also take place during the summer, so a heavy blanket of fog often covers the area from May to September. While the fog typically burns off or recedes from inland areas, it commonly persists for several days or weeks in the Rodeo Watershed. As a result, sunlight is blocked

from the watershed and temperatures remain cool, thereby limiting evapotranspiration and water loss from streams and wetlands during the summer. Fog-drip can also be an important addition of water to the basin during the summer, on the order of 0.01 inches per day, when fog condenses on plants and falls to the ground. Based on region-wide average annual runoff values (Rantz, 1971), mean annual runoff in the watershed is on the order of 7 to 8 inches. The other 14 to 20 inches of rainfall are lost to evapotranspiration and infiltration into the ground.

2.2 Geologic history

In general, wetlands occur where the landscape can support them, both geometrically and hydrologically. They may occur in basins as a result of topography, at seeps or springs as points of ground water discharge, or along evolving stream systems. Thus, an overview of the geologic processes that have formed this landscape may provide insights into where wetlands are present today, and where they may occur in the future.

Plate tectonic theory holds that the crust of the earth is composed of several distinct plates, moving relative to one another, or ‘floating’ atop deeper rock layers that flow plastically and deform, especially along plate margins. The Marin Headlands is a boundary of two plates- the North American Plate and the Pacific Plate. Until about 12 million years ago, this boundary was one of subduction, where the two plates collided- the North American Plate riding atop the Pacific Plate. As this process endured, young marine sediments and volcanic rocks were scraped off the top of the Pacific Plate, and accreted, or thrust upon the North American Plate, thereby creating the coastal mountains, a series of intensely folded and fractured sedimentary and volcanic rocks, with characteristic parallel thrust faults (Blake et al., 1974).

As these mountains were eroded, sand and silt was deposited offshore, and was again scraped off of the top of the subducting plate, and the cycle continued. This process was halted about 100 million years ago, when the plate boundary shifted from one of subduction to one of translation, and the mountains began to be sheared and transported northward along the San Andreas system of faults.

The rocks in the Rodeo Watershed have been mapped as part of the Franciscan Geologic Formation as shown in Figure 3, and consist of three main rock types (Elder, 2001):

1. Greenstone (Kjfg) or ‘pillow basalt’, is named for the dark green color that is produced from the low-grade metamorphism of lava that was extruded from the mid-Pacific about 200 million years ago. This rock tends to have high concentrations of titanium and iron, and is easily weathered. It is therefore not usually well exposed in the watershed, except at road cuts.
2. Chert (KJfch) is easily identified in road cuts and by its characteristic 2- to 10-cm dark red folded

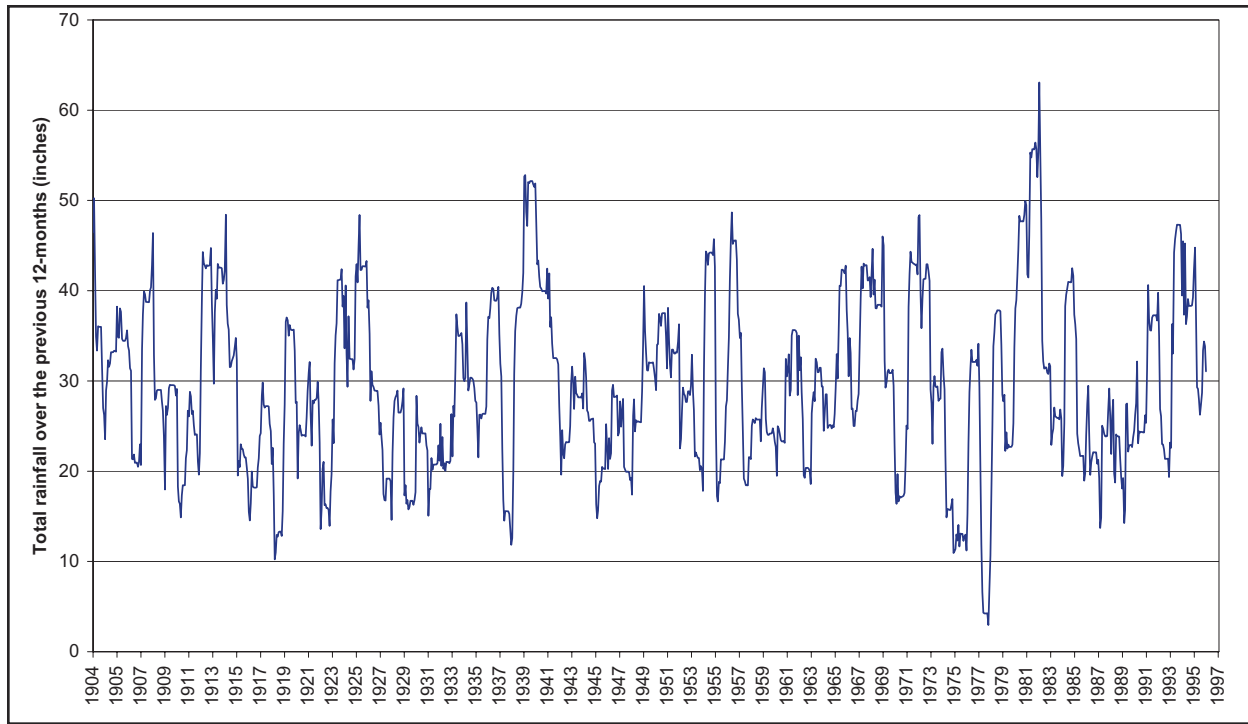


Figure 2. 12-month antecedent rainfall record at Santa Rosa, California. The climate history is characterized by distinct wetter and drier than normal periods. The worst drought on record was recorded in the mid- to late-1970's, and was followed by the wettest period during the early 1980's.

and fractured layers, and was likely formed from a silica-rich ooze of fossils that settled onto the pillow basalt of the deep ocean floor. Of the rock types present in the Rodeo Watershed, chert is the most resistant to weathering.

3. Greywacke (Kfgwy) is a younger sandstone, and was likely deposited near the continental slope over the chert after plate subduction had started, but before the layers were thrust up. Like the greenstone, greywacke tends to weather deeply and is easily eroded.

By about 10 to 100 thousand years ago, these rocks were more or less in place, and the landscape began to experience increased weathering under a changing global climate, swinging from cool, wet periods of widespread glaciation and low sea-level to warmer interglacial periods characterized by higher than normal sea level stands (Atwater, 1977). At the peak of the last ice age, around 15 or 20 thousand years ago, the coast of central California was located about 30 miles to the west, near the Farallon Islands across a broad coastal plain that was covered by sand dune deposits (Wakeley, 1970). As the ice age ended, a climatic transition to wetter conditions occurred around 10 thousand years ago, marking the transition from the Pleistocene to the Holocene era, and leading to the development of deeper soils and landsliding, with valley floors being covered by landslide deposits (Montgomery, 1999), which were then planed over by periodic floodwaters to create alluvial valleys, or wet meadows.

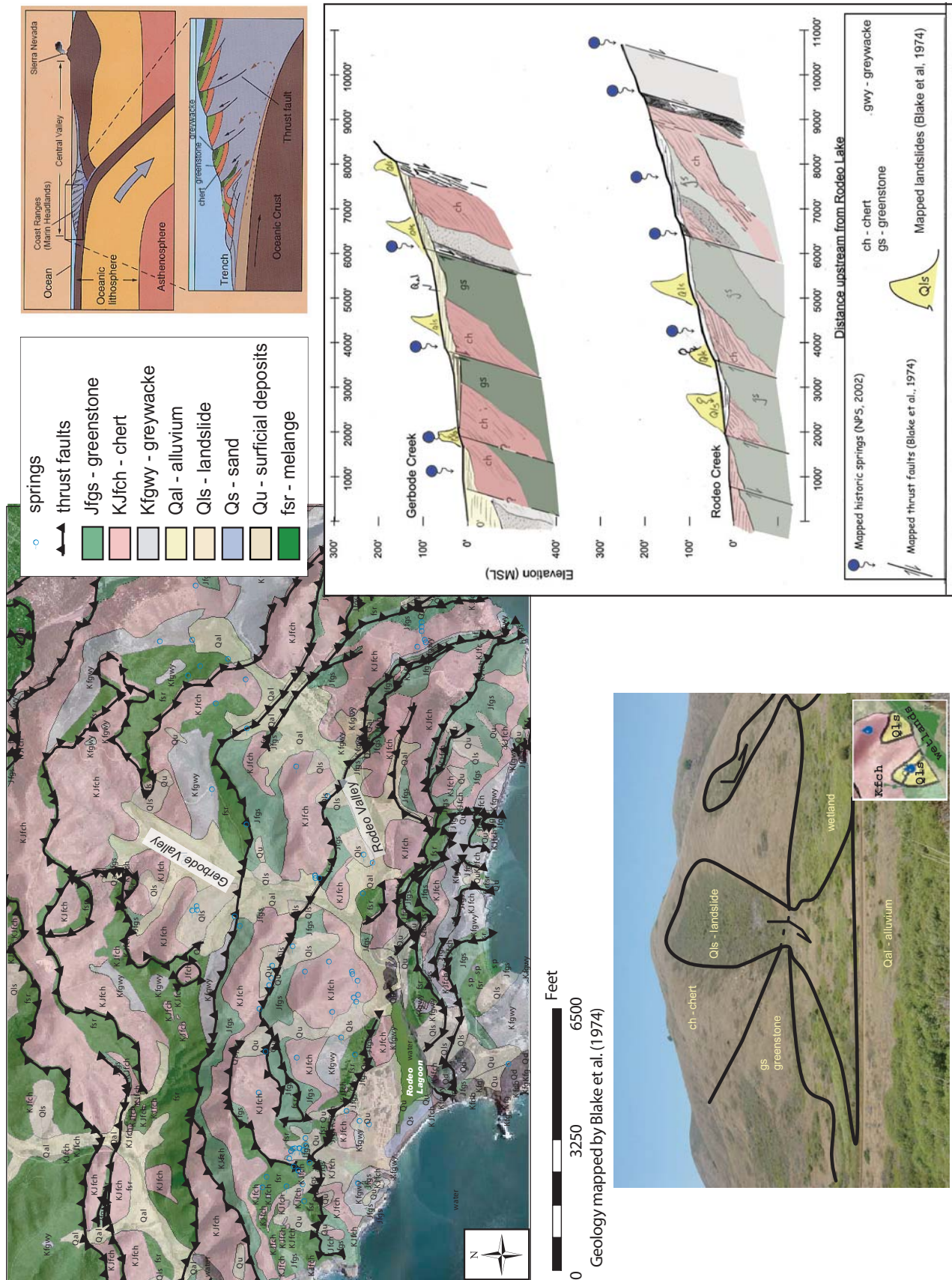


Figure 3. Landscape Evolution. The Marin Headlands Geologic Block is characterized by a series of parallel thrust faults, which have sheared and displaced layers of marine sedimentary rocks. Springs, landslides, and associated slope wetlands tend to occur along these faults and at contacts between rock types. Slopes of the valley floors therefore resemble a stair-stepped pattern; wet meadows form where alluvium and colluvium accumulate, and narrow riparian woodlands occur where valley slopes are steeper and incision has occurred.

Beginning about 200 years ago, deeper channels began to form in these wet meadows, and continued to incise through the valley floors, primarily in response to land practices of the recently-arrived European settlers, such as cattle-grazing and agriculture (Haible, 1980; Montgomery, 1999; Mudie and Byrne, 1980; Lehre, 1982). Increased surface runoff over slopes compacted by cattle, and diversion and straightening of streams for agriculture concentrated water in the channels, and likely led to widespread losses of wet meadow habitat. As streambeds were lowered in the main channels, tributary streams also incised in the upstream direction.

I have observed this process continuing today in the watershed, where active gully erosion is evident in tributaries to Rodeo and Gerbode Creeks, as well as in direct tributaries to the lagoon. Large sediment deposits are located at the mouths of the gullies, and are filling incised channels in some locations. Figure 4 contains several photos showing field evidence of these processes. Slope failures, or large debris flows have been documented after severe wet winters, and active incision is observable in both of the main creeks and their tributaries. In several places however, incised main channels are now being filled by erosion from upper parts of the watershed. As gullies continue to form, sediment is evacuated from channels, moved downstream, and deposited in the lower channels. This process is similar to those observed by Schumm and Hadley (1957) in entrenched valleys, and is depicted diagrammatically in Figure 4.

Rodeo Lagoon is separated from the Pacific Ocean by Rodeo Beach, a steep, narrow beach composed of sand and gravel with a unique mineral assemblage. Wakeley (1970) concluded that unlike most central California beaches, Rodeo Beach receives a relatively small supply of sand from its watershed, but is more likely supplied by erosion of coastal hills and migration of old beach deposits to the east with sea level rise that has taken place over the past 40,000 years.

2.3 Human History

The Coast Miwoks were probably the first people to use this area, likely arriving about five thousand years ago. Four areas that have been identified as possible settlements mark their presence in the watershed, including a large shellmound near Rodeo Lagoon (Striplen et al., 2004). The first Europeans to settle in the region were the Spanish Missionaries who established Mission San Rafael, about 30 miles to the north, and claimed ownership over most of southern Marin County in the early 1800's, before selling part of it to William Richardson (Gilliam and Gilliam, 1993). The land itself was used primarily for cattle grazing by *vaqueros*, Spanish precursors to the American cowboy. Exotic European grasses and wild oats were likely introduced to the area during this time (Mudie and Byrne, 1980).

In 1856, William Richardson sold the southern part of the Marin peninsula to Samuel Throckmorton, a

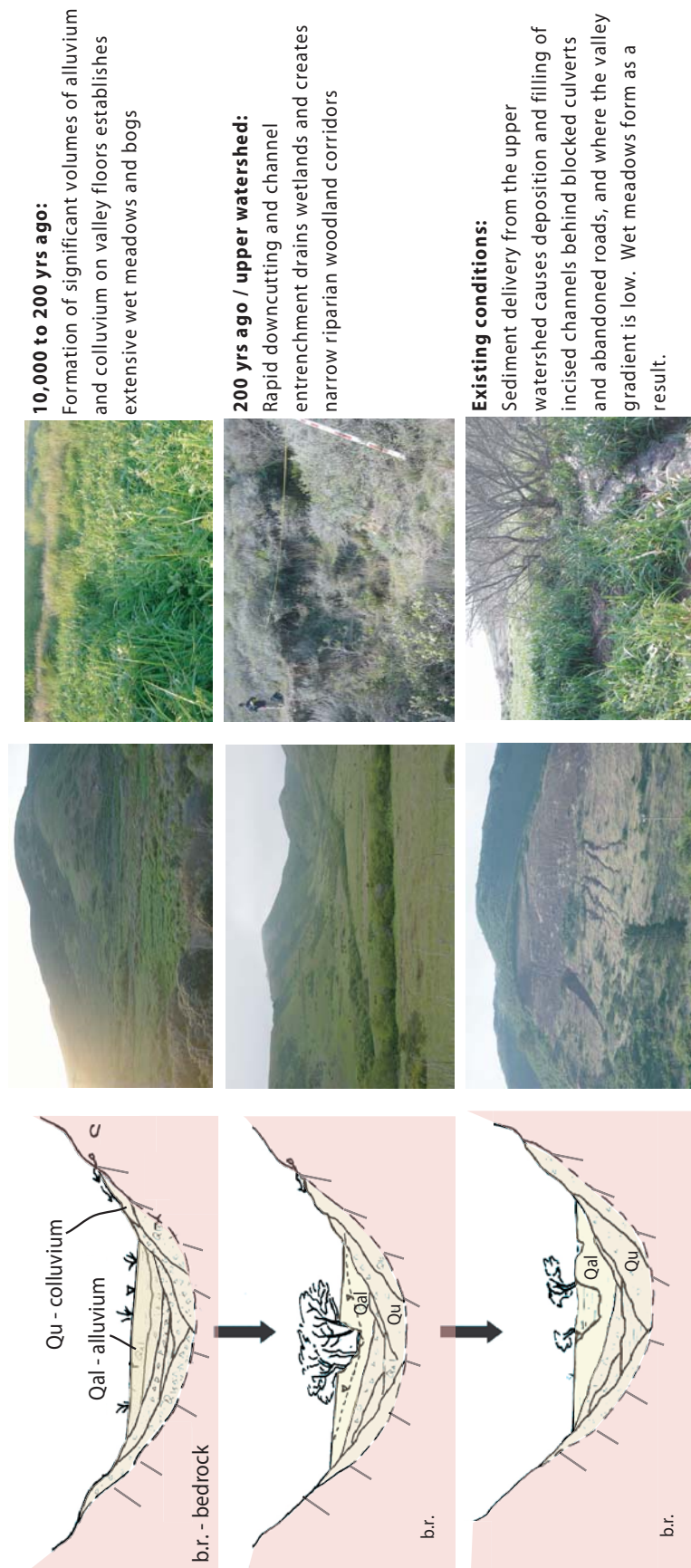


Figure 4. The cycle of erosion, aggradation, and wet meadow evolution

San Francisco businessman. Over the next thirty years, he subdivided the land and sold it to Portuguese immigrants, who established several small dairy ranches, which remained for about the next 100 years (Gilliam and Gilliam, 1993). Several of these farms cleared the land for agriculture and re-routed naturally sinuous streams into irrigation or drainage ditches. A large dairy farm was established in Gerbode Valley, centered about 1500 feet upstream of the confluence with Rodeo Creek, and probably had cattle concentrated around the farm facilities, and did not wander far to graze. An apparently associated but smaller agricultural operation was located near Rodeo Beach, in the small watershed just west of where Fort Cronkhite was built (Striplen et al., 2004).

Around the same time the dairy ranches were being established, the Army built forts and gun emplacements to guard the Golden Gate, but it was not until 1937 that the Army established Fort Cronkhite at Rodeo Beach. During the next twenty years, the Army housed several thousand troops in barracks adjacent to the lagoon. Parking and activity areas were located on fill directly in the lagoon and in adjacent wetlands, while an extensive road-network was constructed in the upper parts of the watershed, in many places directly on top of wetland areas.

Perhaps the most significant impact to the lagoon during this time was the construction of a weir, or low dam, across the upper portion of the lagoon. The primary purpose of the weir was to store freshwater flows from the upper watershed for drinking and/or irrigation, but the pond was also stocked with trout for recreational purposes (Darren Fong, pers. comm., 2004). The weir effectively cut off brackish water from the upper lagoon area, and removed significant areas of rare transitional habitat between the brackish lagoon and upland vegetation, and created a small basin to trap the increasing volume of sediment being delivered from the watershed.

Today, this area remains much as it did during the Army's occupation. Although some roads have been removed or overgrown, many remain for fire control access, and as trails for mountain biking, hiking, and equestrian use. Most of the historic army buildings and associated parking facilities are still in place; many built over former wetlands (Darren Fong, personal communication, 2003), and are used as offices for government agencies and non-profit park partners. Rodeo Beach is currently the most popular recreational site in the Marin Headlands area, accounting for about 12 to 13 percent of visitors to the area (Nelson and Nygaard, 2002). Figure 5 is a summary of the major human influences and changes that have taken place here.



Figure 5. Human history

2.4 Federally listed species

Three federally listed species have been identified in this area. The California red-legged frog has been observed in Rodeo Lake, Rodeo Creek, and Gerbode Creek. The California brown pelican frequents Rodeo Lagoon during the summer months, often roosting at the southwest end of Rodeo Lagoon. It is not known whether the federally listed salt marsh harvest mouse is present in the watershed, as no formal surveys have been conducted, but fringe brackish wetlands along Rodeo Lagoon are potential habitats, and the frogs have been spotted (Darren Fong, personal communication, 2004). Tidewater goby populations have been identified in Rodeo Lagoon (USFWS, 2004). The following discussion summarizes the habitat requirements associated with each of these species.

2.4.1 California Red-Legged Frog (*Rana aurora draytonii*)

The California red-legged frog is one of the largest frogs to inhabit this area, typically growing up to 4 or 5 inches in length. They inhabit deep (2 to 3 feet), slow moving, or still water during the wet months (November to March), but are able to hibernate away from water during the winter months. During the initial life stages, tadpoles depend on heavy cover to avoid predators. Eggs are typically laid after a heavy rainfall, and hatch about 10 days later. The species is noted as being very sensitive to water quality changes; eggs cannot survive in salinities greater than 0.0045 parts per thousand (ppt), and tadpoles require salinities to be less than 0.007 ppt.

The California red-legged frog was historically widespread in central and southern California, and was found throughout the Central Valley, Sierra foothills, down to Baja California, Mexico. Following predation by humans and other introduced species during and after the Gold Rush, and conversion of land for agricultural and increasing human settlement, the species declined dramatically. Today, the species occupies approximately 10 percent of its former range, mostly along the central coast in only 238 streams statewide (USFWS, 2001), including Rodeo Lagoon and Rodeo Creek (Darren Fong, personal communication). Population declines are due primarily to habitat loss and predation by introduced species.

2.4.2 Salt Marsh Harvest Mouse (*Reithrodontomys raviventris*)

The Salt Marsh Harvest Mouse has grooved upper teeth and a red belly (Shellhammer et al., 1992). The preferred habitat is pickleweed, a salt-tolerant plant that grows in tidally-inundated marshes. The mice often use the vegetation or escape onto adjacent uplands to avoid extreme high tides, but are adept swimmers. The mice likely survive on leaf litter, stems and small seeds, and reproduce in small nests from spring through autumn (Shellhammer et al., 1992).

Salt marsh harvest mice are only found in the tidal marshes around San Francisco Bay. Although these

marsh areas were greatly expanded following sedimentation associated with hydraulic mining of the late 1800s, only about 85 percent of the marsh area that bordered the bay in 1850 remains today. Additionally, several of these areas have been converted from salt marshes to freshwater wetlands due to impoundment or increases in freshwater discharge associated with urban areas. It is not known whether Rodeo Lagoon has an appropriate hydrologic regime and salinity levels for the salt marsh harvest mouse (i.e., one that is tidally-influenced).

2.4.3 California Brown Pelican (*Pelecanus occidentalis californicus*)

The California Brown Pelican is a large sea-bird, with a wing span of over 6 feet. The pelicans establish nesting colonies on islands well south of the San Francisco Bay Area, and range as far north as British Columbia, during the summer months, when they are not breeding. When in the area, the pelicans prefer to feed and roost at the mouths of estuaries on sand bars and beaches, as well as on rocks and jetties. The California brown pelican was listed as endangered primarily due to reproductive problems associated with bioaccumulation of DDT, and have seen declines in prey due to over-fishing by humans.

2.4.4 Tidewater Goby (*Eucylogobius newberryi*)

The tidewater goby is a small fish (less than 2 inches in length) that typically spends its entire life in shallow (less than 3 feet deep) areas of estuaries and lagoons, only occasionally venturing upstream into areas more dominated by freshwater. Reproduction generally consists of male tidewater gobies digging borrows into clean, relatively coarse sand, typically in the late spring. The species is noted as being adaptable, and can survive salinities approaching that of pure seawater (around 40 parts per thousand), but prefer the freshwater-saltwater interface of coastal lagoons, estuaries, and stream mouths, where salinities are typically less than 12 ppt.

