Salmon Creek Estuary: Study Results and Enhancement Recommendations

Prepared for:
Salmon Creek Watershed Council
&
Occidental Arts and Ecology Center

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Salmon Creek, like many of California's coastal streams, has lost its coho *(Oncorhynchus kisutch)* salmon run in the last 10 years and is left with a dwindling steelhead trout *(Oncorhynchus mykiss)* population. This project is part of a larger community effort to assess the reasons for the decline of the salmonid runs and to develop an integrated, effective restoration strategy.

The Salmon Creek Estuary Enhancement Plan summarizes the results of sampling and assessment of factors that affect estuarine function and its value as salmonid habitat, and presents recommendation for additional data collection and habitat enhancement. The estuary bed and beach at the mouth were surveyed at the beginning of the study in fall of 2004 and then again after 3 storm events. The topography was described and compared to historical accounts. Upstream factors, particularly water quantity and sediment were assessed through monitoring and review of existing information. Temperature, dissolved oxygen and salinity in the estuary were monitored monthly for one year and then at one additional time in fall of 2005. Biotic monitoring of the estuary to examine fish use was conducted on the same schedule. Historical information was gathered from many local sources as well as oral history interviews.

Although the study only allowed for a limited period of data collection under a very narrow range of weather conditions, sufficient information was gathered to increase understanding of the Salmon Creek system and to develop initial habitat recommendations. Increased water consumption in the upper watershed from groundwater and direct stream withdrawals has reduced base stream flows during critical periods. Low spring and summer flows increase pool stratification in the estuary to create bottom saline layers too hot and low in oxygen to sustain salmonids. Fish are confined to the upper freshwater layer and to the well-mixed area near the sandbar where they are vulnerable to predation by birds. Low spring and summer flows also reduce lagoon elevations and delay the breaching of the sandbar. If the sandbar opens after or near the end of the coho upstream migration period, as occurred in the 2004/2005 winter, coho have little if any chance of returning to Salmon Creek. Low summer flows also reduce viable salmonid rearing habitat in the main channel and tributaries.

Significant amounts of course sediment have dramatically decreased the areal extent and depth of the estuary since the mid 1800s. Over the study period, over 2 feet of sediment was deposited upstream and downstream of the Highway 1 bridge. Summer lagoon depths now range from 2 to 6 feet as compared to 6 to 12 feet in the 1950s and 1960s. Erosion of fine sediments from the upper watershed creates high turbidity levels that impair salmonid physiological functioning and behavior.

Recommendations call for enhancing habitat diversity in the estuary through woody debris structures and possible restoration of side channels and pond connectivity; maintaining beneficial freshwater flows through water conservation and better management of diversions; expanding erosion control, riparian protection and stormwater management practices in the upper watershed; and enhancing upstream rearing habitat to provide alternatives to poor quality estuarine habitat. The recommendations also include continuing the biological and water quality monitoring in the estuary for at least 5 more years, installing a USGS stream gage at the upper end of the estuary as well as several additional flow monitors higher in the watershed, and implementing community education programs on a variety of topics including water conservation and erosion control Best Management Practices. The final recommendation calls for integrating all of the current planning and restoration efforts into a coherent strategy for managing the Salmon Creek watershed to enhance and sustain viable salmonid runs.

CHAPTER 1: INTRODUCTION

Coho salmon and steelhead were once abundant in Salmon Creek, its estuary, and its tributaries. Tales of their numbers, sizes, and favorite pools are still a vital part of the local history and lore. Unfortunately, in Salmon Creek, as in many streams along the California coast, their numbers have dropped substantially. Now only a small population of steelhead continues to return each year, and the last coho was seen in 1996. The residents are intensely interested in and many are actively working towards returning the anadromous fish to their creeks.

Residents and local watershed groups, as well as public agencies have worked to assess the ecological health and functioning of the Salmon Creek watershed, and to document specific sites and/or activities that may be degrading the riparian system and impairing critical fish habitat. The Department of Fish and Game (DFG) conducted an instream habitat assessment of Salmon Creek and its tributaries in 2001 and 2002. Gold Ridge Resource Conservation District (RCD) teamed with the Salmon Creek Watershed Council (Watershed Council) to receive a grant from DFG in 2003 to complete a watershed assessment and plan. This DFG grant provided funding to begin a volunteer water-quality monitoring program, document erosion in the watershed, research land use history, and identify potential restoration projects. UC Cooperative Extension is currently studying the sources and transport processes of pathogens in 5 coastal estuaries, including Salmon Creek. The Community Clean Water Institute has been supporting residents in the Joy Road area and Salmon Creek School in monitoring upstream water quality.

This piece of the watershed planning effort is focused on the estuary. Estuaries provide essential food, cover, migratory corridors, and breeding/nursery areas for many coastal and marine organisms. Recognition of their importance for anadromous salmonid fish has grown as salmon and steelhead populations plummet. Adults use estuaries for staging in preparation for their upstream migration. Juveniles use them for rearing and for completing the physiological adjustment from fresh to salt water that will allow them to live in the ocean. Juveniles may linger in the estuary for weeks and may move in and out several times before remaining in the ocean. Adequate flow, good water quality, sufficient cover, habitat complexity, and invertebrate food source within the estuary are all very important factors for the survival of anadromous fish.

In 2004, the State Coastal Conservancy approved a grant to the Salmon Creek Watershed Council and the Occidental Arts and Ecology Center (OAEC) to investigate the physical condition and functioning of the Salmon Creek tidal estuary and how it is used by salmon and steelhead, assess upstream factors that directly affect critical habitat in the estuary, collect historical information and develop recommendations to enhance the estuary for salmonid habitat. A Technical Advisory Committee was formed to review the study plan and findings. This report contains the results of the investigation along with overall enhancement recommendations and short term actions needed to initiate restoration or collect additional data.

CHAPTER 2: SETTING

2.1 Physiography

The Salmon Creek watershed drains 34.5 square miles of western Sonoma County and enters the ocean just north of Bodega Bay (Figure 2.1.). Its estuary extends approximately 1.3 miles inland from the coast. The lower estuary is part of the Sonoma Coast State Beach and is managed by the California Department of Parks and Recreation. As in most small northern California streams, the mouth of the estuary is closed by a sandbar in spring or summer every year and remains closed until after the first significant storms. Under conditions of adequate summer streamflow, the closed estuary converts to a largely freshwater lagoon.

The small unincorporated communities of Occidental, Freestone, Bodega and Salmon Creek are within the watershed. Grazing based agriculture still dominates the western part with cattle and sheep ranches and a handful of dairies. Rural residential housing is the primary current land use in the upper watershed although in the past ten years, numerous commercial vineyards have been developed around Occidental and Freestone.

The rock formations underlying the watershed are primarily Franciscan complex or melange with Wilson Grove formation overlying much of the eastern portion (Figure 2.2.). Many of the soils associated with these geologic formations are highly erodible on steeper slopes. Vegetation in the watershed closely follows the geology with dense hardwood conifer forests dominating the northeastern area and an abrupt transition to the rolling grasslands of Bodega and the coast (Figure 2.3.). Average rainfall in Occidental is 56 inches per year.