Tidewater gobies are native to the entire California coast, and historically ranged from the mouth of the Smith River near the Oregon Border to Agua Hedionda Lagoon in San Diego County. . Numerous hydrological modifications to this habitat, including off-season lagoon openings, introduction of invasive and predatory species, and physical modifications have caused population declines. Today, the species is still found entirely within its historic range, but in only 28 of 124 historically-occupied locations (USFWS, 2004).

The United States Fish and Wildlife Service recently designated Rodeo Lagoon as available tidewater goby habitat, and noted that tidewater gobies were found in the lagoon in October of 1999 (USFWS, 2004). Highlighted threats to the tidewater goby at this location include reduction or modification of habitat, and exotic fish species.

2.5 Cultural Uses

The Marin Headlands Institute and YMCA environmental education classes make up the majority of weekday outdoor use in the Rodeo Lagoon area, and other non-profit and government agencies use abandoned army bunker buildings as office and storage space. Approximately 10,000 vehicles per day visit Marin Headlands in the spring, summer, and fall (Nelson and Nygaard Consulting Associates, 2002), bringing people who use the area for mountain biking, birdwatching, photography, surfing, fishing, and numerous other activities.

Results of weekend user surveys (Shaw, 2004) indicated that the vast majority of these people were from Marin County or San Francisco, traveling between 5 and 20 miles to use the area. ‘Enjoying the views’ was listed most often as the primary reason for coming to the area, while hiking, surfing, and ‘hanging out’ were commonly listed as secondary activities (Shaw, 2004). Nearly all respondents indicated the value of improving wildlife habitat in the area. Overall, respondents felt that improvement of native mouse habitat was less important than fish, bird, or frog habitat, and that endangered species habitat is more important than non-endangered species habitat. Most people answered that they would be willing to forego access to trails and parking to some extent in order to improve wildlife habitat conditions. On the other hand, only 31 respondents (58%) indicated that they would be willing to sacrifice historical landmarks to improve wildlife habitat, while 23 people indicated that they would not.

3. Rodeo Lagoon Watershed characterization

During the first year of this project, field investigations and literature review were aimed at characterizing the general hydrology of the watershed. While SFEI carried out a historical analysis of the watershed, I investigated existing stream and wetland processes through a field monitoring program and review of published geology and water-related studies of this and nearby areas. Through these efforts, we were able to compare findings and highlight certain heavily-impacted areas and/or processes. These cooperative investigations helped develop a comprehensive understanding of conditions that we are trying to restore, as well as the feasibility of reconstructing wetlands on former wetland areas, and resulted in a list of potential restoration sites. By comparing existing landscape processes to those of the past, I was able to establish specific hydrologic, geomorphic, and human processes that have shaped and continue to shape this landscape. This allowed the project team and park partners to set wetland restoration goals that are in conjunction with these recognized forces, and evaluate each potential project in terms of these processes. This evaluation allowed the Park Service to choose a high-priority potential restoration site to be designed.

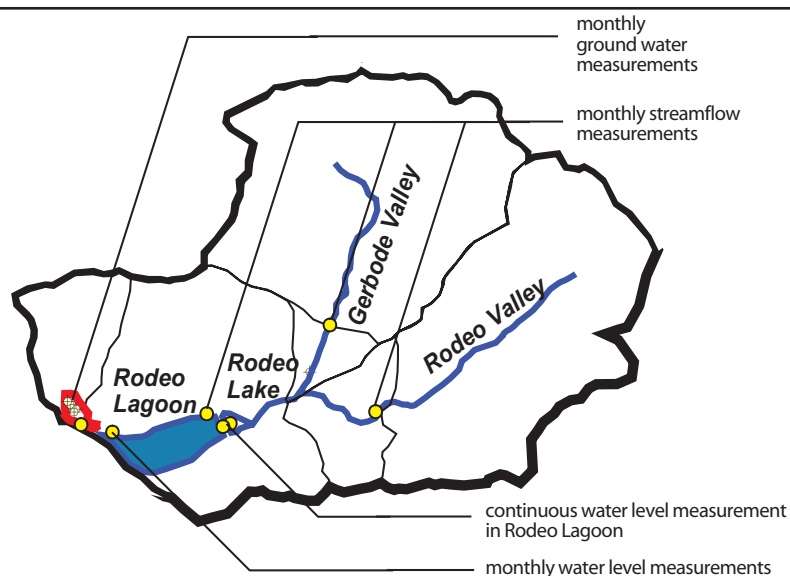


Figure 6. Monitoring station locations

3.1 Rationale and methods

To characterize the current state of wetlands and the processes that sustain them, I established a monitoring program to describe baseline conditions, which consisted of:

- Continuous rainfall measurement
- Streamflow measurement
- Ground water monitoring through shallow monitoring wells (piezometers)
- Measuring channel dimensions and the degree of channel entrenchment
- Continuous measurement of water levels and tidal influences on Rodeo Lagoon
- Water levels and the effects of the weir on Rodeo Lake.

Specific conductance, a measure of the concentration of dissolved ions, was occasionally measured in order to evaluate hydrological connections between water bodies, as well as the influence of the ocean. Additionally, Marin Headlands Institute staff were conducting a field monitoring program for educational purposes, and were able to measure some of these parameters at these stations. Table 1 summarizes the locations of sampling stations and parameters sampled at each station.

No hydrology investigations have previously been carried out to describe the functioning of the lagoon, so this investigation was undertaken to identify basic patterns and relationships between water bodies. The investigation is also intended to simply characterize existing or 'baseline' conditions in Rodeo Lagoon and Lake, and is also a 'first cut' at identifying constraints to re-establishing historic wetland habitat types imposed by the Bunker Road weir.

The upper watershed

Measurements of streamflow and ground water levels through the dry season indicate where and how ground water storage is releasing water to creeks and wetlands during low flow periods. If wetlands are to be designed to draw on these sources, monitoring data will provide some estimate of potential volumes that will be available. Obviously, conditions encountered this year are not necessarily those that will be encountered in other years, but relationships between rainfall and runoff, or more specifically between total seasonal rainfall and late summer streamflow can be expected to persist across the years, as well as to different subwatersheds within the system.

I measured the amount and intensity of rainfall in the entire watershed with a continuous-recording tipping-bucket raingage, and established streamflow monitoring stations on Rodeo and Gerbode Creek for periodic manual measurements of water depth (stage) and streamflow. Prior to installation of the raingage, I used an adjusted daily rainfall record from Point San Pedro, based on a correlated relationship between the two locations. At each station, I have established relationships between stage and streamflow (rating curves), so that other observers' (Marin Headlands Institute and RWQCB staff) depth measurements can be converted to an estimation of streamflow. The monitoring station locations on Rodeo and Gerbode Creeks were chosen in an attempt to measure runoff from as much of the upper watershed as possible while being far enough upstream of the confluence so that a distinct channel was present, as shown in Figure 6.

Periodic measurements were made in smaller tributaries during the dry season as well, in order to evaluate any differences in the relative amounts of water released to streams of different sizes. High

Table 1. Summary of monitoring stations and parameters sampled during water year 2004, Rodeo Lagoon Watershed, Golden Gate National Recreation Area, Marin County, California

	Surface Water		Ground water	
	Sediment transport	Water surface elevation	Streamflow	Water table elevation
Rodeo Creek at Rifle Range	m	m	m	--
Gerbode Creek at Abandoned Dairy Farm	m	m	m	--
Rodeo Lake at Bunker Road	--	m	--	--
Rodeo Lagoon at Bunker Road	--	c	--	--
Building T1111 tributary at Bunker Road	--	--	m	--
Rodeo Lagoon at Rodeo Beach Footbridge	--	m	--	--
Surfer Parking Lot tributary at Rodeo Beach	--	--	m	m

m = manual measurements

c = continuous measurement with a datalogger

water marks and channel dimensions were observed at each station following flow events, and peak flows were estimated using both the Manning equation, and by extrapolating established stage-discharge measurements to observed high-water elevations.

Streamflow was measured using USGS standard methods for open-channel flow with a bucket-wheel (standard AA or pygmy) current meters with a top-setting wading rod. Standard measuring stations were established by installing staff plates on both Gerbode Creek (near the Rodeo Creek Trail crossing and Rodeo Creek (at the Rodeo Creek Trailhead). At extreme flows when water was too shallow for the current meter, or too high to wade, velocities were assessed by measuring the time for a float to travel some distance. In smaller side tributaries, flow was often measured using a bucket-and-stopwatch method, where the amount of time to fill a known volume in a bucket was measured.

Rodeo Lake and Lagoon

In order to evaluate the degree to which streamflow from the tributaries, the weir, and tides affect water levels in Rodeo Lagoon, a continuous-recording datalogger was installed at the Bunker Road bridge about 50 feet west of the weir separating Rodeo Lagoon from Rodeo Lake. A staff plate was also installed in this area to allow for periodic manual measurements and calibration of the water level sensor. To avoid the effects of wave action, additional readings were measured every three minutes and averaged every 15 minutes, and wind-driven elevation differences in the lagoon were assessed by installing and reading a staff plate at the western, lower end of the basin. Manual measurements were recorded from these stations on a regular basis and were used to calibrate the datalogger record. Dataloggers were also installed in Rodeo Lake, but malfunctioned, so the data record from Rodeo Lake is largely unusable.

3.2 Findings of the Rodeo Lagoon Watershed investigation

3.2.1. Upper watershed hydrology

Wet season runoff

Table 2, a summary of daily rainfall, shows that the peak daily rainfall during water year 2004 occurred on November 29, 2004, but the annual maximum flow on both creeks was observed after high rainfall intensities at the end of a 1.7-inch storm on the night of February 24-25, 2004, when 1.2 inches of rain fell in three hours. Published regional rainfall data indicate that this was approximately a 2 to 5-year storm event (Rantz, 1971), and both streams responded by flowing at or just above bankfull capacity; Gerbode Creek peaked at about 29 cubic feet per second (cfs), while Rodeo Creek peaked at about 35 cfs. Normalized to drainage area, it appears that the Rodeo Creek Watershed generated slightly more unit storm runoff (23.01 cfs/square mile) than the Gerbode Watershed (18.33 cfs/square mile).

Low flow (baseflow)

Table 3 shows all streamflow measurements that were recorded during the monitoring period, including low-flow measurements, and Table 4 contains unit runoff values for each of the monitoring stations. These tables show that during the low-flow (baseflow) period, Rodeo Creek supported a higher rate of streamflow per watershed area (about 0.08 cfs, or 0.12 cfs/square mile) than the other monitored tributaries. Gerbode Creek only flowed at an average rate of about 0.02 cfs (0.05 cfs/square mile) during the baseflow period. Lehre (1974) made several low flow measurements in coastal Marin County streams that ranged from 0.003 cfs/sq mi to 0.281 cfs/sq mi, with an average of 0.07 cfs/sq mi. During that time, Rodeo Creek flowed at 0.037 cfs/sq mi., while Gerbode streamflow was slightly lower, at 0.033 cfs/sq mi. It appears that baseflow levels in Rodeo and Gerbode Creeks are fairly typical of coastal Marin County streams.

The highly folded and fractured geology of the Rodeo Lagoon Watershed supports a large number of springs and seeps at various elevations, which are the primary sources for year-round water in streams and wetlands. Published and unpublished geologic maps (summarized in Figure 3) and spring inventories carried out by the National Park Service show that the majority of springs tend to occur at geologic contacts, probably as a result of differing hydrologic properties between the different bedrock types. A large number of landslides have been mapped at these contacts as well, and old landslide scars have been observed in the field (see Figure 3), where springs and wetland vegetation is present on the edges of a landslide. It is possible that differences in creek baseflow between Rodeo and Gerbode Creek can be explained by the differences in the number of springs in each watershed (11 springs in Rodeo Watershed, versus 7 in Gerbode Watershed, as mapped by NPS and shown in Figure 3).

Table 2. Rainfall in Gerbode Valley during water year 2004.

Day	October (inches)	November (inches)	December (inches)	January (inches)	February (inches)	March (inches)	April (inches)	May (inches)	June (inches)	July (inches)	August (inches)	September (inches)
1	0	0	0.59	1.85	0.24	0.46	0	0	0	0	0	0
2	0	0	0.13	0.38	0.93	0	0	0	0	0	0.01	0
3	0	0	0	0	0.31	0	0	0	0	0	0	0
4	0	0	0.15	0	0.01	0	0	0	0	0.01	0	0
5	0	0	0.23	0	0	0.02	0	0	0	0.01	0	0
6	0	0.15	0.38	0.03	0.09	0	0	0.01	0	0	0	0
7	0	0	0	0.12	0	0	0	0	0	0.01	0	0
8	0	0.60	0	0.05	0	0	0	0	0	0	0.01	0
9	0	0	0.37	0.82	0	0	0	0	0	0	0	0.01
10	0	0	0.45	0	0	0	0.01	0	0	0	0	0
11	0	0	0	0	0	0	0.01	0	0	0	0.01	0
12	0	0	0.08	0	0.01	0	0	0	0	0	0	0
13	0	0	0.24	0	0.07	0	0	0	0	0	0	0
14	0	0.18	0.29	0.03	0	0	0	0	0	0	0	0
15	0	0.02	0	0	0.05	0	0	0	0	0	0	0
16	0	0	0	0	2.05	0	0	0	0	0	0	0
17	0	0.01	0	0	0.66	0	0	0	0	0	0	0
18	0	0	0	0	0.03	0	0.11	0	0	0	0	0
19	0	0	0.57	0	0	0	0.01	0	0	0	0.01	0.03
20	0	0	0.79	0	0.11	0	0.06	0	0	0	0	0
21	0	0	0	0	0.03	0	0.21	0	0	0	0	0
22	0	0	0	0	0.10	0	0	0	0	0	0	0
23	0	0	0.22	0.05	0	0	0	0	0	0	0.04	0
24	0	0	0.51	0.20	0.29	0	0	0	0	0.02	0	0
25	0	0	0	0	1.34	0.61	0	0	0	0	0	0
26	0	0	0	0.12	0.13	0.01	0	0	0	0.01	0	0
27	0	0	0	0.55	0.12	0.02	0	0.01	0	0	0	0.01
28	0	0	0.16	0	0.12	0	0	0.13	0	0	0	0
29	0	0	3.03	0	0	0	0	0	0	0.03	0	0
30	0	1.17	0.01	0.31	0	0.01	0	0	0	0.01	0	0.01
31	0	0	0	0	0	0	0	0	0	0.01	0	0

Note: data collected using a Hobo automatic-recording tipping-bucket raingage
gray values were adjusted from rainfall at Pt San Pedro, Marin County (CIMIS station 157)

3.2.2 Rodeo Lake and Lagoon hydrology

Water levels in Rodeo Lagoon appear to be dominated primarily by seasonal inflows of water from tributaries and outflow through Rodeo Beach. Figure 7 is the record of lagoon water levels during the course of the study.

Low flow (baseflow)

Minimum lagoon water surface elevations are associated with the late summer, when inflows are reduced and the lagoon slowly loses water to evapotranspiration and the flow through the beach. Rodeo Lagoon has an approximate surface area of 504,805 square feet, and the datalogger record indicates that elevation declines in the lagoon during the low-flow period at an average of approximately 0.01 feet per day. This implies an average daily loss rate of 5,040 cubic feet per day (0.058 cfs) from the lagoon, including

Table 3. Instantaneous streamflow measurements in tributaries to Rodeo Lagoon during water year 2004

Date	Rodeo Creek (gpm) (cfs)		Gerbode Creek (gpm) (cfs)		Beach Parking Lot (gpm) (cfs)		Bldg T1111 trib (gpm) (cfs)	
10/26/03	7	0.02	37.06	0.08				
12/17/03	271	0.60	214.98	0.48	125	0.28		
1/7/04	1644	3.66	1229.71	2.74				
1/10/04	1504	3.35			449	1.00		
1/17/04					100	0.22		
2/12/04					107	0.24		
2/16/04	3586	7.99	2327.93	5.19	942	2.10		
2/18/04	2491	5.55	8278.56	18.45				
2/25/04								
2/25/04								
2/25/04	9833	21.91	13162.41	29.33				
2/25/04								
2/25/04	15591	34.74						
3/5/04					197	0.44		
3/11/04					74	0.16		
3/24/04	491	1.09	146.76	0.33	30	0.07		
4/11/04	491	1.09	183.56	0.41	21	0.05		
5/6/04	342	0.76	34.56	0.08	4.3	0.01		
6/8/04	13	0.03					11	0.03
6/8/04			30.52	0.07	1.1	0.00		
8/5/04	12	0.03	26.48	0.06			2	0.00
8/6/04					3.2	0.01		
8/10/04			44.88	0.10				
9/10/04	20	0.04			0.9	0.00		

evapotranspirative losses. Burson (2003) surveyed the dimensions of Rodeo Beach at low tide, and Waljewski and Williams (2004) measured probable ground water velocities through the beach (.0058 cm/s), also during low tide. Using their values, and neglecting the influence of changing tidal elevations on the measured velocities, I obtained a rough seepage estimate of 1.34 cfs for flow through Rodeo Beach during summer low-tide periods, significantly higher than the estimated net water loss from the lagoon. Even if only half of the seepage rate is applied to the surface area of the lagoon (to account for reduced flow rates during high tides), water levels would drop much more quickly than observed. These calculations indicate that during the low-flow period in the summer, surface water inflow and ground water seepage to the lagoon (i.e. fresh water) are primarily responsible for maintaining its volume of water, and an average of about 1 cfs (0.22 cfs/square mi.) is contributed from the watershed.

These calculations also offer an explanation for the decreasing salinities in Rodeo Lagoon during the summer months that were observed by Podlech et al. (1993). Although salinity in coastal lagoons typically increases during dry periods, Rodeo Lagoon appears to be hydrologically connected and heavily influenced by its watershed during the summer, only receiving high-salinity ocean water during high-tides and lagoon breaching events during the winter.

Winter runoff

Figure 8 shows that the lagoon filled relatively slowly following rainfall events until overtopping the beach, often several days after the rainstorm. At these points, the lagoon rapidly erodes the sand, drains, and becomes periodically affected by extreme high tides and storm surges. During water year 2005, outflow from the lagoon eroded the beach down to bedrock. Field surveys indicated the top of this bedrock outcrop to be at an elevation of around 9 to 10 feet above mean sea level, reflecting a bedrock control on base level in the lagoon. National Park Service staff however, have observed complete draining of the lagoon in other years (Daphne Hatch, personal communication, 2004). Such observations also highlight the variability in lagoon outflow channel location that was noted by Striplen et al. (2004).

Water levels in Rodeo Lake increase during and after storm periods and decrease during the summer months. Figure 8 also shows that water levels in Rodeo Lake were regularly higher than Rodeo Lagoon, an indication that flow regularly was from the Lake to the Lagoon. On February 25, during one of the season's largest storms, water levels in the two water bodies were nearly equal, but the rate of the flow from Rodeo Lake to the lagoon appeared to be sufficient to prevent flow from the lagoon to the lake. During the October storms of water year 2005, the water level in Rodeo Lake rose in response to rainfall and runoff, but lagoon water levels remained relatively low until the storms of December 7 and 8, 2004, presumably when Rodeo Lake overtopped the weir and began to flow into Rodeo Lagoon.

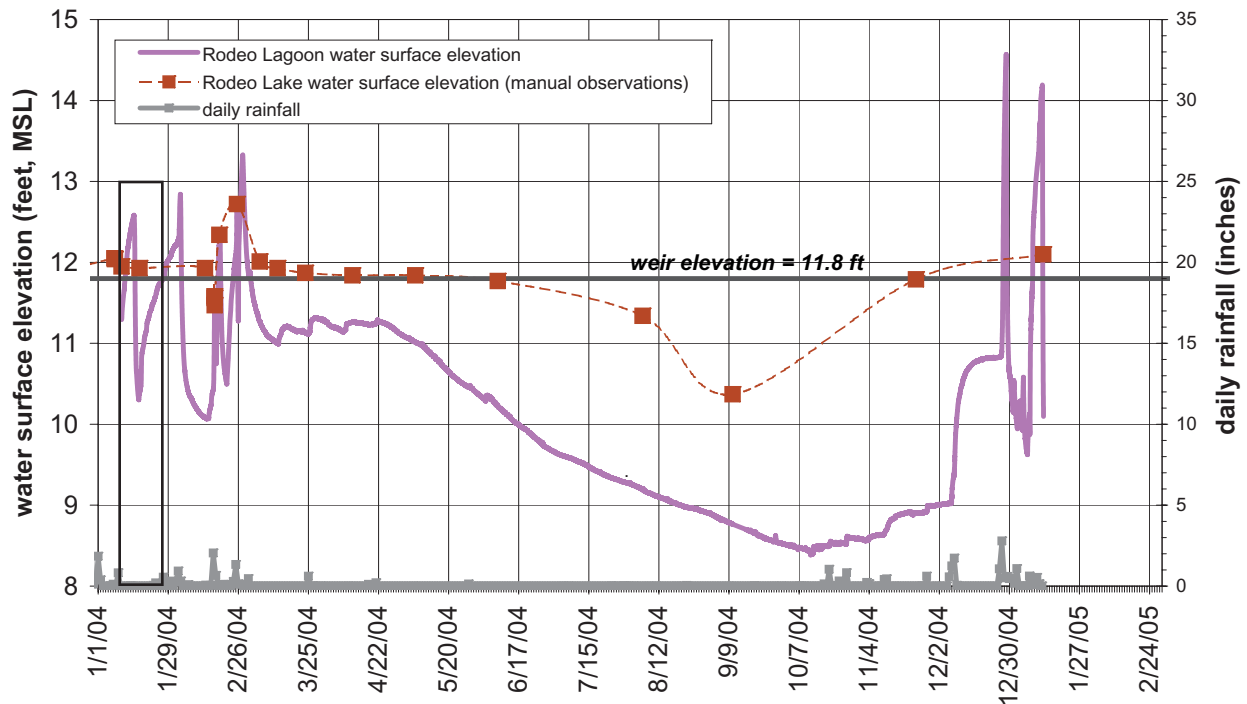


Figure 7. Water level in Rodeo Lagoon at Bunker Road. Several periods of lagoon overtopping are evident during the winters, occurring both during storms and several days after storms. During the spring, outflow by seepage through the beach is approximately equal to inflow from tributaries. As flow from the watershed recedes during the summer, lagoon water levels decline by as much as 4 feet until rainfall begins again. In the fall and early winter, Rodeo Lake water levels rise in response to increasing rainfall, but it is not until Rodeo Lake overtops the weir that substantial water level increases and lagoon overtopping is able to take place.