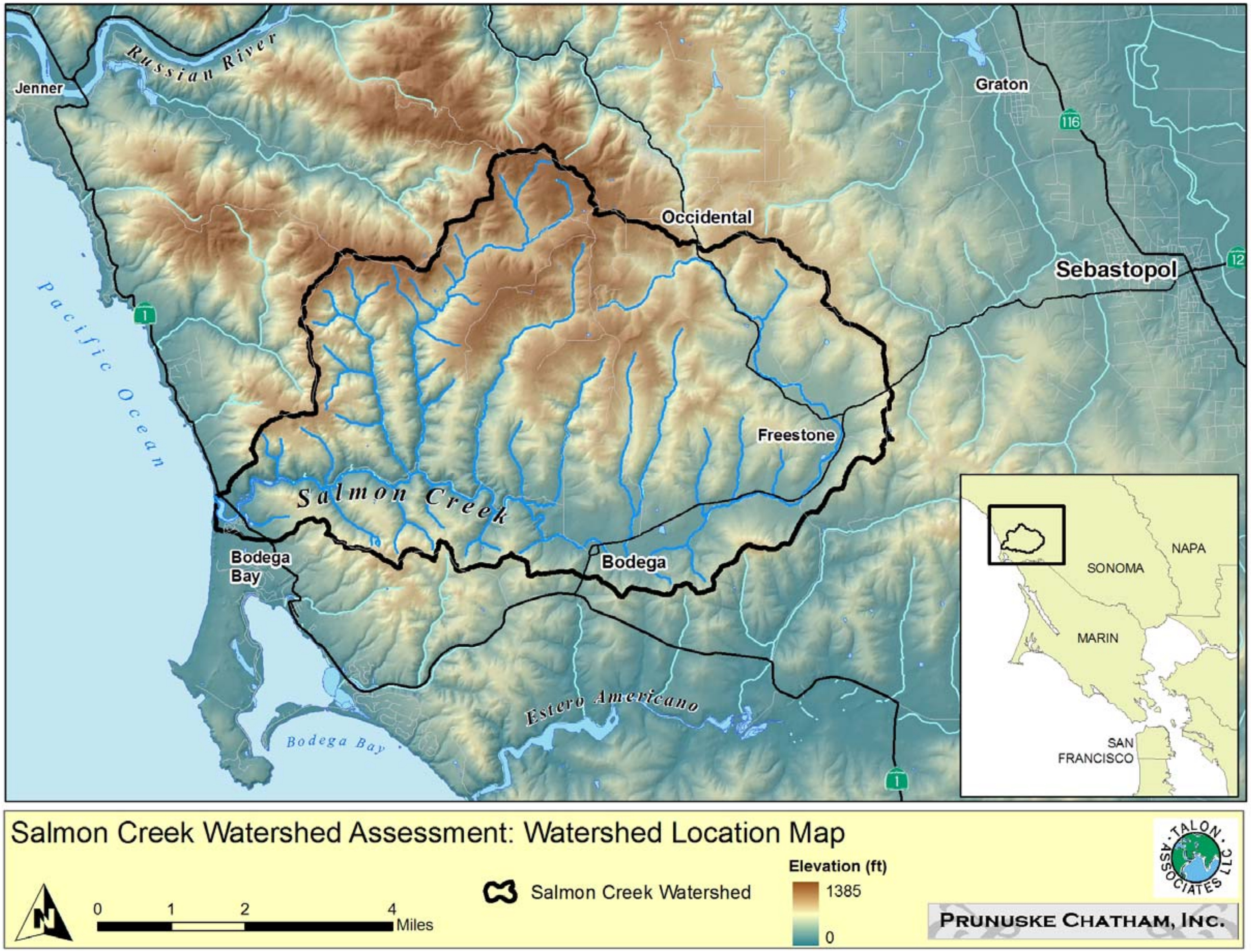


Figure 2.1.1 *Salmon Creek watershed showing locations of towns, roads, streams, and topography.*