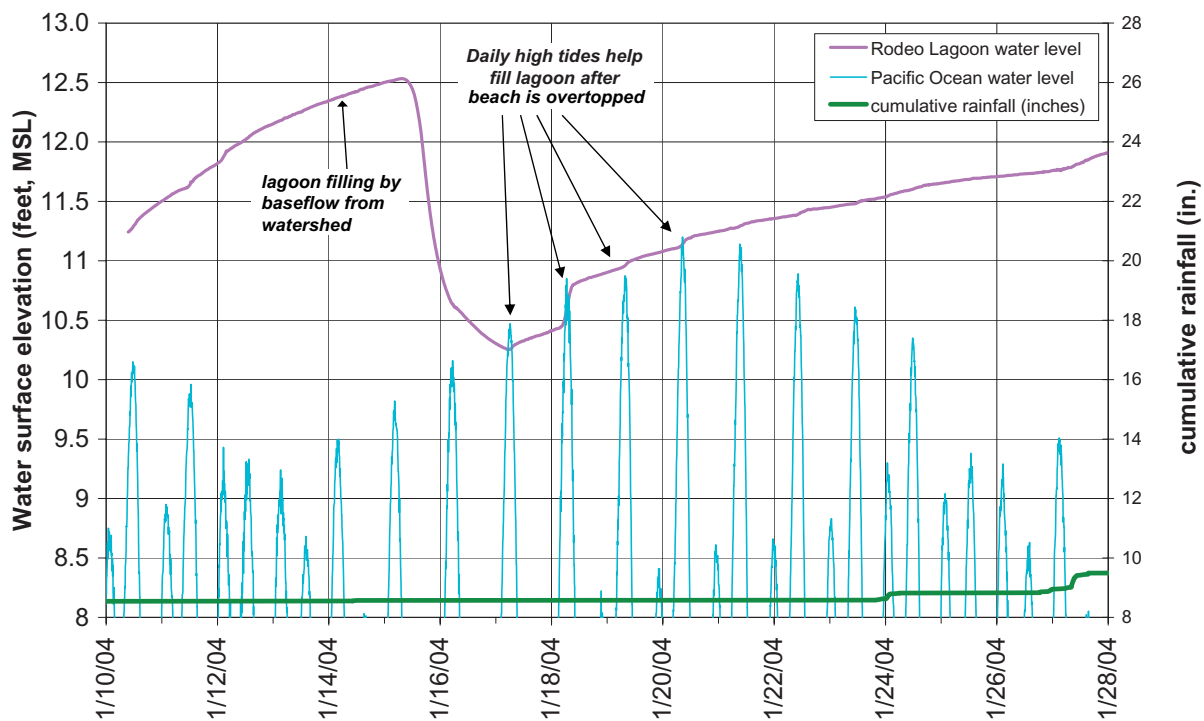


Figure 8. Water level in Rodeo Lagoon and tides. Following storms, the lagoon overtops Rodeo Beach and drains, cutting through the beach in the process until daily high tides deposit sand, block the outflow, and spill sea-water into the lagoon.

These data indicate that until Rodeo Lake fills, the Bunker Road weir severely limits the hydrologic connection between the Lagoon and the upper watershed, but after the lake has filled, attenuation from the weir becomes negligible, and the lagoon responds quite rapidly to rainfall and runoff from the upper watershed.

3.2.3 Landscape evolution and stream channel processes

I have used published geology mapping by Blake et al. (1974) to construct longitudinal profiles² and geologic cross-sections in both Rodeo and Gerbode Valleys. Figure 3 shows these drawings, including the locations of mapped historical springs.³ The stair-stepped valley floor topography can be attributed to alluvial fan and landslide deposits, the location of thrust faults, and differences in underlying bedrock strength. Both Rodeo and Gerbode Valleys are steeper where mapped thrust faults cross the valley floor, and where more resistant bedrock, such as chert, is present. The areas between the faults have lower channel slopes and are located where side tributaries enter the valley bottom. Sediment deposits are located in these low-slope areas in both valleys, and in Rodeo Valley, these areas are marked by the absence of a defined channel and the presence of wet meadows. This may have also been the case prior to channel entrenchment in Gerbode Valley, although one notable difference between the two valleys is the degree and continuity of an incised channel. Gerbode Creek has a continuous channel that is significantly entrenched into its valley bottom and disconnected from its floodplain, while Rodeo Creek is largely discontinuous, and lacks a defined channel in many places.

Schumm and Hadley (1957) presented a model where gully erosion initiates at the oversteepened toe of these depositional areas and progresses upstream, depositing material just downstream. In colluvial valley floors of the Rodeo Watershed, such a process probably resulted in the local draining of wet meadows, but also in the formation of new wetlands in downstream deposition areas, especially if enough sediment is deposited to fill the incised channel completely. In natural discontinuous gully systems of uniform material, this is a migratory process, and the repeating pattern along the channel length creates a stair-stepped sequence of gullies and deposits. The locations of channels and deposits are also probably influenced by the underlying bedrock topography and strength, especially in an active tectonic landscape, as well as the specific locations of tributaries and their sediment deposits. When channels become continuous along the entire length of a valley, the floodplain wetlands and wet meadows become de-watered, flow becomes concentrated, leading to higher shear stress and increased incision (Bravard et al., 1999). Such effects are demonstrated in Gerbode Valley, where the main valley channel has been largely cut off from its historic floodplain. In contrast, wet meadows and a well-connected floodplain are still present today along most of the Rodeo Valley floor.

² Drawn from 20-foot contours on the USGS 7.5-minute Point Bonita Quadrangle

³ Digitized by the National Park Service from historical maps.

Land-use practices, climate change, large floods, and intrinsic geomorphic disturbances are all cited as contributing to the development of incised channels (Elliott et al., 1999), thus it is frequently not possible to confidently determine the cause of incision in a given channel. As cattle and permanent roads were introduced to the watershed in the early 1800s, overland flow likely increased, causing a higher frequency of large-magnitude flow events. Toward the end of that century, the southern portion of Rodeo Valley was purchased by the Army, and became, for the most part, off-limits to cattle grazing. Measured channel geometries in the two valleys highlights the differing geomorphic response between these two systems (Costantino, 2003; Porter-Bass and Choy, 2004). In Gerbode Creek, the channel became continuously entrenched, while in Rodeo Creek, the discontinuous system of gullies, depositional areas, and wet meadows persisted, with only minor degrees of channel entrenchment. These differing histories and channel geometries between these two watersheds suggest that cattle-grazing may be a more important factor in the development of incised channels in this area. It is important to also note the influence of roads, as research in Tennessee Valley, immediately to the north (Montgomery, 1999) has shown that channel heads tend to form more easily in watersheds where roads are present.

I therefore assume that channel incision in both the Gerbode and Rodeo Watersheds originated around the time Europeans introduced cattle, roads, and intense agricultural practices to the watershed. In accordance with the Schumm and Hadley (1957) model, channel entrenchment likely progressed headward (upstream) through the watersheds, and continues to do so today, as evidenced by deep, active gullies throughout the watershed. Aerial photos indicate that vegetation is recovering in the watershed again, and that main channels are now somewhat stable. Streamflow magnitudes have probably been reduced as a result, but sediment influxes remain somewhat high due to continued incision at the upper watershed. As a result, aggradation, sediment accumulation, and wetlands occur near the mouths of these gullies, filling channels to create wider or multiple channels and re-establish a connection between the channel and floodplain. In several locations, channels appear to have filled completely and wet meadows have been established.

I have inferred sediment accumulation rates by approximating the age of buried trees and old fenceposts. Middle reaches appear to also be accumulating sediment at and downstream of tributaries, and are widening, while upstream reaches, in response to a period of incision about 100 years ago, continue to erode. Rough estimates of the maximum age of fenceposts (25 to 100 years) and the minimum depth of accumulated sediment (1 foot) yield minimum average channel aggradation rates of .01 to .04 feet/year in mid-valley areas, although it is likely that these deposits have accumulated during one or a few discreet episodes. The channel is further stabilized in these areas by mature willow tree root systems that extend across the channel, storing sediment in the channel immediately upstream. In the lower most reaches, approximately 25 year-old willow trees appear to be buried by approximately 1 to 3 feet of sediment, implying average deposition rates of 0.04 to 0.12 feet/year just upstream of Rodeo Lake.

3.2.4 The occurrence of wetlands

Wetlands in the watershed have recently been mapped and classified by GGNRA staff, as shown in Figure 2. Two classification systems were used during this mapping project, the Hydrogeomorphic (HGM) classification, and the Cowardin classification system (see Figure 2). The HGM classification uses descriptive terms to delineate several distinct wetland types that are present in the watershed. For the purposes of this study, however, and in order to be consistent with terms used in the historical analysis component of this study (Striplen et al, 2004), I use the terms below (*HGM terms in parentheses*):

Slope Wetlands (Outflow)

Slope wetlands occur on steep hillsides in areas of shallow ground water or ground water discharge. Ground water tends to move along contacts of different bedrock types, where intense chemical weathering is able to create depressions, or hollows, that become filled with soil (Montgomery, 1999; Oerter, 2004). Water is able to collect in the soil of these hollows, which then form wetlands. Figure 2 shows that many springs and slope wetlands in the Rodeo watershed are coincident with these bedrock contacts. It is not uncommon for these steep, saturated areas to be lubricated enough to fail and form landslides during very wet winters.

Floodplain wetland (Throughflow)

Floodplain wetlands can be supported by a variety of flow mechanisms.

- Seasonal Marshes are largely supported by winter rains and overtopping of channel banks by flood waters. Water is usually lost through evapotranspiration and infiltration as soils dry out following storms.
- Riparian trees are able to tap deeper, ground water resources with extensive root systems, and are usually found along main channels (Rodeo or Gerbode Creeks), extending only partially up tributaries. Various willow varieties are the most abundant tree species, and are often complemented by a blackberry and poison oak understory, with occasional cottonwoods and buckeyes.
- Wet meadows are supported by a year-round elevated, or perched ground water table, where large volumes of sediment have recently been deposited. The water supply in these areas is either from low-elevation hillside springs, or from tributaries that transport water from upper elevation springs. Well-defined channels are usually not present in these low-gradient environments, and aggradation is common. In several places, wet meadows are aggrading due to the damming of sediment behind ancient and recent landslides, or at trail crossings with blocked or undersized culverts.

Rodeo Lagoon, Lake and associated fringe wetlands (bi-directional, fringe)

The hydrology of Rodeo Lagoon has been largely altered due both to placement of fill and road-building, as well as construction of the low-head weir that created Rodeo Lake. Although Rodeo and Gerbode creeks usually provide year round flow, these flows are largely attenuated by the weir. This results in elevated water conditions and reduced salinity in Rodeo Lake, and reduced circulation in the lagoon. Rodeo Lake is therefore dominantly a freshwater wetland, and is ringed with willows emergent tules and cattails at the shallow edges, with willows, reeds, and sedges just above the average water surface elevations.

The fringe wetlands at the edge of the lagoon are a transitional environment from open water to upland, and have varying water quality, depending on the rate of surface water inflow from upstream. If inflows are relatively low, the environment is mostly brackish, and characterized by emergent salt-tolerant vegetation. Tidal marsh vegetation, such as pickleweed, is preferred by the salt marsh harvest mouse and is not prevalent in these areas, although it has been observed in isolated areas. Where tributaries deliver freshwater and sediment to the lagoon, small willow-covered deltas have formed. In several areas, fringe wetlands have been largely compromised by the construction of roads, trails, and dumping of fill directly in the lagoon. As a result, the edges of the lagoon are very steep, and lack significant vegetation.

3.3 Summary and description of impaired wetlands and restoration opportunities

As a component of the GGNRA wetlands mapping project, several wetlands were identified as possible candidates for restoration. Direct impacts from particular actions, such as road construction, should be distinguished from widespread land use changes that reflect region-wide shifts in geomorphic processes. While it is possible to address local perturbations and disruptions to wetland processes, it would be unwise to attempt to change these trends on a local scale. For example, many small, upper watershed channels that are incising due to lowering in the main channel can only be stabilized if they achieve some state of equilibrium, where the stream no longer seeks a lower level. I have therefore focused energy on identifying direct impacts of human activities. Many of these areas no longer support wetlands, and were therefore not included the GGNRA analysis, but were identified by Striplen et al. (2004). In choosing potential wetland restoration projects, I have focused on larger areas that have been completely converted from their original form or function, and have only evaluated smaller wetlands (such as isolated gullies) in terms of watershed processes.

The watershed wide analysis resulted in 12 wetland areas being identified as potential restoration sites. Locations of these sites are shown in Figure 9, and summaries of the opportunities and constraints at each site are presented in Appendix B. Although each site is unique, there are a handful of restoration approaches that can be used to address commonly-occurring problems in the watershed. Problem areas

are described in general in the sections below, and summarized in Table 5, along with potential restoration strategies for dealing with each.

3.3.1 Areas of fill in floodplain wetlands and former wet meadows (Capehart housing complex, Rifle Range, and Smith Road, Rodeo Beach Parking Lot)

During the Army's construction of Fort Cronkhite, several roads and housing developments were built directly on floodplain wetland areas, eliminating wetland habitat. Most of these areas were placed at tributary junctions where sediment has been deposited to form large alluvial fans, taking advantage of the natural topographic rise. At the Capehart Housing Complex, three tributaries enter Rodeo Creek from the south, and likely flowed in discontinuous channels across an alluvial fan before reaching Rodeo Creek. These streams have been placed in culverts under the housing complex, but appear to be still delivering large volumes of sediment to Rodeo Valley, as evidenced by partially –buried fenceposts and trees adjacent to and just downstream of Capehart. Upstream of the complex, Rodeo Creek is deeply incised into alluvial sediments.

The Rifle Range is designated as a sensitive historical resource (Paul Scolari, 2004, personal communication), and consists of a large area of fill extending from the base of a large hill to the middle of Rodeo Valley. An abandoned road around the northern edge of the range was formerly used when training exercises were being carried out, but now serves very little purpose, and several piles of debris have been dumped here. This part of Rodeo Valley is steeper and narrower than upstream areas, due to grade controls from shallow bedrock, landslide deposits that extend into the valley, and perhaps the fill associated with the Rifle Range. These factors may explain why the upstream areas of Rodeo Valley have remained as wet meadow habitat.

Smith Road is an abandoned housing development that was built directly in the Rodeo Creek floodplain, just upstream from the confluence with Gerbode Creek. When the Army built the housing development, they realigned the stream several meters to the north, and it now flows through a narrow channel that is deeper than other reaches of the creek (Porter-Bass and Choy, 2004). Structures have been removed from the area, but concrete pads remain. Similar to the rifle range, this volume of fill may actually be contributing to the relative stability of Rodeo Valley, through controlling headward incision along the channel.

The 'Rodeo Beach Parking Lot' was built by the Army at the end of Mitchell road as a 'gun and tractor park' as indicated by Fort Cronkhite construction completion documents (Meyer Construction Company, 1941), and consists of a large dirt parking area at the mouth the westernmost tributary to Rodeo Lagoon. Historical analyses indicate that at the time of European settlement, discontinuous channels were present

in the upper watershed, and sand dunes associated with the beach extended well north of Mitchell Road (Striplen et al., 2004, and as described in Chapter 5). Flow from this tributary has been confined to a ditch running near public restrooms, and is adjacent to a large paved parking lot. Flow exits the culvert onto Rodeo Beach very close to the Pacific Ocean, and is only connected to Rodeo Lagoon on the occasions when the ocean is flowing into the Lagoon. During most of the year, outflow from the culverts infiltrates into the beach. The parking area here currently serves as overflow parking on peak visitor days, and is rarely used on most other days.

Wetland restoration in these filled areas would consist of removing portions of culverts under housing areas and abandoned roadways, and improving culverts under existing roadways to encourage and maintain sediment transport and deposition on the valley floor. Further investigations in these areas should include defining the extent of the original alluvial fan surface and wetland soils that are likely to support wetlands. Soils of the Rodeo Valley floor are bog-like, and support wet meadows, while the gravelly soils of the alluvial fans drain water more efficiently, and would be more suitable for re-establishment of riparian corridors than transition from upland to wet meadows, a much more feasible task than removing several tons of fill, but with smaller gains in wetland area.

3.3.2 Areas of fill in the lagoon and fringe wetlands (Mitchell Road, Rodeo Lake Picnic Area, Across from Building T1111)

Artificial fill has been placed in Rodeo Lagoon in several areas. Many parts of Mitchell Road, the main access road to Rodeo Beach and Fort Cronkhite, were built directly in the lagoon, and large turnout areas near Building T1111 and Rodeo Lake were also filled. These areas not only reduced open water areas of the lagoon, but also created steep edges, eliminating the shallow transitional habitat from brackish water to freshwater or upland that is preferred by several shorebirds as well as the tidewater goby. The Rodeo Lake Picnic Area is located immediately adjacent to a large hill, and is shown on historic maps to have been an area where the shoreline was naturally steep, but along Mitchell Road and in front of Building T1111, the shoreline had a lower slope and was probably more transitional.

Building T1111 is located directly where a tributary enters the lagoon, and now houses maintenance equipment for the National Park Service. As is common with many of the tributaries that flow directly into the lagoon, a delta is formed as the stream encounters a lower gradient and standing water. Year-round streamflow in the tributary supports a large willow and freshwater wetland community on the delta, and this part of the lagoon has substantially lower salinities than elsewhere. The large area of fill on the opposite side of Bunker Road has also impacted this wetland, and it now contains a portion of the Rodeo Lagoon trail, which circles the lagoon. Restoration of the lagoon fringe wetlands would consist of removing fill, and grading to elevations that are conducive to the growth of emergent vegetation. It

Table 5. Summary of potential restoration areas in the Rodeo Lagoon Watershed

Site	Summary of restoration strategy	Primary advantages	Primary Disadvantages	Priority level
Rodeo Beach Parking Lot	Excavate fill to appropriate levels and excavate to encourage trapping of water and sediment	Converts compacted fill to slope, floodplain and wet meadow wetlands	Overflow parking on peak use days would need to be relocated	High
Across Bunker Road from Bldg 1111	remove fill and re-establish emergent wetland vegetation community.	Converts compacted fill to lagoon fringe wetlands and tidewater goby habitat	Lagoon views would be limited.	med-high
Rodeo Lake Picnic Parking area	Remove fill and expand freshwater willow marsh habitat	Re-establishes freshwater marsh and red-legged frog habitat	Would need to re-align utilities.	med-high
Smith Road	Remove fill and expand freshwater willow marsh habitat	Provides floodplain and wet meadow habitat; could potentially serve as water quality treatment for runoff from Presidio Riding Club	Requires large amount of material removal; potential disturbance to stream grade control and existing wet meadows in Rodeo Valley	med
Rifle Range	Remove debris piles, improve landscape and view; improve riparian habitat; repair broken culvert	Provides floodplain and wet meadow habitat.	Alters significant historical resource; potential disturbance to stream grade control and existing wet meadows in Rodeo Valley	low
Dairy Farm in Gerbode Valley	Encourage in-channel sedimentation through tree planting and channel widening	Provides additional floodplain and wet meadow habitat;	Disturbs existing habitat; requires a significant volume of fill to be removed	low
Mitchell Road parking area east of subwatershed GGNRA 7-2	Remove parking, grade to re-establish fringe wetland	Provides a lower-slope transition from upland to the lagoon	Would disturb transportation corridor (bike and walking lanes could be compromised); reduces parking space	low
Sub-watershed GGNRA7-2: 'Headlands Institute creek'	Grade shoreline to re-create transitional freshwater-brackish habitat and delta at mouth of creek; daylight creek through the campus to create connected riparian corridor	Re-establishes riparian wetlands lagoon fringe wetlands	Very expensive; requires re-design of Headlands Institute campus and alterations of historical buildings.	low
Capehart housing	Remove fill from stream corridor, increase stream functions and habitat area; stabilize eroding banks with vegetation planting	Provides additional acres of floodplain and wet meadow habitat	Requires relocation of employee housing	low
Weir removal	Restore lagoon functions to Rodeo Lake; increase flushing and water quality; restore brackish lagoon habitat; improve fish passage;	Converts freshwater marsh back to lagoon fringe wetlands.	Negative affects on California red-legged frog habitat;	med-high
Shellmound tributary	stabilize incised channels, control road drainage and erosion in upper watershed, remove culverts under trails for enhanced connectivity.	Re-establishes discontinuous channel morphology	Disturbs existing habitat; difficult to access	low
Gerbode Creek bypass	replace woody debris (large-diameter trees) in by-pass channel to encourage re-occupation of cut-off meander.	Restores original riparian corridor. Potential re-establishment of wet meadow	Potential seasonal flooding of trails	high

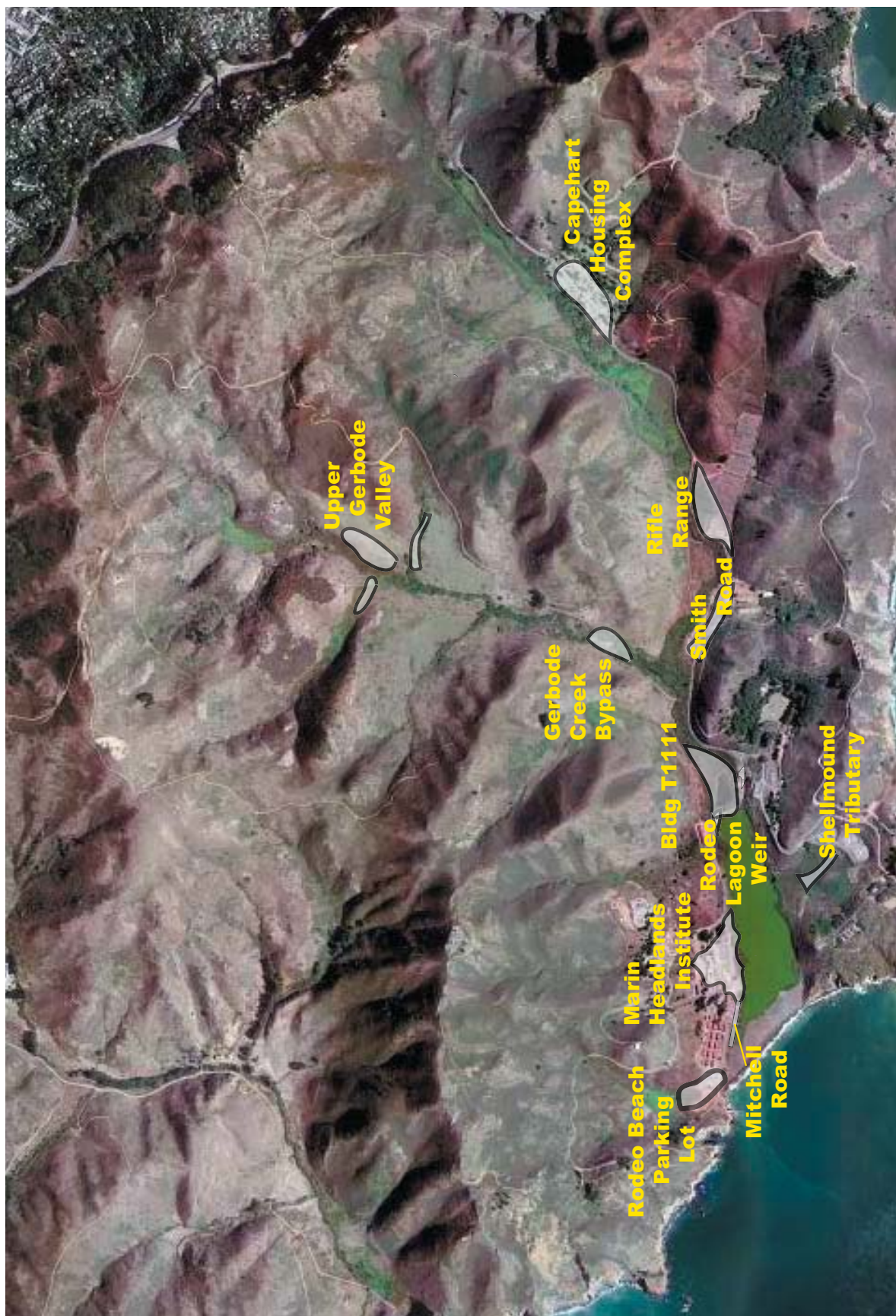


Figure 9. Potential wetland restoration sites in the Rodeo Valley Watershed.

is possible that the area across from Building T1111 contains hazardous material, and would need to be tested prior to removal.

As described in Section 3.2.2, Winter high tides and storm surges appear to be the only source of seawater to the lagoon, which becomes dominated by freshwater inflows during the summer. Since tides do not otherwise exert a strong influence on the hydrology of Rodeo Lagoon this should not be considered to be optimum habitat for the Salt Marsh Harvest Mouse, or a tidal marsh restoration opportunity.

3.3.3 Marin Headlands Institute Creeks

The streams flowing into the north side of Rodeo Lagoon were severely affected by the construction of Fort Cronkhite. When the army base was built, most creeks were realigned and buried in culverts, typically for the last 300 to 500 feet of their length before reaching the lagoon. Two major tributaries flow in culverts under the Marin Headlands Institute, which now occupies several of the buildings that were constructed as 'temporary housing.' The institute is considering options for re-development of the area. Daylighting of some or all of these creeks would provide valuable educational opportunities, and would allow a hydrologic and biological connection to Rodeo Lagoon.

Creeks that passed through this area are not shown in early maps of the area (Striplen et al., 2004), and were likely discontinuous channels that were not well-defined. Restoration of such a system would be difficult and would require a complete evaluation of the sediment loads and flow dynamics of each stream, as well as a commitment to allow floods to spread out over the area. An alternative design, while not 'restoring' the original process, would involve the creation of a more defined channel to address flood hazards, and encourage sediment deposition and wetland formation at or just upstream of the mouth of each creek, creating additional fringe wetland acreage. Removing Mitchell Road in this area would best accomplish these goals, but would require re-routing beach traffic and parking away from the lagoon, perhaps behind the campus.

3.3.4 Incised channels (*Upper Gerbode Valley, Gerbode meander cut-off, Shellmound tributary*)

As described above, Gerbode Valley and the Shellmound Tributary are now entrenched and disconnected from their respective floodplains. In response to a lower base level on the main channel, many of Gerbode Creek's tributaries are incising also. Several deep and narrow gullies have incised into valley floor sediments just upstream of the main stem of Gerbode Creek. Park Service evaluations have recommended filling in these gullies in order to raise the ground water table or flood the adjacent areas more frequently. This option is not likely to be self-sustaining, as the channel is eroding placed fill, and will likely continue to do so. Another alternative would be to excavate adjacent to the channel to create a bench that could be inundated more frequently. Both actions would require an evaluation of the

frequency and height of floods events, and are likely to reduce delivery of sediment to the main stem channel.

Just above Gerbode Creek's confluence with Rodeo Creek, an artificial cut-off channel was constructed to bypass a natural meander. This channel is straight and efficiently carries water through a culvert under a hiking trail and fire access road. Striplen et al. (2004) used aerial photos to conclude that the channel was likely constructed sometime after 1965 and before 1996, probably in order to alleviate flooding of the fire road. The straight channel is about 4 feet lower than the abandoned meander, and as a result, the former floodplain has been abandoned as well. To restore this area, the straight channel could be blocked with large woody debris to force high flows back into the abandoned meander. If done properly, this could slow flows substantially to allow sedimentation to take place, thereby alleviating to some degree the incision that has occurred in this straightened reach.

3.3.5 Rodeo Lake (Rodeo Lagoon weir)

Rodeo Lake, formerly the head of Rodeo Lagoon, has been dammed with a low weir. Sedimentation has filled much of the lake, greatly reducing the area of open water upstream of the weir, and has led to a conversion from semi-tidal brackish marsh to freshwater marsh, marked by the invasion of willows around 1946 (Striplen et al., 2004). The weir attenuates storm flows into Rodeo Lagoon, especially during early winter storms, so lagoon-breaching and the introduction of ocean water to the lagoon probably occurs less frequently now than compared to pre-weir conditions. Average salinities in Rodeo Lake are lower now than in the past, and average water surface elevations are probably higher (see Figure 7). Due both to the impounded water and increased sediment transport rates in the upper watershed, Rodeo Lake has largely been filled with sediment, and areas of open water have been reduced.

Restoring brackish, semi-tidal, open water conditions to this area would require removal of the weir, dredging accumulated sediment as well as areas of fill (i.e. the Rodeo Lake picnic area), and increasing hydrologic connections under the Bunker Road by removing the causeway. Restoration of the upper lagoon through weir removal is only likely to change the lagoon hydrologic regime during the early part of the rainy season, but would re-introduce the circulation of brackish water into the upper lagoon. Weir removal poses no great logistical hurdle, and would increase available tidewater goby habitat, but could also cause a severe pulse of sediment to be delivered to lower Rodeo Lagoon during subsequent major storms. Weir removal would reintroduce lower summer water levels in Rodeo Lake, as well as higher salinities, which could impair the existing willow communities, as well as the California red-legged frogs that have colonized the lake.

4. Selection of the highest priority site

Many ecosystem restoration decision-making frameworks choose a single ecological function or characteristic that will be maximized, and ignore other ecological process and ambient social values. For example, McAllister et al. (2000) propose an ecologically-based functional assessment to choose a wetland restoration project which maximizes the degree to which a wetland will alleviate flooding, without considering other wetland functions. The widely-used Hydrogeomorphic (HGM) approach to restoration decision-making considers a wide variety of ecosystem functions, but still does not consider the social context of the restoration projects. At another extreme, a greater emphasis might be given to social criteria than to ecological criteria through a strong emphasis on public involvement. In this respect, a practical decision-making model considers a variety of ecosystem functions as well as the needs and values of the human community that uses the area. It is necessary that the assigned values reflect *all* of the potential impacts, ecological and cultural, especially in a heavily-used recreation area such as the Rodeo Watershed.

4.1 Lessons from existing prioritization schemes

The Hydrogeomorphic (HGM) approach is a commonly-used model where individual wetlands are assessed and described in terms of the structural components that support it. It is advantageous in that it allows for a thorough representation of wetlands and wetland processes in an area. Functions are assessed with this model through the assignment of functional capacity units (FCUs), which allow for relative ranking of 'ecosystem health' based on ecosystem functions. FCUs consider both the quantity and the quality of a wetland, based on measurements of chosen biologic, physical, and geochemical characteristics of the wetlands (White, 2004), and are therefore adaptable; it can be structured to include measurement of any variable that is deemed important by those who are carrying out the investigation.

Perhaps the most significant constraint of using a functional assessment model however, is its inability to account for the physical and social context and regional values of these wetlands. Consider, for example, the potential restoration site in Upper Gerbode Valley. Expansion of these wetlands would offer significant opportunities for flood control, as well significant gains in California Red-Legged Frog habitat, while a fringe wetland of Rodeo Lagoon offers only a small fraction of habitat improvement for the tidewater goby, with essentially no flood control. Under the HGM classification system, expansion of the floodplain wetland would result in higher functional gains than expansion of a smaller lagoon fringe wetland. In this case though, the 'lower value' wetland offers significant educational or recreational benefits, and improved tidewater goby habitat, which has become rarer and more difficult to restore than California Red Legged Frog habitat in this area. Social considerations offer perhaps the most relevant value system, but are not reflected in functional assessment output. It is therefore necessary to consider different habitat types in terms of their inherent social value, recreational and educational opportunities,

and logistics as part of a decision-making framework.

Johnston et al. (2002) developed an economic-ecological model that attempts to integrate values with functions. This model uses surveys of ecological experts and the general public to assess preferences and assign values to different wetland functions. The experts' survey is intended to determine the extent to which physical attributes of a wetland contribute to specific habitat for different species, while the public survey assesses the relationship between wetland functions and public values. This system is advantageous in that it specifically addresses the values of the community that will be impacted by the restoration, while striving to understand the functionality of the ecosystem. It also provides a scientific approach to ranking different habitat types, so that preferences and decisions are not arbitrarily made.

The general public, of course, cannot be expected to have already formed educated opinions and must be provided with ecological background. Participants in surveys of this type are typically informed of the trade-offs and budget constraints of constructing different habitat types, a process which inherently assigns value to different functions. Surveys also typically take some time to plan and execute, making this a time-consuming process.

Given these constraints, neither model is appropriate for planning wetland restoration in the Rodeo Watershed, but both offer insight and a methodological framework by which public preferences and relative habitat value can be incorporated into the decision-making process. Table 6 is a summary of these models, and highlights the distinct advantages and disadvantages of each with respect to planning in the Rodeo Watershed.

4.2 The highest priority site

I used a combination of these frameworks to assess the advantages and disadvantages of each potential wetland restoration projects. I evaluated the conditions at each site so that a prioritized list could be developed and ranked. In a separate study (Shaw, 2004), I assessed park user's perceptions of habitat improvement, and allowed for a general valuation of habitat types versus recreational and historical resources. Evaluation forms presented in Appendix B show the criteria that were used to evaluate each potential site, and the relative ranking of the sites. These forms served as qualitative discussion guide, rather than a quantitative tool for assigning numerical values to each potential site, and allowed park planners and stakeholders to discuss the relative values, opportunities, and constraints of the potential projects described above. The discussions took place during two meetings where each potential site was evaluated by staff from the GGNRA Natural Resources Division, the GGNRA Interpretive Division, the GGRNA cultural resources division, GGNRA planning division, The GGNRA Native Plant Nursery, the San Francisco Estuary Institute, and the Marin Headlands Institute.

Table 6. Summary of advantages and disadvantages of decision-making models. Positive attributes are indicated with a , while negative attributes are shown by a .

	Hydrogeomorphic (HGM) Model	Ecological-Economic Model (Johnston et al., 2002)
Basic Approach	Quantifies ecological functions for comparison of wetland design alternatives	Evaluates opinions of experts and public preferences to prioritize different wetland restoration alternatives
Decision guidelines	Decision is implicitly based on the number of acres of improved ecological value	Decision-making is explicitly linked to willingness-to-pay values
Evaluation	Based directly on quality and quantity of wetland habitats 	Public preferences require education by experts, which can be value-laden 
Community / Stakeholder involvement	Does not consider community/stakeholder impacts 	Considers stakeholder / community preferences 
Implementation time	Relatively quick to implement 	Takes a long time to implement 
Habitat type differentiation	Does not distinguish different species' habitat requirements 	Assigns different values to different species' habitat 

As a result of the meetings, it was agreed that a restoration of the Rodeo Beach Parking Lot provides the most opportunities with the fewest significant constraints for wetlands restoration. The compacted, fill-covered area has very little existing habitat value, and is considered by both Cultural Resources and Transportation Staff as being expendable as a parking lot, and its removal is included as a component in the recently-completed Marin Headlands Transportation Management Plan (Dave Kruse, personal communication, 2005). Impacts to historic resources and existing habitat are minimal at the Rodeo Beach Parking Lot, while many of the other sites have the potential to negatively affect existing habitat. In general, visitors to this area have indicated that they would be willing to forgo access to parking in order to improve habitat (Shaw, 2004).

Building T1111 is another high-priority site for similar reasons, but it was agreed at stakeholder meetings that a complete restoration of the area would be difficult without removing the building itself, which is a historical resource and is currently used by park maintenance crews. Rodeo Lake is also a high priority site and currently has impaired habitat value, but until the weir is removed and the basin is re-connected to the lagoon, it is impossible to restore the original lagoon habitat to this area. The Gerbode Creek meander cut-off also is a high priority site, and restoration of the abandoned meander bend is potentially a straight-forward and simple activity, and would not require as in-depth analysis and detailed planning as other sites. The Park Service therefore chose to use the funds that had been set aside for this project to assess the more complex hydrology and history of the Rodeo Beach Parking Lot area.

5. The high priority site investigation: Rodeo Beach Parking Lot

The watershed-wide investigation presented in Chapter 3 highlighted several dominant mechanisms that influence different wetland types in the Rodeo Lagoon Watershed. In order to specifically assess these processes in the Rodeo Beach Parking Lot Watershed, I conducted a local site investigation. The Rodeo Beach Parking Lot is a filled wetland area that lies at the mouth of a 0.31-square-mile watershed, but I have expanded the 'site-specific' investigation to include the contributing watershed in order to better understand the water and sediment-delivery processes that are likely to affect projects that are carried out here in the future. I measured the dimensions and volume of material removed from a large gully upstream of the wetland, and measured streamflow and ground water surface elevations in the lower watershed in order to evaluate the effects of gully formation in this area on ground water levels. Conclusions drawn from these observations have allowed me to develop a conceptual restoration design for the Rodeo Beach Parking Lot, which is presented in Chapter 6.

The contributing watershed consists of several sub-drainages that feed a wet meadow located just upstream of the parking lot, as shown in Figure 10. The upper watershed is grass- and shrub-covered, with occasional hillside springs and associated slope wetlands, while the lower watershed consists of large floodplain wetlands and discontinuous channels with discontinuous riparian woodlands. Several of these channels have experienced severe erosion in the past 60 years, resulting in the formation of deep gullies. Material removed from these gullies has been deposited where valley gradients are less steep, essentially forming the wet meadow.

The existing parking lot occupies a portion of the original gun and tractor park, and consists of a paved and an unpaved parking area. The paved parking lot has approximately 195 parking spaces, while the unpaved area is roughly the same size, though parking spaces are not delineated. The two areas are separated by a drainage ditch, lawn, public picnic area and restrooms that have been constructed in recent years by the GGNRA. A culvert under Mitchell Road routes water from this ditch and the upper watershed onto Rodeo Beach.

Rock types under the Rodeo Beach Parking Lot Watershed are the generally the same as those found elsewhere in the Rodeo Lagoon Watershed (see Section 2.2 for a complete description), but are more fractured and faulted than in other locations. A major east-west thrust fault has been mapped as crossing the watershed at an intermediate elevation of approximately 300 to 400 feet with mostly chert on the south side (upper fault block), and Franciscan greenstone and melange on the north side (lower fault block; Blake et al, 1974). Another major fracture was mapped along the axis of the East Fork Valley (Shlocker, 1974), nearly perpendicular to the grain of most thrust faults.

Given the complex and highly fractured geology, it is not surprising that a large number of springs are concentrated on the north side of the fault, near a contact between chert and greenstone. These springs were mapped as channel heads by the Army in 1925, and are still present today. Only one spring was mapped in the lower portion of the watershed, very close to where the historic farm was located, but several unmapped springs and small slope wetlands have been observed in the field.

USDA soil maps show the flat bottoms of these valleys to be overlain by the Rodeo clay loam. This soil is described as having a very low permeability, with slow runoff, with an ability to perch and hold water between December and April. The area covered by the Rodeo clay loam in USDA mapping appears to extend below the Rodeo Beach Parking Lot, and serves as a rough first approximation of the extent of historic wetlands in this area, but should be verified through a more thorough subsurface investigation. The Cronkhite-Barnabe complex has been mapped on the upland slopes adjacent to the valley, and are described as shallow, well-drained soils with rapid runoff. Soils under the built areas of Fort Cronkhite are mapped entirely as fill ('xerothents'), from the paved portion of the Rodeo Beach Parking Lot to the Marine Mammal Center.

5.1 Site-specific investigation methods

5.1.1 Historic map and aerial photograph analysis and interpretation

Striplen et al. (2004) presented a comprehensive evaluation of recent landscape development in the lower portion of the valley and at Rodeo Beach using historic maps and aerial photos. To further evaluate the specific changes that have taken place at this location, and in the watershed, I have acquired the same set of historic maps and aerial photos, beginning with topographic coastal surveys of the 1850's through modern USGS digital topographic data. I also conducted a two-day topographic survey of the area using a TOPCON GTS-212 total station with Park Service Staff. I then used an inverse distance-weighted nearest-neighbor interpolation method in ArcMap GIS software to generate a 1-foot contour interval map for comparison to historical conditions.

5.1.2 Assessment of sediment transport and deposition rates

To assess rates of sediment delivery from the upper watershed to lower wetlands, I have measured the volume of the 'West Tributary of the East Fork Gully' (renamed 'Gun Gully'), the most actively eroding channel in the watershed. I obtained and examined historic maps and stereo-paired aerial photographs in order to characterize the timeframe or episodes of gully development, and then surveyed six representative cross-sections along the length of the gully (as shown in Figure 10) using a hand-level and stadia rod. Dimensions of a channel draining the deposition area downstream of the gully were also measured. Cross-sectional areas were multiplied by the length of the channel to obtain a volume of

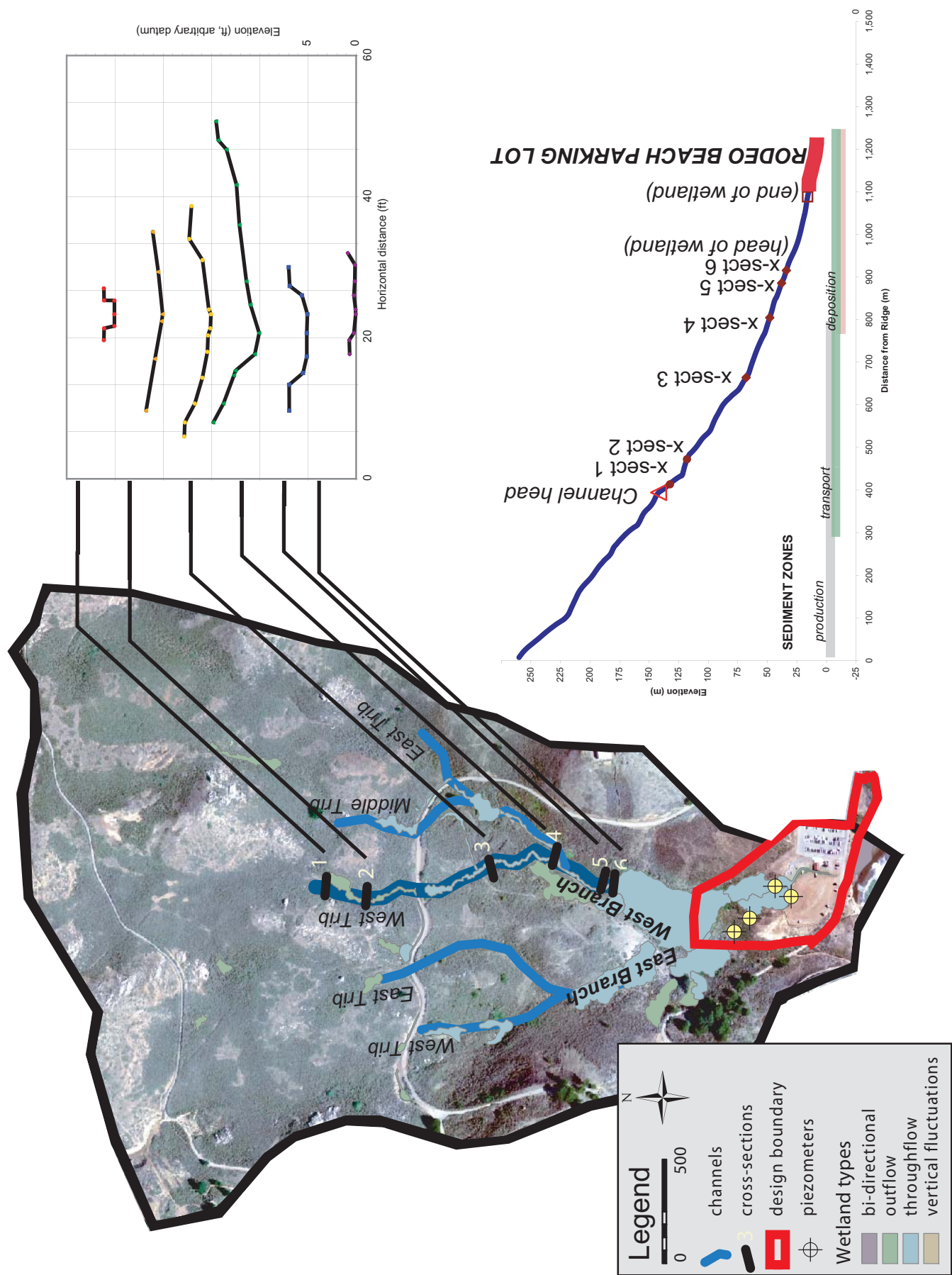


Figure 10. Rodeo Beach Parking Lot Watershed showing Gun Gully cross-sections and longitudinal profile

sediment removed. Deposition rates were calculated by dividing volume estimates (depth and width of deposits at the head of the fan) by the age of the deposit, as inferred from partially buried willow trees and aerial photographs. I calculated a watershed-wide volume of sediment evacuated from gullies by measuring width and depth of several representative channels, and multiplying the cross-sectional area by channel length, as measured off of aerial photos.

Gaging records are not available for this area (the closest gauged stream is below a dam, about 25 miles away), so estimation of typical stream discharges is difficult. I have approximated 'bankfull' flow in this watershed based on direct observations of peak streamflow in nearby streams for a 2 to 5-yr rainfall event (approximately 1 km to the east). I estimated velocities associated with this discharge according to Manning's equation, using roughness (n) estimates from photographic guides and field observations.

5.1.3 Ground water levels

Four shallow monitoring wells (piezometers) were installed in the lower area of this watershed, as shown in Figure 11. Piezometer locations were chosen in order to coarsely define the water table and bedrock surface and to evaluate the degree to which channel incision is associated with a lower ground water table. A small piezometer network was installed just upstream of the dirt parking area. Piezometers were constructed of 2-inch diameter schedule 40 PVC pipe, as shown in Figure 8, and inserted into a hand-augered 3.5-inch diameter hole. The bottom 2 to 4 feet of each piezometer was constructed from screened PVC, and the remaining upper portion was unscreened. The hole was backfilled with sand, and the upper 1-foot was sealed with native clays. 2-inch PVC cap was used to close and seal the top and bottom of each well. Subsurface conditions encountered during excavation of the hole were logged, and samples were retained from different stratigraphic layers. Analyses of these soils were not carried out, but the samples have been preserved, should lab analyses be required in the future.

Water level measurements were taken from the north side of the top of each piezometer, which were surveyed to established benchmarks, so that water surface elevations could be recorded in both in terms of true elevations (MSL), and depth below the ground surface. Depth-to-water readings were taken monthly. Specific conductance, a measure of the dissolved ions, was measured in piezometers during the late summer in order to evaluate and distinguish different water sources. Specific conductance is dependent on water temperature, and was first measured at field temperatures and then corrected to a 25 degrees Celsius, the standard reporting temperature for comparison purposes.

5.1.4 Surface water flow

I took manual streamflow measurements at the Rodeo Beach Parking Lot culvert outfall on an approximately monthly basis, as shown in Table 3. During winter storms, streamflow from this location was too high to measure using a bucket, so flow rates at the culvert outfall were estimated visually, while more precise measurements were carried out in the surface ditch of the parking lot.