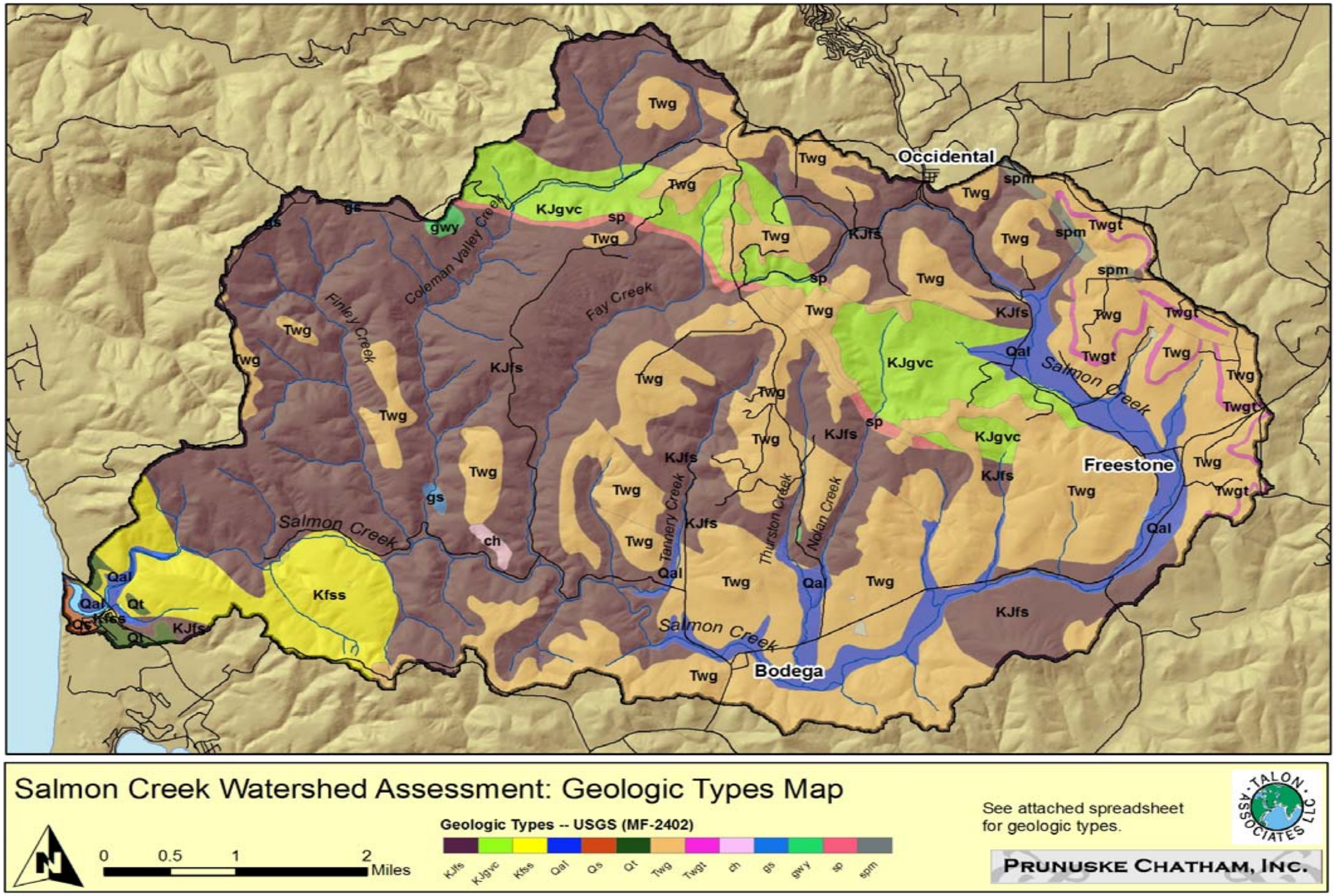


***Figure* 2.1.2** *Watershed geology.*

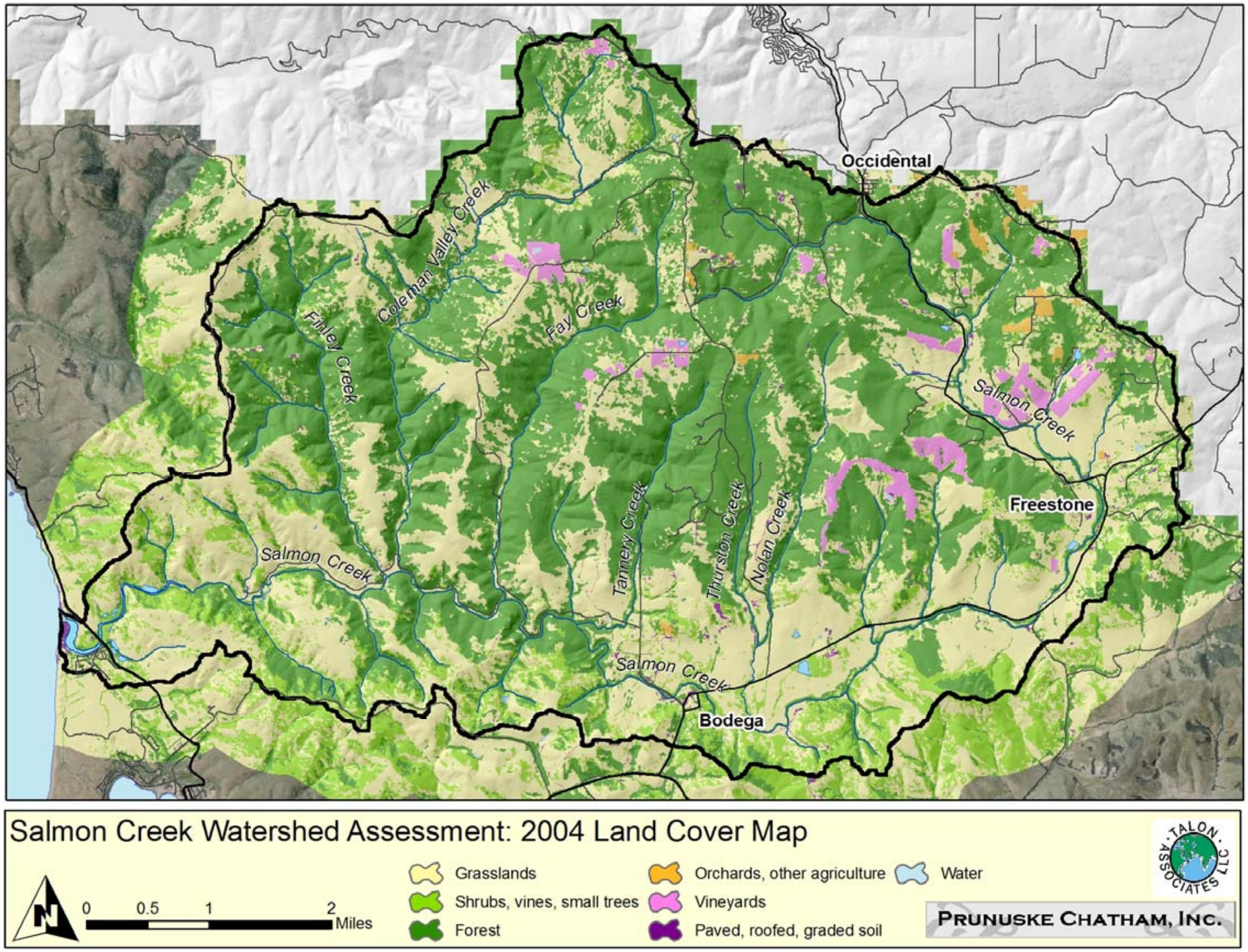


Figure 2.1.3 *Landcover and use in the Salmon Creek watershed.*

2.2 *History*

Coast Miwok people were living in and managing the Salmon Creek watershed when Russians established farms in Bodega and Freestone in 1812. European settlers began to arrive in the 1840s and immediately began logging for their own needs as well as for the developing city of San Francisco. Salmon Creek farms produced dairy products, potatoes and grain for California's growing population. The following timeline includes some of the events that have lead to profound changes in the watershed that have in turn affected fish populations. Appendix A contains a more thorough history, including numerous oral histories of the Salmon Creek watershed.

Historical Timeline of Salmon Creek Watershed	
Date	**Activity**
Prehistory	Native Americans may have occupied the area for 8,000± years. Coast Miwok people were the latest indigenous people to live in SCW, with communities in areas of Freestone and Bodega into mid-1800s. Indigenous management techniques were used to manage productivity and populations of forest, grassland and riparian species. (Anderson, 2005)
1775	Don Juan Francisco de la Bodega y Cuadra, Spanish explorer, sails into "Bodega" Bay and claims the region for Spain. Plans to return to develop the area, but never does. (Hill, 2005)
1776	Since Mexico is a colony of Spain, California is too. Missions in San Francisco, San Rafael and Sonoma recruit local indigenous people for religious conversion and labor. Salmon Creek Watershed remains just beyond the edge of their influence and control.
1812	A party of Russians and Native Alaskans establish Fort Ross and come to Bodega Bay to found farming settlements in Bodega, Freestone and Coleman Valley. The first timber cutting occurs, also tanoak harvesting for tanning hides. (Wilson, 1999)
	California's first shipment of grain leaves from the port of Bodega, bound for Russian settlements in Alaska
1817	Russians plant Sonoma County's first vineyards in Coleman Valley; also first apple orchards, possibly the first Gravensteins. (Wilson, 1999)
1835-1846	To create a buffer from Russian settlement, Mexico gives huge land grants (8,000 to 60,000 acres) in the coastal range. The first Anglo settlers in Salmon Creek watershed were given farmland in Freestone with instructions to bother the Russian settlements nearby. (Wilson, 1999)