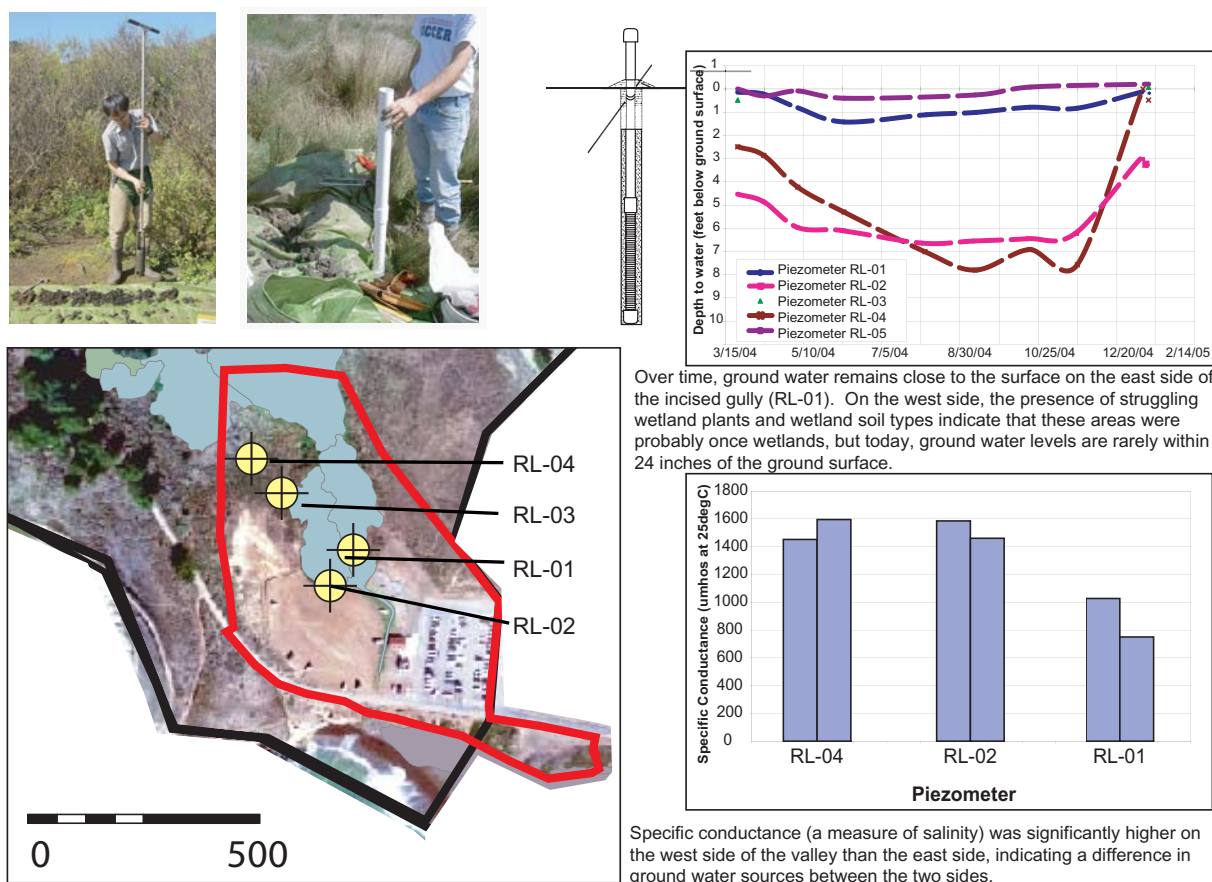


Figure 11. Ground water monitoring at the Rodeo Beach Parking Lot

5.2 Findings of the site-specific investigation

5.2.1 Landscape development

Several generations of activity that have shaped the Rodeo Beach Parking Lot Watershed can be inferred from historic maps and aerial photos, as shown in Figure 12. Coastal mapping in 1853 shows that no channels were present in the lower watershed prior to settlement by Europeans, although topographic lines indicate that channels may have been present at upper reaches of the creeks. In 1925, prior to the development of Fort Cronkhite, the watershed was home to a small agricultural and dairy operation. An Army-produced map from 1925 shows that several grain fields and a barn were located about 1500 feet upstream of the current dirt parking lot area, and were connected to Rodeo Beach by a main road up the center of the valley.

The East and West Forks are shown as continuous channels at that time, each fed by a hillside spring at the headwaters. The forks are also shown as joining together just before crossing under the farm road. It appears that, in an effort to maintain only one bridge crossing, the farmers diverted the West Fork into the East Fork just upstream of the road. An oblique aerial photo of the area taken at approximately the

same time (1922 or 1925) shows that the large dirt turnaround area had not yet been established. Fort Cronkhite construction completion documents show that this road crossing was improved by the Army, when the culvert was replaced and routed straight to the beach, and reinforced at the upstream end with a concrete headwall (Meyer Construction Company, 1941). The same documents show another road on the west side of the valley, parallel to the stream channel, when Fort Cronkhite was built. This road is not visible on later aerial photographs, but its remnants are visible in the field.

The 1946 aerial photo shown in Figure 12 shows the established gun and tractor park. The paved road that traverses the watershed at intermediate elevations was also established between 1922 and this time. Darker areas of the parking lot are also visible in this photograph and mark the trace of the farm-era channel as it emptied directly to the ocean.

Aerial photos from 1960 and 1965 indicate that the discontinuous channel grew during this time. By

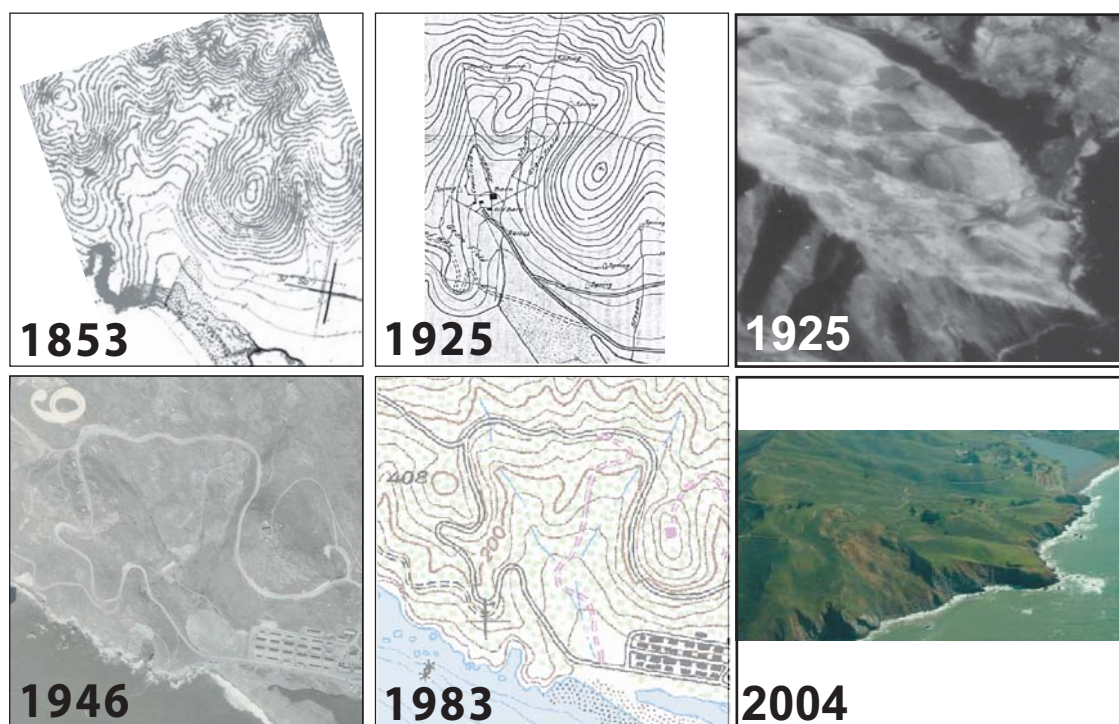


Figure 12. Changes over time at the Rodeo Beach Parking Lot. Early coastal mapping (two separate surveys and maps) does not show channels to be present in the watershed, except perhaps for the East Tributary to the West Branch. Sand dunes were drawn to extend well to the base of the hill, behind where Fort Cronkhite exists today.

1984, these willow patches had grown significantly, and much of the dirt parking lot began to be overgrown. While the West Fork channel appears to have stabilized by this time, Gun Gully had formed in the west tributary to the East Fork, propagating upstream and downstream from channels at the army road crossing near the culverts. This channel was almost continuous from an approximate elevation of 120 feet to 440 feet, with the exception of a short reach at the confluence with the neighboring east

tributary, where a large amount of sediment had been deposited. By 1996, the gully had enlarged and was continuous along its length, ending about 40 feet downstream and east of where another channel begins. The lower channel originates from a roadside ditch that is shown on 1946 photos, and does not appear to have changed much since that time.

Sediment removed by the gully has been deposited in a large fan across the wetland that lies just upstream of the gun and tractor park. As is typical of alluvial fans, material is coarsest at the head of the fan and becomes finer with increased distance from the fan head. Willows became established near the mouth of Gun Gully, but have since been buried by coarse sediment in this area, similar to other valley floors in the Rodeo Watershed. A comparison of wetland areas between 1946 and 2004 shows that the alluvial fan area has remained covered by wetland vegetation over the past 60 years.

The lower watershed – Rodeo Beach Parking Lot and Rodeo Beach

Downstream of the old farm road crossing, historical channel alignments are not as clear. The beach was mapped twice during early United States Coastal Surveys, once in 1850 and again in 1853; in both cases it was at the northern or southern extent of the mapping area (Striplen et al., 2004). In the 1850 map, the beach is shown as extending well into the present-day Rodeo Beach Parking Lot, while the 1853 map shows the northern beach extent to be more limited, ending approximately 100 feet north of Mitchell Road. These maps imply that beach sands accumulated at the mouth of this valley, deposited by winds, and/or high tides, while the outflow from Rodeo Lagoon during mid-winter storms occasionally cut a channel through the beach. The early aerial photograph Figure 12 shows no roads to be present at the edge of Rodeo Lagoon, while the Dairy Farm access road was several hundred feet north of the Lagoon edge. The trace of this original road is visible in the field and on recent high-resolution aerial photographs, and appears to have been located behind where Fort Cronkhite lies today, at an elevation of approximately 70 feet.

It is likely that the East and West Forks consisted of discontinuous channel systems prior to European settlement, as described in Chapter 3. If the erosional cycle presented in Chapter 3 was occurring in this watershed, these discontinuous channels probably migrated laterally, as well along the axis of the valley, and transitioned to the beach and dunes at the western end of Rodeo Lagoon. The exact location of a channel draining the Rodeo Beach Parking Lot Watershed was therefore given to chance, just as the locations of shifting beach sands and dunes were.

When the army replaced the farm road culvert, they also installed an approximately 600-foot-long culvert from the upstream portion of the project area to the south side of Mitchell Road, where two 36-inch corrugated metal pipes spill onto Rodeo Beach. This culvert is still in place, and has effectively cut off

the hydrologic connection between the Rodeo Lagoon outflow channel and the upper watershed. Since this long culvert has failed in many places, several deep (8- to 10-feet) sinkholes and gullies have formed immediately upstream of the parking lot, as shown in Figure 13. During the winter and spring, surface water flow is captured by these sinkholes and routed to the beach via the culvert, where flow discharges into the ocean or the lagoon, depending on the position of beach dunes. Water that is not captured by the sinkholes and culvert is currently routed around the Rodeo Beach Parking Lot through ditches, and enters the culvert through a storm drain at Mitchell Road.

5.2.2 Streamflow from the Rodeo Beach Parking Lot Watershed

Streamflow and wet conditions persist year round in this watershed. In August and September 2004, outflow from the culverts dropped to about 1 to 5 gallons per minute (0.002 to 0.01 cfs) at the culvert outfall. Water was also present in the surface ditch around the edge of the parking lot at this time, draining the surface water from the east side of the valley floor. A summary of streamflow measurements taken in this area is presented in Table 3.

I have estimated bankfull discharge based on direct observations of peak flows in nearby streams. On February 25, 2004, a major winter storm occurred, with a peak rainfall intensity of 1.2 inches in three hours. The recurrence interval for a storm of this intensity is about 2 to 5 years (Rantz, 1971), and I observed peak discharge just above streambanks (but still within incised channel corridors) in the Rodeo Watershed at this time. Peak streamflow on Rodeo Creek was 34.75 cfs (23 cfs /square mi), and peak streamflow on Gerbode Creek was 29.3 cfs (18.3 cfs /square mi). Flows were too high to measure in the Rodeo Beach Parking Lot, but I did observe suspended sediment-laden water discharging from the watershed on this day. Applying the average of these unit runoff values to the Rodeo Beach Parking Lot and Gun Gully watersheds yields an estimate of bankfull discharge, or the discharge associated with rainfall intensities that occur on average 2 to 5 years, approximately 6.2 cfs at the outlet of the Rodeo Beach Parking Lot Watershed and 2.6 cfs in Gun Gully. Using Manning's equation with surveyed channel dimensions at cross-section 3, I found bankfull streamflow velocity and depth at bankfull discharge to be 4.40 ft/s at a depth of 0.39 feet in Gun Gully and 5.18 ft/s at 0.164 ft depth in the wetland channel, just upstream of the Rodeo Beach Parking Lot.

Published relationships between drainage area (d.a.) and bankfull discharge (Q_{bf}) yield slightly higher values than what I have estimated for the Rodeo Beach Parking Lot Watershed. Leopold et al. (1964) found this relationship to be

$$Q_{bf} = d.a.^{0.75} \quad (3)$$

while Dunne and Leopold (1978) published a relationship for the San Francisco Bay region of a similar form;

$$Q_{bf} = 53d.a^{0.93} \quad (4)$$

Applying these relationships to the Rodeo Beach Parking Lot watershed yields significantly higher values than what I have estimated (29.9 and 17.8 cfs, respectively), so my calculations of the size particle that will be entrained at bankfull discharge may be considered a low estimate.

5.2.3 History of sediment transport and channelization

Montgomery (1994) showed that channels receiving drainage from roads tend to form with smaller drainage areas and at lower slopes than undisturbed channels in Tennessee Valley (which borders the Rodeo Beach Parking Lot Watershed), due to the concentration of runoff, so it is likely that culverts and roads contributed significantly to the formation of Gun Gully. Aerial photos show that incision and erosion from the gully reached a maximum between 1965 and 1984, when Gun Gully propagated upstream and downstream from road crossings that were built in the early 1940s. Several channels were formed prior to the development of these army roads, including a nearly continuous channel in the West Branch of the Rodeo Beach Parking Lot Watershed. Increased peak discharges from grazed slopes probably also contributed to the development of a continuous channel in this area. Incision likely occurred in the early 1980s, when the climate was transitioning from the driest period in the century to the wettest period in the century, as shown in Figure 2. Schumm (1999) and Hecht (1994) concluded that extremely dry periods can reduce the amount of vegetative cover and associated root cohesion, while wet periods generate more runoff. During the late 1970s and early 1980s, the conditions were perfect for gully-generation.

Figure 10 shows measured channel cross-sections in Gun Gully. Based on the geometry of these sections, the channel length between them, and the gully history as inferred from aerial photos, it appears that approximately 55,000 cubic feet of soil was removed from the channel during the 30-year period between 1965 and 1996. This implies an erosion rate of 1830 cubic feet per year (415,220 kg/yr/km²). Estimates of channel geometry and lengths on other portions of the watershed imply that at least 203,000 cubic feet of material was removed by channel incision over the entire watershed, presumably since the time of development for agriculture (based on US Coast Survey mapping). These figures imply a watershed-wide erosion rate of 1340 cubic feet per year (143,843 kg/yr/km²).⁴

Sediment removed by the gully is deposited in a large fan across the wetland just upstream of the gun and tractor park, and in a typical alluvial fan fashion, material is coarsest at the head of the fan and becomes finer with increased distance from the fan head. Willows that formed after 1965 have been buried approximately 1 m of coarse sediment in this area, similar to other valley floors in the Rodeo Watershed. During the winter, water flows diffusely across the top of this wetland, and continues well

⁴ Assumes an average soil density of 2.65 gm/cm³, equal to that of quartz, the most dominant mineral in the basin.

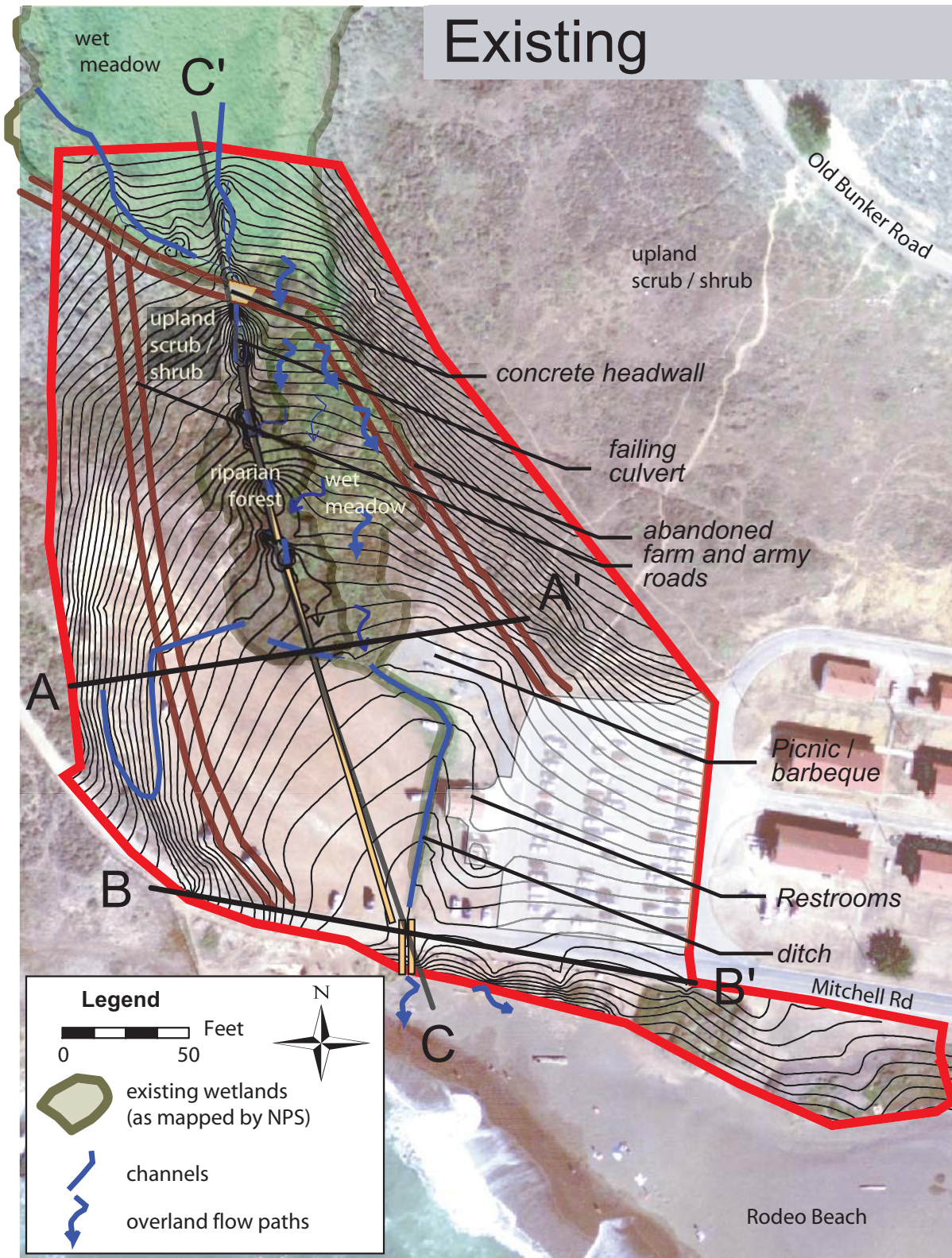


Figure 13. Existing conditions at the Rodeo Beach Parking Lot. On the east side of the damaged culvert, water flows diffusely across the top of the wetland surface. On the west side the ground water table is low, and water is only present immediately following rainstorms. Abandoned road grades and associated drainage ditches, as well as ground water discharge, appear to be delivering water to the east side, while flow to the west side is diverted into the culvert, upstream of the historic road crossing. It also appears that the reinforced concrete culvert is preventing incision from propagating upstream into the wet meadow.

into the summer, apparently maintained by the numerous hillside seeps and springs emanating from the East Fork. Modeling the alluvial fan as a wedge 170 m long and 90 m wide, according to these figures, I estimate the total volume of material deposited in this wedge to be approximately 275,000 cubic feet. This figure implies that approximately 20 percent of the material deposited in the alluvial fan is a result of sediment loss from Gun Gully, and that additional sediment is derived from the other tributaries, and / or this alluvial fan and wetland began forming prior to the development of Gun Gully.

Even though these sediment production rates reflect a minimum estimate for this area, they at the upper range of worldwide sediment production

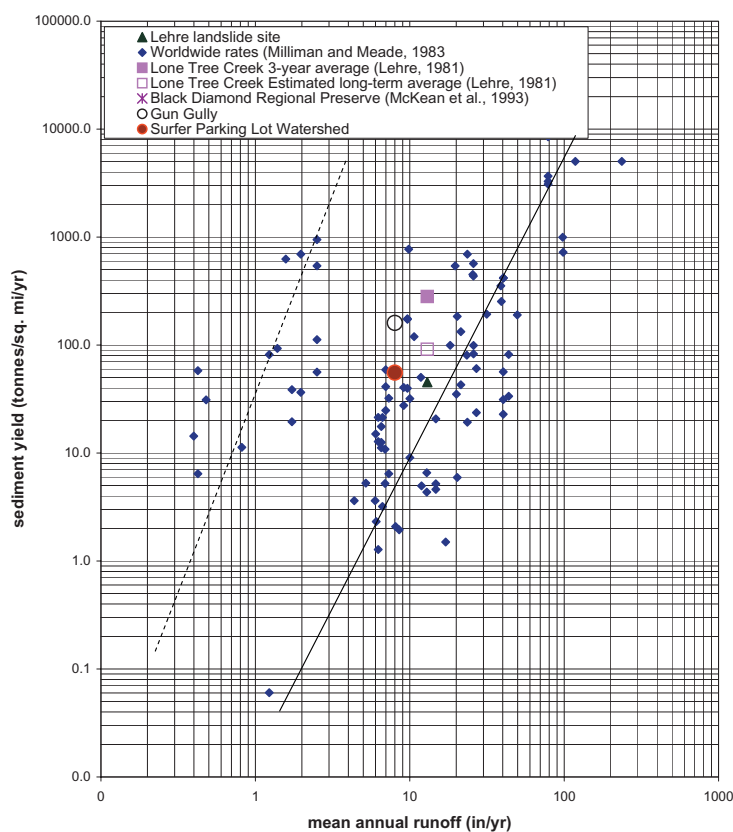


Figure 14. Sediment production rates in the Rodeo Beach Parking Lot Watershed in comparison with rivers of the world and Lone Tree Creek. For comparison purposes, the data sets have been grouped according to mean annual runoff. The dashed line reflects rivers with less than 2 inches per year of runoff.

different rates in different areas of the Rodeo Beach Parking Lot. On the east side of the culvert, the water level remained near the ground surface through the winter, and never dropped more than 1.5 feet below the ground surface, implying that a regular source of water, such as a spring or seep is present in or upstream of the eastern side of the valley. In contrast, ground water levels on the west side of the channel and culvert dropped from 6 to 8 feet below the ground surface during the summer, as shown in Figure 11.

rates (Milliman and Meade, 1983), and similar to the 730 tons/yr/km² measured by Lehre (1982) in the Lone Tree Creek Watershed, about 20 miles north of the study site (Figure 14). Poesen (2003) reported mean sediment yields in Mediterranean catchments with some gullies to be 297 tons/yr/km², while catchments with numerous gullies had mean yields of 961 tons/yr/km². Where no gullies were present, mean sediment yield was 74 tons/yr/km². My findings are slightly below these values, probably because I have not considered other sources of sediment; minimum sediment yield from the entire watershed, Gun Gully, and the alluvial fan wetland were 144, 415, and 50 tons/yr/km², respectively.

5.2.4 Ground water

Figure 11 shows that ground water levels during the spring and summer recede at

At piezometer RL-02, almost directly above the culvert, I observed water being diverted by the small ditch around the perimeter of the parking lot, while ground water levels just past the ditch dropped significantly. Even during peak runoff periods, the ground water level rarely came within 3 feet of the ground surface in this area, an indication that the fill material in the north end of the parking lot is well drained, and probably very well connected to the culvert that empties onto Rodeo Beach.

During the late summer, I found specific conductance of ground water to be different on the opposite sides of the buried section of the Main Branch of the Rodeo Beach Parking Lot channel, indicating that at least two distinct sources of water are present in this area. On the east side of the channel, specific conductance was in the 1000 $\mu\text{mhos}/\text{cm}$ range, while it was significantly higher on the west side, around 1500 $\mu\text{mhos}/\text{cm}$. In general, differing specific conductance values indicate ground water transit through differing or more easily dissolved geologies, or simply a longer transit time through (and more opportunity to dissolve) the same rock types, or a combination of these two conditions (Hem, 1985). In the case of the Rodeo Beach Parking Lot, the geology on both sides of the valley is mapped as similar, so it is likely that ground water on the west side of the valley has experienced longer residence times in the ground. I am unsure whether this is due to a more distant recharge area, or simply slower ground water velocities.

5.3 The occurrence of modern-day wetlands

Figure 13 show the observed movement of water at the site and other physical features that affect the site hydrology. Figures 15, 16, and 17 contains cross-section representations of existing subsurface conditions, as inferred from field investigations. A large wet meadow is present on the valley floor, upstream of the Rodeo Beach Parking Lot, presumably due to the deposition of sediment at the mouth of Gun Gully. During the winter, water exits the gully and flows diffusely in several small channels across and down the axis of the valley, remaining perched on the low-permeability Rodeo clay loam. The historic road crossing, reinforced with concrete in the late 1930s, appears to control the elevation of this wetland, keeping water and sediment from moving away from the area.

Downstream of the historic road crossing, the valley floor and historic wetlands appear to be severely impaired due to drainage by the long culvert that extends to the beach. The culvert is damaged and broken in several locations, resulting in several sinkholes. During water 2005, I observed significant volumes of water (0.25 to 1.0 cfs) disappearing directly into these sinkholes. In several locations, channel incision has degraded to below the original culvert elevation and piping is taking place, where water actually flows through subsurface openings below the original culvert. On the east side of these sinkholes, some water appears to be captured by ditches associated with the old road, and help maintain a small wet meadow. On the west side, conditions are much drier.

5.4 Summary of historical and current conditions

Some combination of road-building, cattle-grazing, channel re-alignment, and climatic conditions appears to have led to the development of gullies and a more continuous channel system in much of the Rodeo Lagoon Watershed, including streams and channels of the Rodeo Beach Parking Lot Watershed. Similar observations have been documented elsewhere in Marin County (Lehre, 1982; Montgomery, 1994; Montgomery, 1999; Haible, 1980), as well as along much of the central California coast. Deposition of a portion of this sediment load in a large alluvial fan appears to be offsetting this process somewhat, apparently aided by the historic farm road crossing, which now acts as a grade control, reducing the degree of headward incision into the alluvial fan. Surface water flow across the surface of this fan and along the east side of the valley is diffuse, and perched on clay-rich soils, and therefore sustains the wet-meadow ecosystem.

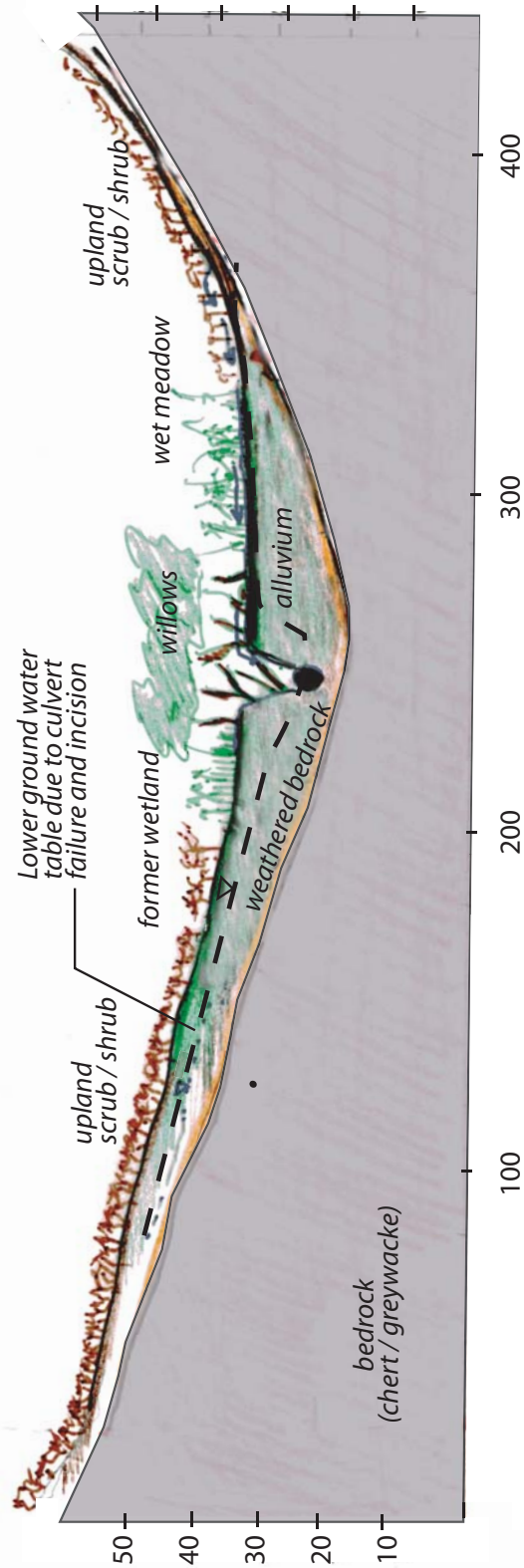
This area was also central to unique biota of the central California coast, in that it provided a relatively rare transitional environment between the ocean, the lagoon, dunes, and freshwater wet meadow. Early mapping suggests that sand dunes associated with Rodeo Beach were present at the lowermost elevations at the mouth of the valley, and probably shifted annually with high tides, and as Rodeo Lagoon overtopped the beach and flowed out to the ocean. Flow from the watershed likely alternated between the lagoon and the ocean, depending on the geometry of beach dunes, as dictated by high tides and storm surges. This hydrologic connection was probably one of shallow ground water flow through the dunes during the dry season, with a surface water connection forming during the winter months.

Just north of the dunes in the lower valley, overland flow was probably diffuse across a wet meadow surface, and / or through a network of discontinuous channels, possibly alternating between these forms in response to changes in climate and or disturbance in the watershed. As such, it is likely that the area now occupied by the Rodeo Beach Parking Lot supported a unique transitional ecosystem, from open water of Rodeo Lagoon to emergent lagoon fringe wetland to sand dunes to wet meadows, floodplain wetlands, and riparian trees.

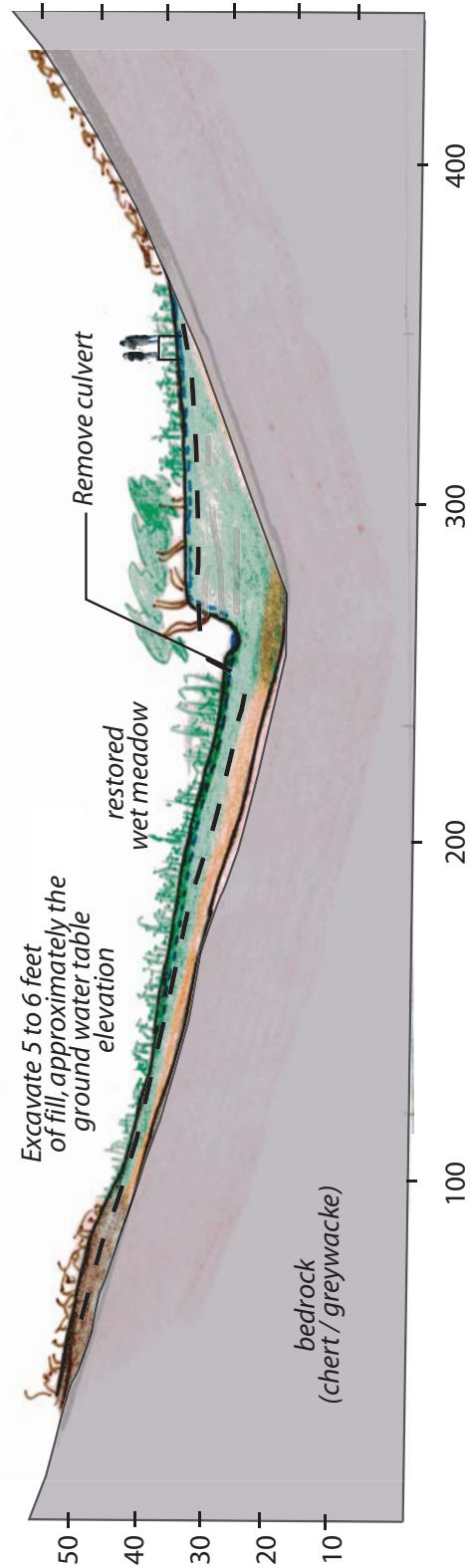
Mitchell Road and the Rodeo Beach Parking Lot were constructed directly on top of this complex, completely eliminating this natural transitional zone. The transition is now one of parking lot to beach, marked by a steep and abrupt slope of rip-rap, which is failing due to high tides and surf. A 300-foot long culvert has replaced the lower valley wet meadow, diverting water straight to Rodeo Beach, bypassing historic wetland areas. Alterations from the weir that was installed at the upper end of the lagoon attenuate the rate of lagoon rise during early winter storms, and has likely reduced the frequency of lagoon opening events during the early rainfall season, thereby reducing the amount of time when the watershed is connected to the lagoon.

A ————— A'

Existing: culvert and channel incised into wet meadow



Proposed: terraced wet meadow

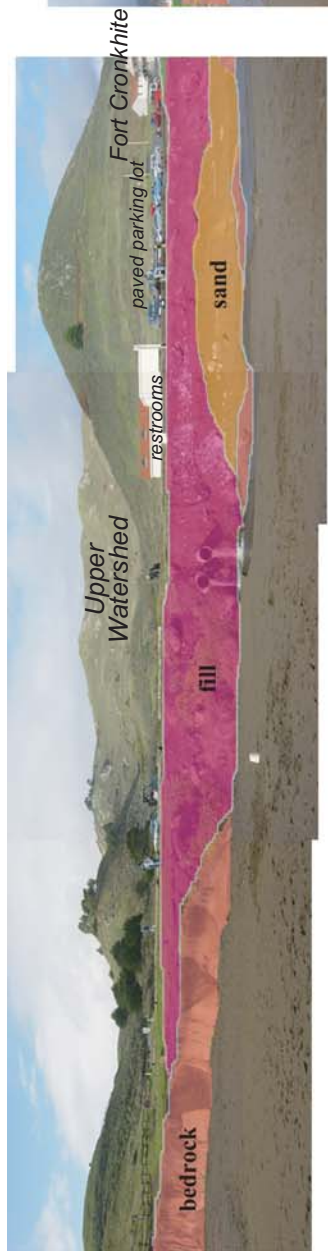


Approximate vertical exaggeration = 4

Figure 15. Schematic cross-section A-A'

B _____ B'

Existing: double culvert in fill



Proposed: remove fill, construct bridge, restore wetland-dune-lagoon transition



Figure 16. Schematic cross-section B-B'. The view from Rodeo Beach makes it easy to discern the depth and extent of artificial fill. Removal of fill and replacement with a footbridge would allow for a more continuous transition zone between the brackish emergent wetlands of Rodeo Lagoon's fringe, dunes, and the upland freshwater wet meadows and riparian trees.

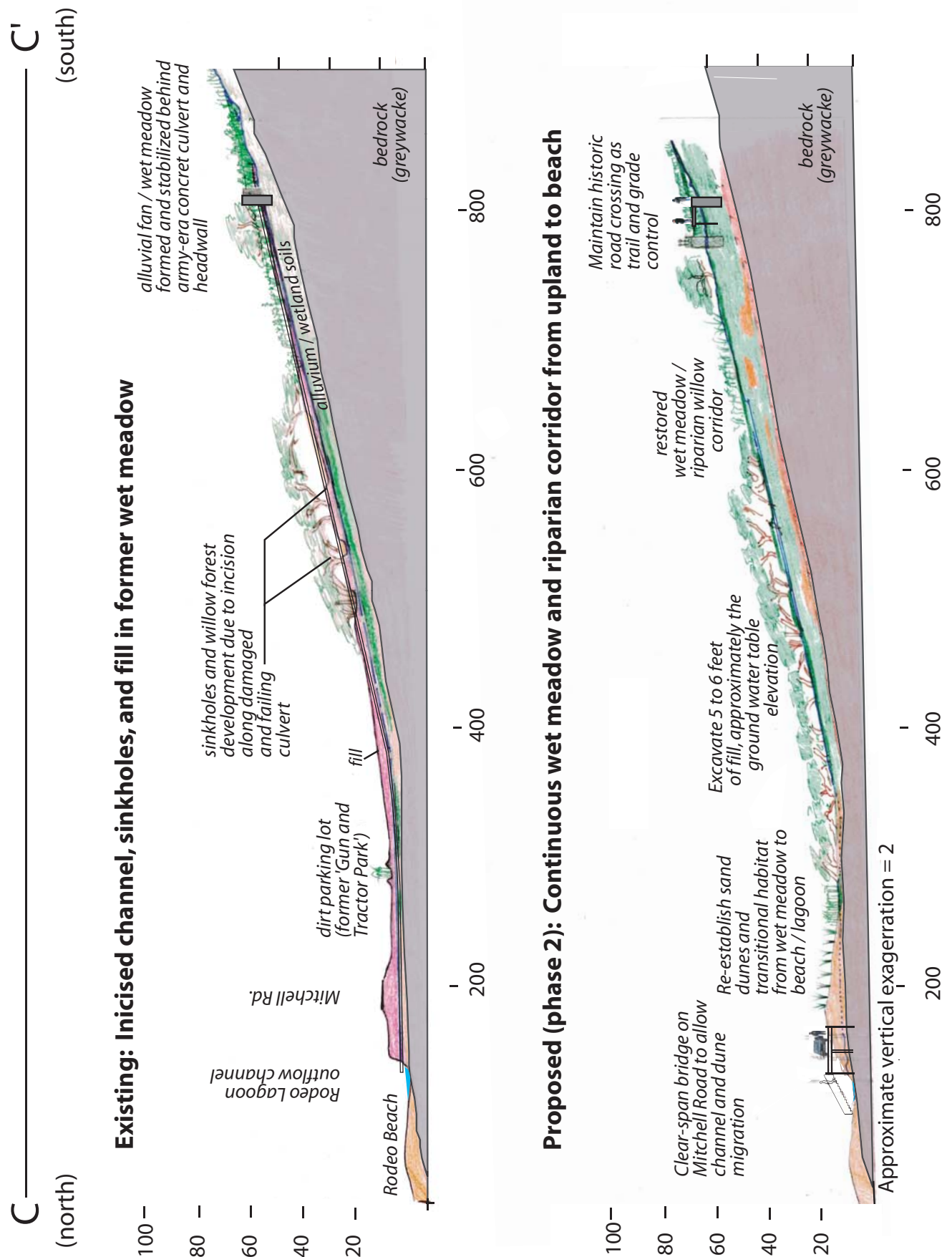


Figure 17. Schematic cross-section C-C'

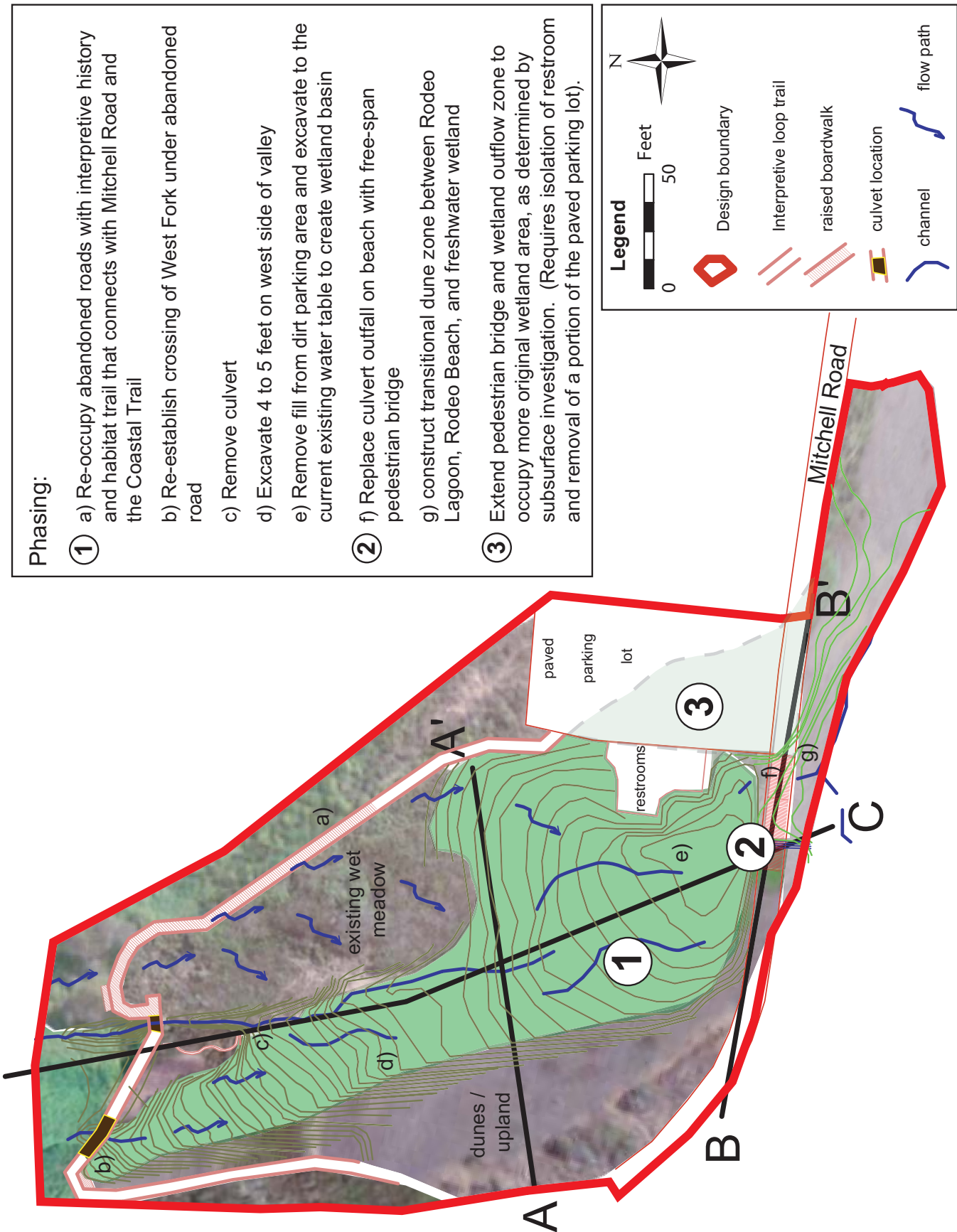


Figure 18. Conceptual wetland restoration plan for the Rodeo Beach unpaved Parking Lot.

6. Conceptual wetland restoration design and guidelines

Based on the site-specific analysis presented in Chapter 5 and summarized in Section 5.4, I am presenting a design that restores conditions which were present prior to the filling of wetlands for roads and parking, while drawing on the positive aspects of the altered processes and forms that are present today. Another goal of the plan is to improve recreational access to the beach, hiking trails, historic areas, and the wetland area itself, in an attempt to increase the public's appreciation for wetland and historic processes in this area. I have identified these processes at the watershed scale, and described the specific influences of these processes on the landscape form at the Rodeo Beach Parking Lot, as follows. Springs and landslides are regularly associated with upper slope wetlands, while lower channels, which recently have experienced incision, are now being filled by sediment delivery from the upper watershed. At the restoration site itself, channel diversions and the placement of fill associated with historic farms and army activities appears to be causing incision and ground water table lowering. As a result, this area has been converted from a transitional freshwater-brackish wetland area to upland and exposed dirt.

The proposed restored wetland at this site consists of a renewed ecologic corridor, transitioning from upland freshwater wetlands to Rodeo Beach and Rodeo Lagoon and the ocean. As such, this corridor has the potential to provide a wide array of habitat types, from wet meadows and riparian woodlands to sand dunes to lagoon fringe to open water of the lagoon. I present an optional phased approach to establishing this wetland complex, so that if necessary, funding opportunities can be obtained over time from a variety of sources. Ideally however, the project would be completed in one step. The primary components of the plan are as follows:

- a) Construct a recreational and interpretive loop trail around the perimeter of the project site that follows the alignment of historic roads.
- b) Separate the East and West Branches upstream of the historic road crossing,
- c) Remove the 300-foot long failing culvert,
- d) Excavate a portion of the valley floor on the west side of the failed culvert to create an entrenched wet meadow,
- e) Excavate portions of the parking lot area to elevations that are closer to the ground water table and plant appropriate native wetland plant species,
- f) Reconstruct a portion of Mitchell Road as a clear-span foot bridge to allow migration of the dunes and outflow channel, and
- g) Construct dunes on the north and south side of Mitchell Road,

Steps a through e will be completed during Phase 1, and bridge and dune construction will occur during Phase 2. Phase 3 consists of expanding the project to incorporate more of the original connection between the upper watershed and the lagoon, including the public restrooms and a portion of the paved parking area. Phase 3 is a more complete restoration of the wetland that once occupied this area, but will not likely be feasible as a component of the Park Service's Transportation and Management Plan, due to

parking needs and restroom relocations costs.

6.1 Restoration overview

When the West Branch was realigned and forced to join the East Branch at the historic road crossing, peak discharges were effectively doubled in the lower East Branch channel. Separating the two streams will reduce the peak flows through the existing incised gully, and distribute water more diffusely across the restored wetland area. To prevent nickpoint, or headward, incision into the wet meadows upstream, this re-alignment will require grade control, a function currently provided by the historic road and concrete headwall at the upstream end of the incised gully. A second crossing under the historic road at the new West Branch crossing would likely achieve this function, especially if properly engineered, and is included as a component of the proposed interpretive loop trail. The channel could be reinforced with rip-rap or poured concrete in order to exert the same elevation control currently provided by the existing reinforced concrete culvert.

The existing channel bottom elevation at the upstream end of the road is currently at an elevation of 59 feet above sea level. On the downstream side, the elevation is approximately equal to this, so some excavation will be required in order to attain a connection to the channel upstream. Excavated material and planted willow trees can be used to create the diversion between the two channels, although initially, reinforcing material such as riprap, will likely be necessary. This excavated area will also create a shallower ground water table, as shown in cross-section A-A' (Figure 15), and will provide access for culvert removal, as the culvert currently lies about 10 feet below the valley floor in an incised channel.