1836	Mexican General Vallejo in Petaluma Hacienda forbids continuing native practice of quickly burning the grassland and wooded hills in late fall, a practice which fertilized the fields, and helped prevent weed competition, brush accumulation, and forest blights.
1837-1841	Smallpox epidemic decimates North Coast Indian population; 80-90% die. Decrease in land and resource use and management may be affected harvesting, hunting, fishing and those species' populations.
1842	Russians depart from Sonoma Coast, sell their holdings and equipment.
1843-1844	Captain Stephen Smith delineates and receives 35,000 acre land grant called Rancho Bodega, which includes most of Salmon Creek watershed, plus land north to Russian River. He introduces the first steam engine in California, sets up a steam-operated lumber mill and flour mill in the Bodega area, as well as a tannery.
1848	Kolmer family immigrates from Germany, lease land from Capt. Smith, settles in Coleman Valley. Years later a mapmaker changes spelling from Kolmer to Coleman.
1848-49	After defeat in Mexican-American War, Mexico cedes California to the United States. Pioneering European, Canadian and American settlers establish holdings in Salmon Creek watershed (Occidental, Freestone, Bodega).
1849-50	Land rush after the 1849 Gold Rush brings Anglo-Americans, Canadians and Europeans to West Sonoma County. Era of large-scale farming, ranching and timber-cutting begins in Salmon Creek watershed. William "Dutch Bill" Howard clears trees on Occidental ridge to start cattle ranch. Salmon Creek watershed soon becomes known for its potatoes, pigs, chickens, sheep, beef cattle and dairies. Logging begins, boards hand-hewn. Sawmills later proliferate. Lumber and goods shipped from Bodega Bay or taken by wagon to Petaluma River, then carried on barges to SF Bay. (Hill, 2005)
1849?	Potato and pork farming begins to be established in Salmon Creek valley.
1850s	Era of road building is launched along with era of logging. With settlement and logging, dozens of roads are built over the hills and through the creeks in Salmon Creek Watershed. When easy to reach trees are gone, logging roads delve deeper in to more remote areas. Roads are heavily used by wagons drawn by team of 4-12 oxen or many horses, often with heavy loads. Some roads become stagecoach roads. (Wilson, 1999)
1859	"Squatters' wars" break out in Sonoma County, between settler and large landowners. In Bodega, Tyler Curtis, the second husband of Capt. Smith's widow Manuela, sold much of her land, permanently drove off the Coast Miwok population, and tried to evict hundreds of pioneers whom Smith had encouraged to farm Rancho Bodega and to populate the town of Bodega. Curtis brought in troops, who engaged in a stand-off with 300 of Bodega's angry pitchfork-wielding squatters on the road to Petaluma. They defeated him and stayed to get deeds of their own

	and build the local ranching and dairy industries. (Wilson, 1999)
1865	The first lumber mill in Coleman Valley was built in 1865. It was moved around the valley to be near the timber, as was the custom of that time. A succession of owners logged that valley with multiple mill sites until 1913, when the last mill owner, Wade Sturgeon operated a mill there until 1923. (That restored mill is now set up on Green Valley Road, near Sebastopol.) (Historical newletters, SCHS)
1866	"Boss" Meeker built a sawmill southwest of Occidental, expanded in 1866-67 with a half-mile long railroad to it. In 1868 he cleared and homesteaded Wyammy Ranch area on Bittner Rd., headwaters of Salmon Creek. The one-lane "Long Bridge" was built across the 'headwaters' canyon and lasted into the 1920s. (Hill, 2005)
1873-1876	Narrow-gauge railroad is built to carry lumber and goods from West Sonoma County to San Francisco Bay. Runs from Tiburon through Tomales, Valley Ford, Freestone, and Occidental to Duncan's Mill. Local populations swell for several years, while ~1,500 people work on construction. (1,300 workers in Freestone-Occidental were Chinese, later driven from the county in an 1886 boycott.) The tallest timber trestle in the U.S. is built over Salmon Creek, in Brown's Canyon, lifting the train between Freestone and Occidental (575 ft. elevation). Freestone becomes known as "Gateway to Sawmill Country." All local building is done with local lumber.
1890s	Clara Tarwater, daughter of Bodega Finleys, describes Finley dairy of the 1890s: Cows grazed in fields, milked twice daily, for large-scale production of butter, cream, milk. By-products of curds and whey used to fatten pigs. Goods traded at Freestone Creamery or delivered to "Bodega Roads" train depot near Freestone for transport to San Francisco markets. Every town had a creamery. (Journal of the Sonoma Co. Historical Society, 1964)
1876	Town of Occidental, built up by presence of construction workers and lumbermen, is formally established and named by Boss Meeker. Town of "Howard's" co-exists on north end of Occidental for `15 years. Train brings first boom in tourism to the region, with hotels, summer cabins and service for their needs.
1870s-1920s	Redwood timber industry thrives. Timber cutting has major impact on watershed. Mills are built and moved, sometimes to several locations within upland and lowland areas of each tributary. Douglas fir is harvested for lumber, oak for firewood, tanoak for charcoal production and tanning. Felled logs are dragged by long teams of oxen through creekbeds and over rough roads on slopes, then trucked out or, later exported by train.
1870s-1920s	Tanoak bark industry thrives. Tan oaks are skinned, bark dried and warehoused in Occidental, shipped to Bay Area tanneries.
1885-1890s	Early Sonoma County environmental concerns arise, concerning county-wide over-fishing of salmon and trout species; rules regarding fishing season and take are implemented. Concern expressed over effect of