Figure 18 is a site plan of the proposed restoration, showing proposed 1-foot contours. The proposed contour lines were drawn based on the existing ground surface, as determined through a topographic survey (Figure 13). The ends of the proposed contour lines correspond to the existing ground surface elevation, so where proposed contours are not shown, little or no grading is recommended. Side slopes of the excavated area have been drawn at 3 to 1 slopes as a first approximation, and should be reviewed by a registered civil engineer.

Filling and /or repair of the gully and sinkholes that have formed around this damaged culvert will be difficult due to piping and subsurface flow paths that have developed, and would require severe alterations to the existing concrete culvert stabilizes the upstream wetland elevation. It is therefore advantageous to leave this gully open and connected to the excavated area after removing fill associated with the dirt parking lot. As described in the previous chapter, a dominant wetland-forming process in this watershed appears to be high rates of sediment delivery from erosion in the upper watershed and deposition in the lower watershed. It is expected that excavation and basin creation will provide the space for both

sediment and water retention- the ideal natural conditions for formation of a system of discontinuous incised channels and wet meadows. It should also be expected that these channels and wetlands will shift, both horizontally and vertically, so construction of distinct low-flow channels is unnecessary, and could even slow sediment deposition rates.

Moving downstream, the East and West Branches will join together in a broad depression formed by removal of parking lot fill, and bound at the downstream end by Mitchell Road and constructed sand dunes, as diagrammed in Figures 17 and 18. During both phases, Mitchell Road will be maintained at its current elevation in order to provide access for hiking and biking. During Phase 1, the roadway will remain as it is, above the wetland after fill is excavated from the dirt parking lot. Some degree of protection or reinforcement will therefore be required on either side of the road at this time. Phase 2 calls for replacement of the paved road and culvert with a free span pedestrian bridge, perhaps pier supported (see Figure 16) or constructed from a flat bed railcar. Although this upper watershed entry point will become impassable to cars and trucks, access for fire control will still be available via Old Bunker Road along the northern edge of Fort Cronkhite.

USDA soil maps (Kashiwagi, 1985), field investigations, and historic maps and photos indicate that buried wetland soils extend well east of this area, underneath the restrooms, public showers, and paved parking lot, so it seems that the connection between the Rodeo Beach Parking Lot wetland and Rodeo Lagoon was historically quite wide, formed over thousands of years by meandering channels emanating from the Rodeo Beach Parking Lot watershed. It is also possible, even likely, that these wetland soils continue along the northern shore of Rodeo Lagoon, well east of the proposed wetland alignment. Phase 3 of this project will address this issue by removing portions of this infrastructure and Mitchell Road to create a more complete connection between the freshwater wetland and the lagoon. These actions will create a wider wetland and dune corridor that closer approximates pre-Army conditions.

Land management in the upper watershed

A variety of approaches are typically used to control erosion from incision and gullies, such as bank stabilization through vegetation planting, grading back banks, or installing grade control structures. Schumm and Hadley (1957), and numerous researchers afterward, have shown however, that the process of incision and upstream nickpoint migration is common, especially in episodic environments, where deposition occurs in lower reaches due to the evacuation of sediment in upper reaches. In the case of the Rodeo Beach Parking Lot watershed, deposition in downstream areas due to erosion from upstream has significant potential to fill in channels and naturally construct a wetland, and appears to be doing so. Erosion control above or beyond normal road maintenance in upper reaches of Gun Gully is therefore unnecessary.

6.2 The human dimension

Central to the restoration approach is the development of an interpretive loop trail and boardwalk that follows the historic alignment of old farm roads, raised to prevent trampling and hydrologic disturbance of the existing wetland. Topographic remains of these roads appear to be key in dispersing water across the site today (see Figure 13), and therefore should be preserved. Similarly, since the abandoned road crossing helps maintain the grade and wetland upstream of the restoration area, it should also be preserved. This relatively short loop trail offers walking opportunities to those who are unable to climb the steeper trails nearby, but also meets Mitchell Road at its western extreme, so people can continue up the coastal trail if they choose. Since the former road alignment has become overgrown by willow forest near the old road crossing, this interpretive trail deviates from the historical alignment at its northeast extreme to skirt the forest. The features along this trail provide a unique opportunity for park visitors to experience the blending of natural and cultural history that dominates this area, as they discover abandoned wells, troughs, and barn foundations of the farming era, old water-pumping stations and military training areas associated with Fort Cronkhite, and deep gullies and wetlands that result from these activities. For example, the seasonal appearance of strikingly white calla lilies against a green wet meadow refers the visitor to the abandoned human component of this landscape.

While past field studies offer insight to the physical processes at work in the Rodeo Watershed, experiences in natural systems management in other environments can also guide how this restoration plan is approached. Numerous researchers have explored the impacts of recreation and human use on wilderness areas, ecology, and/or biodiversity, as well as the effects of land management techniques on recreational uses.

It is widely recognized that in general, human activities are likely to have negative impacts on biodiversity. Hester et al (1999) and Redford and Richter (1999) provide comprehensive literature reviews in this regard, and recognize that the type and magnitude of these impacts varies according to the activity and in the characteristics and habitat quality of a site. Bauer et al. (2002) found that the addition of public access in a wetland restoration plan greatly increased the public's willingness to accept the plan. Respondents in that study were more likely to choose a restoration design that included public access than one that did not, even if the design which did not include access resulted in the introduction or preservation of endangered species or came at a lower taxpayer cost. This study highlights a general public philosophy, in which people are interested in preserving and maintaining ecosystem functions primarily for recreation, but not necessarily in order to preserve the non-human ecology of the system itself.

Bauer's study also implies that if the cost of providing public access is relatively small, the gain in public support for restoration expenditures may allow expansion of the number of acres restored or protected, increasing the amount of habitat conserved. Supporting principles of 'eco-revelatory' design have emerged in the past decade and call for acceptance of humans into the ecosystem that is being restored, especially in urban areas (Galatowitsch, 1998; Nassauer, 1995; Clergeau et al., 2001; Schroeder, 1996; Mozingo, 1997). Nassauer's (1998) 'cues to care' and Ryan's (2002) 'people-centered approach to restoration' highlight that advocacy and stewardship of natural areas can be developed simply by encouraging people to experience those areas, while Schroeder (1996) explains that it is just as important to restore the human experience of relationship to the ecosystem, as it is to restore the ecosystem itself. Higgs (1997) argues that simply creating harmonious human relationships with ecosystems sets up conditions for successful restoration projects.

Several themes become apparent in evaluating the literature regarding the human interaction with natural and ecological restoration areas. The general public's desire to preserve and restore such areas stems primarily from recreational desires. Managers who wish to protect ecological systems from overuse are more likely to be successful if they include the public in the management and stewardship process, rather than prohibit them from those areas, even if this might compromise ecological quality. Maintaining public access in order to restore and/or preserve human dimensions of an ecosystem, is therefore an acceptable and even desirable goal for a restoration project, especially in a heavily-used area such as the Rodeo Beach Parking Lot, and is therefore included in this plan.

6.3 Success criteria, monitoring, and adaptive management

It is important to recognize the inherent dynamism of this restored environment, and that a successful restoration is one where oscillations and episodes of severe change result from the processes that we are attempting to restore. In establishing a successful habitat restoration however, measurable goals must be identified and established in order to quantify the degree to which the intended processes have been restored. Both prior to and following construction of the restored wetland and trail at the Rodeo Beach Parking Lot, the following methods and measurements can be used to summarize the degree of success of this project:

- **Cross-sections topographic surveys** will outline the degree to which sediment is filling the wetland, and will record the development and / or migration of channels within the excavated basin. Success in this regard is considered to be the accumulation of sediment after several years, and development of a wide floodplain or wet meadow with year-round shallow ground water conditions.
- **Vegetation transects** will record the development of wetland plant species, and will outline the degree to which native wetland plants are recovering in the area. One or more of these transects

should be longitudinal, from the Rodeo Lagoon outflow channel to upstream of the restoration area to evaluate the degree of connectivity that is re-established across these features. A native species richness indicator should be developed as a goal.

- **Ground water monitoring** will measure the degree to which wetland plants are able to be sustained. Ground water elevation and specific conductance data can be also be used to infer directions and pathways of ground water flow.
- **Rainfall, streamflow, and sediment transport monitoring** will provide the context against which to consider monitoring results. For example, channel cross-sections and vegetation changes should be considered in light of rainfall and runoff, as well as temporal position in the multi-year climate cycle.
- **Trail use and user surveys** will record the degree of public involvement and reaction to the restoration project, and can indicate the degree of success of the historic interpretive trail (i.e. How much is it being used? Who is using it? How clear are the interpretive features?)

Pre- and post-project monitoring in this area should be used not only to evaluate the success of this project, but also to guide management decisions and strategies, so resources can be directed to areas where goals are not being achieved. For example, if post-project monitoring indicates that ground water levels are higher than expected in areas designated as dunes, those areas should be actively managed as wetlands, not dunes. Adaptive management of this type will induce land managers to continue evaluating and understanding the wetland processes at this restoration site, and will contribute information to the relatively young and inexact practice of wetland restoration in general.

6.4 Future studies and data needs

I have presented a conceptual restoration plan that draws on the analysis of the watershed and site-specific properties. As is typical, the site design and results of these analyses bring up a host of new questions that should be answered while more detailed restoration plans are being developed and funding for this project is secured.

A subsurface investigation has recently been carried out, using a backhoe and trenches to evaluate the extent and type of historic wetland soils at the site. Results of this study will be summarized in a report to the Park Service in August 2005, and will help to determine the volume of fill and / or native material that will need to be removed and / or re-graded. The report will include recommendations for disposal or re-use of the excavated material as well. For example, the angular chert baserock that currently covers fill of the dirt parking lot could perhaps be used by the roads and maintenance crews, while the underlying sandy material could be used to re-create dunes.

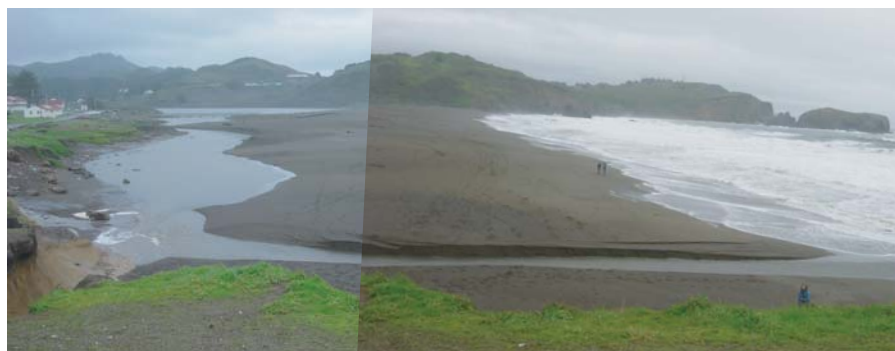
The periodic manual measurements of streamflow and conductivity have added to the understanding of hydrology at the site, but without a continuous record of rainfall, runoff, and dry-season flows, development of an accurate water and sediment budget is difficult. Continuous stream gaging would contribute greatly to this understanding, and would allow for more informed sizing of the wetland basins and stream channels in the restoration area. A convenient gaging station location is at the existing confluence of the East and West Branches of the Rodeo Beach Parking Lot, where the concrete culvert headwall serves as a streambed control and access point. Storm monitoring in this area would ideally include the measurement of both suspended and bedload sediment transport rate, so potential sediment accumulation rates in the restored wetland basin and excavated areas can be inferred. Similarly, the ground water monitoring program developed during this study should be continued, with frequent (weekly to daily) measurement of ground water levels during the winter. Following construction, the streamflow gaging station could be relocated to the outflow channel at Rodeo Beach, or an additional gage could be set up at the West Branch crossing.

Many of these activities are well-suited for volunteer monitoring groups that could offset the costs of monitoring and provide a much more detailed data set. The Marin Headlands Institute has expressed interest in this project in general, and would be an effective partner in developing an appropriate curriculum / monitoring program, that might also consist of visiting the GGNRA Native Plant Nursery to help in the propagation of plants being grown for the project.

6.5 Closing

This report outlines very specific processes and characteristics of a small coastal watershed in southern Marin County, California. Though site-specific in nature, this type of content is necessary for any natural resource planning process, and this study outlines the process by which the information is gained. The natural history, vegetation, geology, soil types, climate, hydrology, human history, and current human uses all have a bearing on the type and amount of habitat that can be made available to other creatures. The chronology and scale by which I approached this problem has allowed me to become familiar with these factors first at a watershed, or regional, level, so I could understand the different types of wetland functions and processes throughout the watershed. Once these processes were identified, I had a context in which to thoroughly present existing wetland impairments and possibilities of wetland restoration, highlighting distinct locations and approaches that might be used. Once the highest priority site was agreed upon, I was able to evaluate the site in this context, and had the appropriate background with which to formulate questions and technical studies. Working across these scales, I have been able to identify an approach to establishing higher biodiversity in central California's unique ecology.

Though this stage of research has been completed, I view it as the beginning of a process. I have presented a vision of what might become of a desolate parking lot and impaired wetland, but without further action, including the future studies and evaluations by certified engineers and professionals, this report is only a description of one alternative for this area. In order to carry this vision beyond the National Park Service and academia, the vision should be revisited, evaluated, adapted, and implemented in order to provide the most benefit to those who use this area on a daily basis.



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Appendix A

Observation Log
Rodeo Watershed
Golden Gate National Recreation Area
Marin County, California

Station	Date and time	Observer	Discharge	Instrument / method	Stage or Depth to Water	Depth to water in piezometers	Water Surface Elevation	Hydrograph	High Water Mark	Water Temperature	Field Specific Conductance	Adjusted Specific Conductance	Additional Sampling?	comments
			(cfs)	(gpm)	(py/AA/lb)	(feet, TOC)	(feet, stc)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)	
Rodeo Lagoon at footbridge to Rodeo Beach														
	elevation =		feet, MSL											
	12/17/03 13:28 DS	--	--	--		3.59		S		9.7	2275	3186		installed staff plate; checked for salinity stratification- none; evidence on beach of surf overtopping into Lagoon
	1/7/2004 11:56 DS					2.53		F		8.8	330	481		
	1/10/2004 10:00					3.39 +/- .02								Lagoon is open, Qoutflow ~3 cfs (vis.est.)
	1/17/2004 12:45 ds					2.46 +/- .02								Lagoon is closed
	2/12/2004 15:30 ds					2.15								
	2/16/2004 11:28 ds					3.43 +/- .03								Lagoon is closed, but flow is slowly creeping over beach, while surf washes sand and gravel to block outflow and flow into lagoon; in equilibrium
	2/16/2004 13:25 ds													Lagoon has opened, is cutting into beach. Check tidal data
	2/17/2004 13:42 ds					3.63 +/- .03								
	2/18/2004 10:00 ds					4.37								Waves washing over N end of beach into Lagoon
	2/25/2004 11:20 ds													Lagoon is open
	3/5/2004 16:20 ds					3.34								
	3/23/2004 17:50					3.20								Lagoon is flowing out into pool below surfer lot culverts and soaking into beach gravels
	3/27/2003 9:00 ds					4.39								
	8/5/2004 11:00 ds					1.21				18.7	7730	8790		GH+/- .02
	9/10/2004 0:00 ds					0.8				18.9	8460	9570		
Surfer Parking Lot outflow														
	elevation =		feet, MSL											
	12/17/03 13:48 DS		0.28	125 float										
	1/10/2004 11:00 ds		1.00	449 vis										
	1/17/2004 12:45 ds		0.22	100 vis										
	2/12/2004 16:20 ds		0.24	107 b										
	2/16/2004 11:00 ds		2.10	942 vis										
	2/25/2004 11:20 ds													very turbid water; too much flow for bucket measurement
	3/5/2004 15:55 ds		0.44	197 b										very turbid water; too much flow for bucket measurement
	3/11/2004 14:00 ds		0.16	74 b										
	3/23/2004 17:25 ds		0.07	30 b										
	4/11/2004 14:24 ds		0.05	21 b										
	5/6/2004 16:00 ds		0.01	4.25 b			0.208333							
	6/8/2004 16:31 ds		0.00	1.080 b										
	8/6/2004 0:00 ds		0.01	3.155 b						17.4	308	362		
	9/10/2004 0:00 ds		0.00	0.8584 b						16.4	420	500		
	11/22/2004 0:00 ds		0.01	2.329										
	1/8/2005 0:00 ds		1.04	467.650 float										
	1/12/2004 0:00 ds		0.42	188.496 float										Estimated about .25 to .5 cfs coming from each culvert; Qmeas is from ditch (approximately equal)
														estimated about 2 cfs coming from culverts (combined); Qmeas is from ditch

Golden Gate National Recreation Area
Marin County, California

Station	Date and time	Observer	Discharge	Instrument / method	Stage or Depth to Water	Depth to water in piezometers	Water Surface Elevation	Hydrograph	High Water Mark	Water Temperature	Field Specific Conductance	Adjusted Specific Conductance	Additional Sampling?	comments
			(cfs)		(feet, TOC)	(feet, Sfc)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)		
Rodeo Lagoon below weir														
			elevation = feet, MSL											
	10/5/2003 DS									19.6	3450	3860		
	12/17/2003 14:28 DS				8.88		11.53 S			9.6	1400	1980		installed staff plate; stratified (changes at depth = 2.0')
										9.7	2230	3157		
	1/7/2004 11:38 DS				7.80		10.45 F			9.8	135	190		not stratified
	1/7/2004 17:05 DS				7.77		10.42							
	1/10/2004 8:17 DS				8.61		11.26							datalogger downloaded to file RL040110.dat
	1/17/2004 12:15 ds				7.72		10.37							
	2/12/2004 16:38 ds				7.43		10.08							datalogger downloaded to file RL040212.dat; GH+/- .02
	2/16/2004 11:28 ds				8.75		11.4							waves colliding with outflow from over weir; GH+/- .25
	2/16/2004 12:48 ds				8.8		11.45							GH+/- .2
	2/16/2004 16:45 ds				8.9		11.55							GH+/- .2
	2/18/2004 10:30 ds				9.5		12.15 R							GH+/- .2
	2/25/2004 11:51 ds				9.98		12.63 R							
	3/5/2004 13:51 ds				8.61		11.26							
	3/12/2004 16:45 ds				8.37		11.02							GH+/- .05
	3/23/2004 18:00 ds				8.45		11.1							GH+/- .05
	4/11/2004 14:25 ds				8.6		11.25							datalogger download to file: RL040412.dat; GH+/- .1
	5/6/2004 16:45 ds				8.37		11.02							GH+/- .05
	6/8/2004 15:29 ds				7.59		10.24							GH+/- .1
	8/5/2004 11:50 ds				6.55		9.2			19.5	7290	8140		not stratified; gage height estimated, water surface is below bottom of staff plate.
	9/10/2004 10:17 ds				6.07		8.715833					3550		stratified: SCT= 8450@25 at bottom; datalogger downloaded to file RL040910.dat
	11/22/2004 16:40 ds				6.20		8.85							downloaded to file: RL041122.dat
	1/12/2005 13:06 ds				7.32		9.97 F							dropping rapidly; downloaded to file RL050112.dat

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Station	Date and time	Observer	Discharge	Instrument / method	Stage or Depth to Water	Depth to water in piezometers	Water Surface Elevation	Hydrograph	High Water Mark	Water Temperature	Field Specific Conductance	Adjusted Specific Conductance	Additional Sampling?	comments
			(cfs)	(gpm)	(py/AA/l/b)	(feet, TOC)	(feet, sfc)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)	
Rodeo Lake above weir														
	elevation =		feet, MSL											
	10/5/2003 DS									15.3	374	460		
	12/17/2003 DS					5.81	11.89 S			9.5	175	254		installed staff plate; uniform flow across all of weir
	1/7/2004 11:38 DS					5.97	12.05 F			9.5	135	190		weir is completely overtopped by 4 to 6 inches
	1/7/2004 17:05 DS					5.96	12.04 F							
	1/10/2004 9:00 ds		8.72	3913.54 py		5.87	11.95							weir is overtopped by ~3-5 inches;
	1/17/2004 12:15 ds					5.85	11.93							
	2/12/2004 16:38 ds					5.85	11.93							
	2/16/2004 11:42 ds					5.50	11.58 F							
	2/16/2004 12:48 ds					5.48	11.56 F							
	2/16/2004 13:45 ds					5.39	11.47 F							
	2/18/2004 10:30 ds					6.26	12.34 R							Weir is completely submerged, wind-driven waves are colliding with laminar flow over weir, very subtle diff. in water sfc elev; waves do not pass into Lake.
	2/25/2004 11:51 ds					6.64	12.72 R							weir is submerged, but outflow appears to be stronger than waves
	3/5/2004 13:51 ds					5.93	12.01 S							Installed 2 waterloggers
	3/12/2004 16:45 ds					5.85	11.93							
	3/23/2004 18:00 ds					5.79	11.87							
	4/11/2004 14:40 ds					5.76	11.84							
	5/6/2004 16:45 ds					5.76	11.84							water sfc elev is almost flush with top of weir, just above water barely flowing over right side of weir, and through flashboards
	6/8/2004 15:47 ds					5.69	11.77							
	8/5/2004 12:00 ds					5.26	11.34			15.6	249	306		~4 to 5" below the top of the weir; removed PTs from stilling well and cleaned
	9/10/2004 11:00 ds		0.11	50		4.29	10.37			14.2	325	408		
	11/22/2004 16:40 ds					5.71	11.79							
	1/12/2005 13:10 ds					6.02	12.1							
Building T1111 tributary														
	6/8/2004 0:00 ds		0.0255	11.4444										
	8/5/2004 12:50 ds		0.00446	2						16.7	253	300		