	coastal logging on local climate change. (Santa Rosa newspapers)
1890s	Clara Tarwater, daughter of Bodega Finleys (of Finley Creek), describes Finley dairy of the 1890s: Cows grazed in fields, milked twice daily, for large-scale production of butter, cream, milk. By-products of curds and whey used to fatten pigs, who became sausages, etc. Goods traded at Freestone Creamery or delivered to "Bodega Roads" train depot near Freestone, for transport to San Francisco markets. Major local industry; many dairies along Salmon Creek and every town had a creamery. Most dairies continue into mid-1900s and a couple to present day. (Journal of the Sonoma County Historical Society, 1964)
1900	Huge forest fire started at Coleman Valley Rd. just above Occidental, "burned out thirty ranches" as it ran down to Freestone, through Joy Woods and over to the edge of Bodega. Scars still visible in old Doug Firs in year 2000. Cleared the skyline of trees.
~1900	Railroad introduces refrigerated cars, which are boon to local dairy industry.
1906	Great San Francisco Earthquake shakes this area badly. Many buildings damaged. Santa Rosa devastated, affects railway and urban markets for dairy goods, etc. Cities rebuilt with North Coast lumber.
1920	Era of Prohibition begins. West Sonoma County forests and county roads hide many private vineyards and stills. Alcohol smuggled from offshore through Bodega distribution system. (Tuomey, 1926)
1920s	By the 1920s, automobile travel is on the rise, for trucking and tourism. After years of residents' complaints about bad west county roads, the tourist drivers of private automobiles, out to see the coast, push Sonoma County Road Dept. to improve many roads near Salmon Ck. And along the coast. In 1926, grading, culverts, walls and bridges are constructed to meet higher demand, especially along Bohemian Hwy., Bodega Hwy., Hwy. 1 and Salmon Ck. Rd. (Coleman Valley Rd. remains privately maintained by ranchers until the 1960s.) (Rancho Bodega Historical Society and Wilson, 1999)
1928	Late in logging era, Finley descendant sells upper part of Finley ranch to Meeker descendant, who logs it, by building and operating another sawmill there. (Another late-era mill is the Chenoweth Mill, right on Salmon Creek in Bodega, which operated until the 1970s.)
1929	Sportsmen call attention to the falls at Salmon Creek. On the property of Mr. Farrel of Freestone, who does not want them removed. Sufficient spawning areas exist below the falls, DFG estimates that 5 miles of spawning gravels are upstream. The falls are estimated to be 12' high. DFG does not think the cost is worth the spawning grounds and believes at times of high water, fish could pass.(DFG, April 1929)
1930	The Northwest Pacific Railroad Co. closes down the train that passed through west Sonoma County for 54 years, so Bodega, Freestone and Occidental no longer have the shipping and tourism the train provided. Trestles and tracks are gradually removed, leaving roadbeds. (Wilson, 1999)

1930	Great Depression: WPA projects in area include road-building, culverts, walls, grading. Colonies of CCC workers camp and work locally, for several years.
1934	Sonoma Coast State Beach established, including mouth of Salmon Creek. Later expanded to include estuary. (Wilson, 1999)
1935	Prohibition repealed. Salmon Creek watershed wineries officially reopen, such as Indian Mound Winery on Joy Road. (Wilson, 1999)
1937	The Golden Gate Bridge opens. Automobile tourism to Bodega and Bodega Bay area greatly increases. Road use increases. Trucking goods from region to cities increases. Dairies thrive with this development. (Wilson, 1999)
1941	World War II starts in Pacific. Lookouts and patrols begin on Salmon Creek Beach; soldiers stay in camps that CCC had used during the Depression. (Wilson, 1999)
1951	Salmon Creek falls were partially eliminated, probably by blasting, and the stream above is now easily accessible to SH. The party or parties who removed the barrier are unknown, but it is suspected that the county did it on the recommendation of the local sportsmen." (DFG, 1951)
1953	DFG recommends that catchable rainbow trout be planted in the estuary anytime after June 1, and periodically thereafter. The 1953-54 winter steelhead fishery creel census: 20 anglers fishing for 39 hours caught 13 silver salmon ranging from 2.5 to 10 lbs. Staff estimated a total of 50 fishermen. (DFG, 1953)
1950s	At least 12 dairies still operating along Salmon Creek between Freestone and Bodega. (John Mache, interview)
1961	Proposal to construct a saltwater barrier 2 miles upstream from the mouth for Bodega Bay Public Utility District (BBPUD) and a dam and reservoir on Finley Creek, approximately 1¾ miles upstream from the well site. Dam would be constructed of earth fill 75' high to impound 700 acre feet. The water will be discharged during the dry season to "maintain adequate stream flow at their well site, thus recharging the underground gravels and preventing the intrusion of salt water." DFG notes that the dam may delay the opening of the mouth which would delay spawning and migration to the ocean. To evaluate the project, a complete survey of Salmon Creek and its tributaries is underway. (DFG, 1961)
1961	Fish found during DFG field visit: sculpin, 3 adult steelhead, 2 adult silver salmon (coho), 1 grilse (unknown), 3 mechanically injured (poaching) silver, no young observed (3 weeks after first major rain). (DFG, December 1961)
mid-1960s	Two significant wildfires in the northern portion of the watershed. The Robertson Fire in 1961 burned ~2000 acres in Fay Tannery, and Coleman Valley Creeks. The 1965 Coleman Valley Fire burned 1,840 acres on the ridge between Fay and Coleman Creeks, burning almost to Salmon Creek. This fire took out most of the trees and the understory.

1964	Fish found during DFG field visit: Majority of fish are silver salmon 1½ to 2", 20% steelhead 1-2". 50-100 fish/100 feet. Steelhead 4-8" observed below Bodega. (DFG, March 1964)
1965	Fish found during DFG field visit: Silver Salmon (2" avg) 150 per 100 feet; Steelhead (2" avg) 100 per 100 feet; Stickleback (1-2" avg). 149 fingerlings caught: 85 Silver Salmon, 64 Steelhead (DFG, August 1965)
up to 1970s	Observers report an old practice: eager "fishermen" annually broke through the sandbar just as creek flow rose to nearly high enough and as coho were seen gathering in the waves outside the bar. Good fishing at the estuary as soon as the bar broke and the fish rushed in. Practice continued to at least late 1970s. Some say they "always" had salmon for Thanksgiving.
Early 1970s	Bodega Hwy. west of Freestone was very narrow country road, barely two lanes. County widened and surfaced it in early 1970s, some of that along riparian area between Freestone and Bodega. Early 1970s was also the last time the County Flood Control crew came to clear the willows out of the center of Salmon Ck., which the ranchers had also done every summer for years, for flood control and to maintain channel. (Mache interview)
1970	Fish found during DFG field visit: Silver Salmon (3-4") and Steelhead (1-2") 25-40 per 100 feet; Stickleback (1-3") 60+ per 100 feet (DFG, Dec 1970)
9/1974	Record salmon catch at sea off Salmon Creek (Grady, 1996)
1975	Salmon fishing fleet begins to diminish due to economic factors (Grady, 1996)
1976	Salmon Creek watershed briefly becomes world-famous in art world, due to Christo Javacheff's Running Fence, which partly ran through the valley and near the creek.
1977	Survey from Freestone to Occidental. Intermittent pools with 1 tributary ½ mile downstream of Occidental flowing at 1 cfs. Notes that the area would be good habitat for California freshwater shrimp "if the need arises to transfer them from areas lower in the drainage." Juvenile salmonids observed 200 feet upstream of tributary, sculpin and CA roach seen throughout. No freshwater shrimp. (DFG, August 1977)
1977	Fish found during DFG field visit: Stretches near Watson School: threespined stickleback, California freshwater shrimp, sculpin, crayfish ½ mile downstream of Occidental at tributary: sculpin, crayfish. (maps) (DFG, Sept 1977)
1977	Very dry winter, after several years of drought. Local residents report that the number of steelhead and coho declined significantly after this period, with the fall run of steelhead never returning to "normal".
1978	Observers noticed that sand excavated to free a beached boat in 1970 was slowly moving eastward, into the estuary. Attempts to truck it out failed. (Grady, 1996)
1979	More dune grass is planted on the dunes at the mouth of Salmon Creek, to hold sand back. Helicopter provides aerial fertilization to dunes. (Grady, 1996)