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Station	Date and time	Observer	Discharge	Instrument / method	Stage or Depth to Water	Depth to water in piezometers	Water Surface Elevation	Hydrograph	High Water Mark	Water Temperature	Field Specific Conductance	Adjusted Specific Conductance	Additional Sampling?	comments
			(cfs)	(gpm)	(py/AA/lfb)	(feet, TOC)	(feet, Sfc)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)	
Rodeo Creek at Rodeo Valley Trailhead (Rifle Range)														
	elevation =		feet, MSL											
	10/26/2003 Erik		0.0166	7.5 bucket										
	12/17/2003 DS		0.604	271.075 py										notched water surface elev in tree trunk
	1/7/2004 12:25 DS,CS		3.664	1644.4										
	1/10/2004 13:15 DS		3.352	1504.38		1.28								Installed staff plate; HWM = 3.90 on 12/31/03(?); water is slightly turbid, secc depth ~3'; GH +/- .02
	1/17/2004 11:45 ds					1.04								GH +/- .03
	2/12/2004 15:05 ds					1.02								GH +/- .02
	2/16/2004 13:00 ds		7.99	3585.91 f		1.68		F					Qss	
	2/18/2004 9:00 ds		5.55	2490.84 f		1.49		F					Qss	branch that was stabilizing staff plate has moved; GH +/- .02
	2/25/2004 9:15 ds					1.96		R						
	2/25/2004 9:23 ds					2.01		R						
	2/25/2004 9:30 ds					2.05		R					Qbed	
	2/25/2004 9:45 ds		21.91	9833.21		2.10		R					Qss	
	2/25/2004 13:15 ds		34.74	15591.3 f		2.30		R						season HWM
	2/25/2004 12:05 ds					3.22		R					Qss,Qbed	
	3/24/2004 8:15 ds,ar		1.093	490.538		0.81								
	4/11/2004 12:00 ds		1.09	490.987		0.80								
	5/6/2004 14:15 ds		0.763	342.434		0.73		B						
	6/8/2004 12:45 ds		0.028	12.5664 py		0.71		B						
	8/5/2004 14:20 ds		0.027	12.1176 py		0.72		B		14.5	202	253		
	9/10/2004 12:00 ds		0.04456	20 vis		0.69								
	10/19/2004 13:30 ds					0.86			0.95					water is more clear than Gerbode
	11/22/2004 0:00 ds					0.71								extensive veg growth at d/s end of pool
	1/12/2005 0:00 ds					1.47								
Gerbode Creek upstream of Rodeo Valley Trail														
	elevation =		feet, MSL											
	10/26/2003 Erik		0.0826	37.1 bucket										
	12/17/2003 0:00 DS		0.479	214.975 py					0.25					HWM = 1.2 above present WSE at staff plate loc
	1/7/2004 13:00 DS, CS		2.74	1229.71 py					1.4					HWM = 1.4 above present WSE; water is more turbid than Rodeo Creek
	2/16/2004 12:20 ds		5.187	2327.93 f				F					Qss, Qbed	Qpeak around 8am this morning
	2/18/2004 9:30 ds		18.446	8278.56 f		5.8		F						suds in water
	2/25/2004 10:25 ds		29.328	13162.4 f		7.6								SWE marked with willow stake, ~5' d/s of red flag; suds in water; season HWM
	3/5/2004 15:11 ds					5.08			7.6,5.8					Installed staff plate; HWM = 7.6 (2/25/04); HWM = 5.8 (2/18/04)
	3/24/2004 0:00 ds		0.327	146.758 py		4.75			7.6					meas taken just u/s of root grade control
	4/11/2004 13:00 ds		0.409	183.559 py		4.74								
	5/6/2004 15:00 ds		0.077	34.5576 py		4.64		B						
	6/8/2004 13:22 ds		0.068	30.5184 py		4.63		B						
	8/5/2004 14:54 ds		0.059	26.4792 py		4.60		B						
	8/10/2004 0:00 ds		0.1	44.88 vis		4.57		B						
	10/19/2004 12:30 ds					4.85		F	4.95					
	11/22/2004 13:00 ds					4.70		B						
	1/12/2005 0:00 ds					5.29		B,F	5.9, 6.2					

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			(cfs)	(gpm)	(py/AA/l/b)	(feet, TOC)	(feet, sfc)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)	
Piezometer RL-01 - adjacent to surfer lot wetland, on East side														
elevation (Top of Casing) =					30 feet, MSL									
stikup =					0.88 feet									
	3/12/2004													Installed
	3/24/2004	ds,ar				1.02	0.14	28.98						
	4/11/2004	ds				1.10	0.22	28.9						
	5/6/2004	ds				1.69	0.81	28.31						
	6/8/2004	ds				2.3	1.42	27.7						
	8/6/2004	ds				1.99	1.11	28.01		15.8	850	1027		
	9/10/2004	ds				1.89	1.01	28.11		15.9	601	750		
	10/19/2004	ds				1.67	0.79	28.33						
	11/22/2004	ds				1.71	0.83	-0.05						
	1/8/2005	ds				1.00	0.12	-0.76						water flowing at sfc; flow is diffuse, but also somewhat concentrated in ditch next to abandoned road, especially near the old gate
	1/12/2005	ds				1.06	0.18	-0.70						
Piezometer RL-02 - at upstream (North) end of surfer parking lot														
elevation (Top of Casing) =					30 feet, MSL									
					0.3 feet									
	3/12/2004													Installed
	3/24/2004	ds,ar				4.83	4.53	25.17						
	4/11/2004	ds				5.16	4.86	24.84						
	5/6/2004	ds				6.27	5.97	23.73						
	6/8/2004	ds				6.4	6.1	23.6						
	8/5/2004	ds				6.94	6.64	23.06		16.2	1317	1585		
	9/10/2004	ds				6.85	6.55	23.15		16.5	1240	1460		
	10/19/2004	ds				6.75	6.45	23.25						
	11/22/2004	ds				6.54	6.24	23.46						
	1/8/2005	ds				3.31	3.01	26.69						water flowing at sfc
	1/12/2005	ds				3.54	3.24	26.46						
Piezometer RL-03 - adjacent to surfer lot wetland, on West side														
elevation (Top of Casing) =					30 feet, MSL									
					1.25 feet									
	3/23/2004													Installed
	3/24/2004	ds,ar				1.73	0.48	28.27						
	4/11/2004	ds				dry								
	5/6/2004	ds				dry								
	6/8/2004	ds				dry								
	8/5/2004	ds				dry								
	9/10/2004	ds				dry								
	10/19/2004	ds				dry								
	11/22/2004	ds				dry								
	1/8/2004	ds				1.25	0	28.75						
	1/12/2005	ds				1.18	-0.07	28.82						

Station	Date and time	Observer	Discharge	Instrument / method	Stage or Depth to Water	Depth to water in piezometers	Water Surface Elevation	Hydrograph	High Water Mark	Water Temperature	Field Specific Conductance	Adjusted Specific Conductance	Additional Samling?	comments
			(cfs)	(gpm)	(py/AA/lb)	(feet, TOC)	(feet, sfc)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)	
Piezometer RL-04 - adjacent to surfer lot wetland, on West side														
	elevation (Top of Casing) =		30	feet, MSL										
			2	feet										
	3/23/2004													Installed
	3/24/2004	ds,ar				4.49	2.49	25.51						
	4/11/2004	ds				4.86	2.86	25.14						
	5/6/2004	ds				6.23	4.23	23.77						
	6/8/2004	ds				7.3	5.30	22.70						
	8/5/2004	ds				9.01	7.01	20.99		14.8	1168	1452		
	9/10/2004	ds				9.8	7.80	20.20		14.8	1265	1595		
	10/19/2004	ds				8.92	6.92	21.08						
	11/22/2004	ds				9.57	7.57	20.43						
	1/8/2005	ds				2.00	0.00	28.00						
	1/12/2005	ds				2.48	0.48	27.52						
Piezometer RL-05 - adjacent to lower Rodeo Creek														
	elevation (Top of Casing) =		30	feet, MSL										
			2.083	feet										
	3/23/2004													Installed
	3/24/2004	ds,ar				2.08	0.00	27.92						water ponded at sfc
	4/11/2004	ds				2.38	0.30	27.62						oilly sheen on water ponded at sfc
	5/6/2004	ds				2.17	0.09	27.83						no water ponded at sfc
	6/8/2004	ds				2.48	0.40	27.52						
	9/10/2004	ds				2.34	0.257	27.66		15.4	337			stratified: SC@T = 910@25 at bottom of hole
	10/19/2004	ds				2.00	-0.083	28.00						water is flowing across surface
	1/12/2005	ds				1.88	-0.208	28.13						

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Station	Date and time	Observer	Discharge	Instrument / method	Stage or Depth to Water	Depth to water in piezometers	Water Surface Elevation	Hydrograph	High Water Mark	Water Temperature	Field Specific Conductance	Adjusted Specific Conductance	Additional Sampling?	comments
			(cfs)	(gpm)	(py/AA/l/b)	(feet, TOC)	(feet, s/c)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)	

Notes:

- 9/17/2003 On site for introduction and overview of potential restoration areas with Darren Fong, Robin Grossinger, David Shaw, and Matt Kondolf
Toured the surfer parking lot, lagoon fill across from Building 1111, Rodeo Lake Picnic area, and Smith Rd.
- 10/5/2003 On site with Kyla Burson, Raymond Constantino, Erik Oerter and David Shaw for overview of potential river restoration term projects
Examined Gerbode Creek from Confluence with Rodeo Creek up through old Dairy Farm area.
Recorded cross sectional geometry in several locations along the way.
- 10/26/2003 Conducted Survey of Rodeo Beach - David Shaw and Kyla Burson
- 11/12/2003 David Shaw and Raymond Constantino
Recorded channel geometry in Gerbode Creek and several tributaries
- 11/19/2003 David Shaw and Raymond Constatino
Recorded channel geometry in Gerbode Creek and several tributaries
- 12/17/2003 Installed staff plate on Rodeo Beach footbridge, Rodeo Lagoon just below weir, and Rodeo Lake just above weir
Established photopoints
Established standard measuring stations for Rodeo and Gerbode Creeks
Installed event-recording tipping bucket rain gage in Gerbode Valley, about 50' downslode from road, approx 0.25 mi up from Eucalyptus grove
- 1/7/2004 On site about 4 days after heavy rains - David Shaw and Chuck Striplen
- 1/10/2004 Minor rain last night; Lagoon is open
- 1/17/2004 Overcast, Foggy, ~55degF, offshore wind

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[illegible]

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Station	Date and time	Observer	Discharge	Instrument / method	Stage or Depth to Water	Depth to water in piezometers	Water Surface Elevation	Hydrograph	High Water Mark	Water Temperature	Field Specific Conductance	Adjusted Specific Conductance	Additional Sampling?	comments
			(cfs)	(gpm)	(py/AA/l/b)	(feet, TOC)	(feet, s/c)	(feet)	(R/F/S/B)	(feet)	(deg C)	(μ mhos/cm)	(μ mhos/cm)	

Appendix B

Location(s):

Surfer Parking Lot (former gun and tractor park)

**Historic Conditons:**

Pre-Contact: Spring-fed slope wetlands (upslope) transitioned into sand dunes and colluvial wetlands

Post-contact: Conversion to grain fields, then military cul-de-sac

Existing Condition:

Parking, bathroom, and shower facilities above weathered colluvial deposits; no habitat value

Restoration Action:

Remove fill and drainage ditches to appropriate elevation, based on existing ground water table conditions

Summary of benefits:

Restoration would convert approximately ___ acres of compacted fill to slope, floodplain and seasonal lagoon fringe wetlands

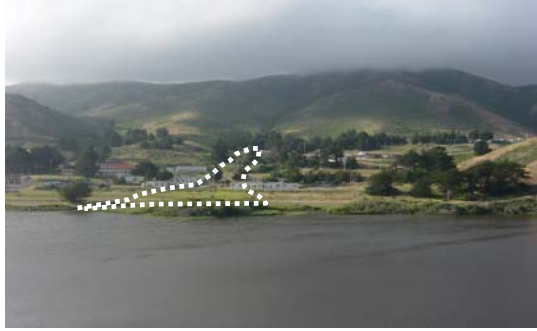
Summary of impacts:

The existing bathroom and shower area would likely need to be relocated. Overflow parking on peak use days would need to be relocated

List of Opportunities		List of Constraints	
☒	Improves terrestrial habitat (snowy plover?)	☐	Impacts Viewshed
☐	Improves tidewater goby habitat	☒	Impacts historic buildings or areas
☐	Improves California brown pelican habitat	☒	Requires severe landscape alterations
☐	Improves California red-legged frog habitat	☒	Requires significant archeological investigation
☒	Improves habitat connectivity	☒	Requires hazardous waste analysis
☒	Restores natural geomorphic processes	☒	Impedes transportation
☐		☒	potentially impedes recreation
☒	Attenuates peak flows (flood control)	☐	equipment access limitations
☒	Reduces erosion and sedimentation	☐	Impacts existing ecosystems
☐	Contributes to water quality protection	☒	Impacts other infrastructure
☒	Improves aesthetics	☒	High cost
☐	Restores Native American Uses	☐	requires ongoing maintenance
☐		☐	Other
☒	offers teaching opportunities		
☒	offers research opportunities		
☒	Enhances access to trails		
☒	Enhances wildlife viewing		
☐			
☒	Transportation plan alternative		
	Aspect of General Plan		
	General Plan component		
	ES recovery component		
	Other		

Location(s):

Headlands Institute Creek

**Historic Conditions:**Pre-Contact:Post-contact:**Existing Condition:**

Environmental Education Center built on fill and native colluvium; several channels have been moved, straightened or buried. Mitchell Rd is built on fill at the edge of the lagoon.

Restoration Action:

Re-design Marin Headlands Institute Campus to daylight creeks; remove Mitchell Rd and fill material to establish fringe wetlands

Summary of benefits:

Restoration would re-establish approximately ___ acres of riparian wetlands and ___ acres of lagoon fringe wetlands

Summary of impacts:

Transportation corridor along Mitchell Road would need to be removed or re-located; HI campus would need to be redesigned.

List of Opportunities

☒	Improves terrestrial habitat
☒	Improves tidewater goby habitat
☒	Improves California brown pelican habitat
☒	Improves California Brown Pelican habitat
☒	Improves California red-legged frog habitat
☒	Improves habitat connectivity
☒	Restores natural geomorphic processes
	Attenuates peak flows (flood control)
	Reduces erosion and sedimentation
☒	Contributes to water quality protection
☒	Improves aesthetics
	Restores Native American Uses
☒	offers teaching opportunities
☒	offers research opportunities
	Enhances access to trails
☒	Enhances wildlife viewing
	Transportation plan alternative
	Aspect of General Plan
	General Plan component
	ES recovery component
☒	Other: Component of HI goals

List of Constraints

☒	Impacts Viewshed
☒	Impacts historic buildings or areas
☒	Requires severe landscape alterations
☒	Requires significant archeological investigation
☒	Requires hazardous waste analysis
☒	Impedes transportation
☒	Potentially impedes recreation
	Equipment access limitations
	Impacts existing ecosystems
☒	Impacts other infrastructure
☒	High cost
	Requires ongoing maintenance
	Other

Location(s):

Area of fill across from Building T1111

**Historic Conditons:**

Pre-Contact: Lagoon Fringe wetland

Post-contact: Stream diverted to southwest, building established with road and turnaround on fill in lagoon;

Existing Condition:

Flat mowed grass on fill, stream passes under road through culvert and is establishing an alluvial fan at the lagoon edge.

Restoration Action:

Remove fill and establish lagoon fringe wetland.

Note that this is not a complete restoration, as it does not address the associated riparian corridor, but could be a component of other transportation or restoration activities.

Summary of benefits:

Restoration would re-establish approximately __ acres of lagoon fringe wetlands

Summary of impacts:

Lagoon views would be limited.

List of Opportunities		List of Constraints	
☐	Improves terrestrial habitat	☒	Impacts Viewshed
☒	Improves tidewater goby habitat	☐	Impacts historic buildings or areas
☐	Improves California brown pelican habitat	☒	Requires severe landscape alterations
☐	Improves California red-legged frog habitat	☒	Requires significant archeological investigation
☒	Improves habitat connectivity	☒	Requires hazardous waste analysis
☐	Restores natural geomorphic processes	☐	Impedes transportation
☐		☐	Potentially impedes recreation
☐	Attenuates peak flows (flood control)	☐	Equipment access limitations
☐	Reduces erosion and sedimentation	☐	Impacts existing ecosystems
☐	Contributes to water quality protection	☒	Impacts other infrastructure
☒	Improves aesthetics	☒	High cost
☐	Restores Native American Uses	☐	Requires ongoing maintenance
☐		☐	Other
☒	offers teaching opportunities		
☐	offers research opportunities		
☐	Enhances access to trails		
☐	Enhances wildlife viewing		
☒	Transportation plan alternative		
☐	Aspect of General Plan		
☐	General Plan component		
☐	ES recovery component		
☐	Other:		

Location(s):

Rodeo Lagoon weir

**Historic Conditons:**

Pre-Contact: Coastal lagoon transitioning to wet meadow and willow marsh

Post-contact: Increased sediment depostion at upper limit of lagoon; Road fill, bridge and weir constructed across lagoon;

Existing Condition:

Upper lagoon converted to freshwater marsh ('Rodeo Lake'); stocked with trout?

Restoration Action:

remove weir and road fill to re-establish bi-directional flow in upper lagoon (Rodeo Lake)

Summary of benefits:

Restoration would convert approximately _ acres of freshwater marsh back to lagoon fringe wetlands.

Summary of impacts:

Conversion of freshwater marsh to brackish marsh would negatively affect habitat in Rodeo Lake; sediment could potentially be flushed into lower lagoon.

List of Opportunities		List of Constraints	
	Improves terrestrial habitat		Impacts Viewshed
X	Improves tidewater goby habitat	X	Impacts historic buildings or areas
X	Improves California brown pelican habitat		Requires severe landscape alterations
	Improves California red-legged frog habitat		Requires significant archeological investigation
X	Improves habitat connectivity	X	Requires hazardous waste analysis
X	Restores natural geomorphic processes		Impedes transportation
			Potentially impedes recreation
	Attenuates peak flows (flood control)		Equipment access limitations
	Reduces erosion and sedimentation	XX	Impacts existing ecosystems
	Contributes to water quality protection	X	Impacts other infrastructure
X	Improves aesthetics	X	High cost
	Restores Native American Uses		Requires ongoing maintenance
			Other
X	offers teaching opportunities		
X	offers research opportunities		
	Enhances access to trails		
	Enhances wildlife viewing		
	Transportation plan alternative		
	Aspect of General Plan		
	General Plan component		
	ES recovery component		
	Other:		

Location(s):

Rodeo Lake Picnic Area

**Historic Conditions:**

Pre-Contact: Narrow lagoon Fringe wetland at base of hillslope

Post-contact: Road cut into hillslope, fill material placed in lagoon

Existing Condition:

Flat dirt parking and turnaround area, several utility lines run through.

Restoration Action:

Remove fill and expand freshwater marsh.

Summary of benefits:

Restoration would establish approximately ____ acres freshwater marsh

Summary of impacts:

Would need to re-align utilities.

List of Opportunities		List of Constraints	
	Improves terrestrial habitat	X	Impacts Viewshed
	Improves tidewater goby habitat		Impacts historic buildings or areas
	Improves California brown pelican habitat	X	Requires severe landscape alterations
X	Improves California red-legged frog habitat	X	Requires significant archeological investigation
	Improves habitat connectivity	X	Requires hazardous waste analysis
	Restores natural geomorphic processes		Impedes transportation
			Potentially impedes recreation
	Attenuates peak flows (flood control)		Equipment access limitations
	Reduces erosion and sedimentation		Impacts existing ecosystems
	Contributes to water quality protection	X	Impacts other infrastructure
X	Improves aesthetics	X	High cost
	Restores Native American Uses		Requires ongoing maintenance
			Other
X	offers teaching opportunities		
X	offers research opportunities		
	Enhances access to trails		
	Enhances wildlife viewing		
X	Transportation plan alternative		
	Aspect of General Plan		
	General Plan component		
	ES recovery component		
	Other:		

Location(s):

Smith Rd, Rifle Range, Capehart housing

**Historic Conditions:**

Pre-Contact: wet meadows and floodplain wetlands with discontinuous channels

Post-contact: fill material placed on floodplain, adjacent to channels for housing or other Army activities

Existing Condition:

Concrete roadways, dumped material, and housing on top of fill

Restoration Action:

Remove fill and grade to floodplain elevation or below to recreate wet meadows

Summary of benefits:

Will provide additional acres of floodplain and wet meadow habitat; could potentially serve as water quality treatment for runoff from Presidio Riding Club

Summary of impacts:

Historic rifle range could be altered; Capehart would require re-location of government/non-profit housing;

List of Opportunities		List of Constraints	
☒	Improves terrestrial habitat	☐	Impacts Viewshed
☐	Improves tidewater goby habitat	☒	Impacts historic buildings or areas
☐	Improves California brown pelican habitat	☒	Requires severe landscape alterations
☒	Improves California red-legged frog habitat	☒	Requires significant archeological investigation
☐	Improves habitat connectivity	☒	Requires hazardous waste analysis
☐	Restores natural geomorphic processes	☐	Impedes transportation
☐		☐	Potentially impedes recreation
☒	Attenuates peak flows (flood control)	☐	Equipment access limitations
☒	Reduces erosion and sedimentation	☐	Impacts existing ecosystems
☒	Contributes to water quality protection	☐	Impacts other infrastructure
☐	Improves aesthetics	☒	High cost
☐	Restores Native American Uses	☐	Requires ongoing maintenance
☐		☐	Other
☒	offers teaching opportunities		
☒	offers research opportunities		
☐	Enhances access to trails		
☐	Enhances wildlife viewing		
☐			
☒	Transportation plan alternative		
☐	Aspect of General Plan		
☐	General Plan component		
☐	ES recovery component		
☐	Other:		

Location(s):

Shellmound Tributary; Upper Gerbode Valley

**Historic Conditions:**

Pre-Contact: wet meadows and floodplain wetlands with discontinuous channels

Post-contact: Incised channels formed

Existing Condition:

Continued erosion of sediment at upper elevations is causing filling in some incised areas.

Restoration Action:

Stabilize incision through planting and grade controls and/or fill gullies; excavate down to water table to establish wet meadows

Summary of benefits:

Will provide additional acres of floodplain and wet meadow habitat;

Summary of impacts:

Could require significant removal of fill. Might adversely affect existing habitat

List of Opportunities		List of Constraints	
☒	Improves terrestrial habitat	☐	Impacts Viewshed
☐	Improves tidewater goby habitat	☐	Impacts historic buildings or areas
☐	Improves California brown pelican habitat	☒	Requires severe landscape alterations
☐	Improves California red-legged frog habitat	☒	Requires significant archeological investigation
☐	Improves habitat connectivity	☐	Requires hazardous waste analysis
☐	Restores natural geomorphic processes	☐	Impedes transportation
☐		☐	Potentially impedes recreation
☒	Attenuates peak flows (flood control)	☒	Equipment access limitations
☐	Reduces erosion and sedimentation	☒	Impacts existing ecosystems
☒	Contributes to water quality protection	☐	Impacts other infrastructure
☐	Improves aesthetics	☐	High cost
☐	Restores Native American Uses	☐	Requires ongoing maintenance
☐		☐	Other
☐	offers teaching opportunities		
☒	offers research opportunities		
☐	Enhances access to trails		
☐	Enhances wildlife viewing		
☐			
☐	Transportation plan alternative		
☐	Aspect of General Plan		
☐	General Plan component		
☐	ES recovery component		
☐	Other:		

Location(s):

Gerbode Creek bypass channel

**Historic Conditions:**

Pre-Contact: meandering channel in alluvial floodplain

Post-contact: limited channel incision; construction of straight bypass channel

Existing Condition:

bypass channel has incised and completely cut off old meander

Restoration Action:

Stabilize incision through planting and grade controls; encourage sediment deposition and re-occupation of former meander bend

Summary of benefits:

Will re-establish natural stream functions and processes; will expand and improve riparian corridor

Summary of impacts:

Aggradation could cause flooding of trails

List of Opportunities		List of Constraints	
☐	Improves terrestrial habitat	☐	Impacts Viewshed
☐	Improves tidewater goby habitat	☐	Impacts historic buildings or areas
☐	Improves California brown pelican habitat	☐	Requires severe landscape alterations
☒	Improves California red-legged frog habitat	☐	Requires significant archeological investigation
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☐		☐	Other
☒	offers teaching opportunities		
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☐	Enhances access to trails		
☐	Enhances wildlife viewing		
☐			
☐	Transportation plan alternative		
☐	Aspect of General Plan		
☐	General Plan component		
☐	ES recovery component		
☐	Other:		