1/1982	Coast reports 9" rain in 36 hours, heavier inland; very heavy simultaneously in both lower and upper SCW, flooding at Bodega and all the way downstream. Town of Bodega overwhelmed. Welling Ranch above estuary loses ground and ranch equipment. Everyone, including DFG, reports astonishing quantity of sediment washed down the tributaries. Some note that Coleman Valley Creek, Finley Creek and Fay Creek particularly fill up with sediment above and at their confluences with SC and downstream. Pools throughout SC fill up. Estuary breadth and depth changes dramatically both above and below Hwy. 1 bridge. Large amounts of sediment deposited in the channel and on floodplain; changing tidal wetlands to terrestrial upland. North abutment of SC bridge is destroyed, Hwy. 1 closed.
1982	Request for a hatch box program on Salmon Creek. Results of Bill Cox's electrofishing: steelhead population healthy, 6 silver salmon. (Fisherman's Marketing Assoc. of Bodega Bay, 1982). DFG turns down the request for a hatchbox program due to predation by yearling steelhead. DFG plans to stock 20,000 Noyo strain coho yearlings in Salmon Creek in spring. (DFG, 1982)
1983	DFG writes to inform that the Noyo facility had a poor egg take and the Mad River hatchery had disease problems. DFG does not have enough coho to meet brood stock requirements. They do have several thousand YOY coho from Warm Springs Hatchery to stock Salmon Creek later that spring. (DFG, April 1983)
2/1986	Very wet week-long rainstorm (with 12" in 24 hrs in Occidental) referred to as "Valentine's Day Flood" or "Massacre." Mentioned as second biggest to 1982 storm. Effects on Salmon Ck. watershed are not detailed, but probably continued erosion and deposition.
1988	(DFG response to Sonoma County Public Works) Letter appears to respond to a County desire to breach the sand bar at Salmon Creek lagoon. DFG states that they have not studied the lagoon, though they cite other research in CA which proves breaching has a negative impact to fish populations. DFG states they know that the tidewater goby (candidate for endangered status) use the lagoon. DFG states that until it is shown that the opening of the bar would have no significant adverse effects, they are opposed to the artificial opening during the dry season. (DFG, June 1988)
1996	Last documented coho salmon seen in Salmon Creek (Bill Cox, DFG Biologist)
2000	Logging of private land in upland watershed continues, e.g. 60 acres of up to 100 yr. old Douglas firs harvested in upland Tannery Ck. Selective harvesting methods for forest health are employed in some areas of the watershed.

CHAPTER 3: PROJECT STUDIES AND RESULTS

3.1 Morphology and Hydrodynamics (prepared by Lauren Hammack)

Introduction

In this study we have examined several of the physical drivers of estuary dynamics in relation to summer lagoon formation and fall sandbar breaching—key factors for critical habitat conditions for juvenile salmonid rearing and adult migration patterns. Hydrologic factors related to sandbar breaching in the late fall are examined to answer the question: "Has the fall lagoon breach timing changed over time, affecting salmonid spawning runs?" The topography of the estuary was described and compared to historical accounts of the size, shape, and sediment distribution to document long- and short-term changes due to upstream, watershed conditions.

Methods

A detailed survey of the estuary was performed in October and early November 2004. Thirty-four cross sections were surveyed between the mouth and the upper summer extent of the lagoon. Within this 1.3 mile reach barrier beach dimensions, channel topography, pool locations and depths, bank heights, and floodplain pond and drainage features were measured. During the winter/ spring of 2005 the channel bed and beach at the mouth were surveyed twice to document changes after large storm events. Changes to the lower and middle estuary following the 2005/6 New Year's Eve storm were surveyed in February 2006. Topographic maps for each survey time and location were produced using AutoCAD. Estuary volumes at specified water surfaces, changes in thalweg elevations and cross section dimensions over the study period, and sediment erosion/deposition volumes were calculated based on the detailed fall 2004 baseline survey and subsequent surveys.

Estuary stage level was monitored at half hour intervals with a pressure transducer water-level logger. The level logger was initially installed in early November 2004. However, due to equipment failure and the associated loss of data, continuous stage measurements were collected for the period February 2 to December 31, 2005. During the summer and fall of 2004 water surface elevations were marked once a month during the biological sampling cruises. In addition to estuary stage levels, hydrologic data used in the hydrodynamic analyses includes daily rainfall totals at Occidental (1948-2005), rainfall at Bodega (2004-2005), and discharge records at Bodega (1964-1975, late 2004, 2005).

Mean daily discharges at Bodega were converted to acre feet and proportioned to total watershed area to estimate daily flow volumes entering the estuary. Annual rainfall statistics were calculated for the entire period of record in Occidental. Monthly and seasonal (Oct 1st- Dec 15th, Apr 1st-Jun15th) statistics were also calculated, including totals, averages, and cumulative rainfall.

Morphology

The estuary can be divided into three distinct reaches; the lower estuary from the mouth to the Highway 1 Bridge, the middle estuary from the bridge to river mile 1.1, and the upper estuary from river mile 1.1 through Chanslor Ranch. Channel form, substrate size and distribution, habitat features, and hydrologic characteristics are unique to each.

Lower Estuary

The complex interplay of waves, wind, and stream flow shape the mouth of the estuary, determining where and when it opens, the depth of the channel, and the movement of sediment and water. From the mouth, the lower 1000 feet of channel parallels a long, broad barrier beach and then turns inland. Longshore currents tend to keep the channel mouth at the north end of the beach. This pattern was broken in the late 1990s when the sandbar breached at the southern end of the barrier beach, cutting through a high vegetated dune. Over the next three years the channel migrated north, systematically eroding the entire length of protective dune.

At the start of the study (October 2004) the barrier beach ranged in elevation (in NGVD) from 14 feet near the middle to nearly 12 feet at the northern breaching area. Average elevation of the channel bed along the sandbar was 3 feet NGVD during the baseline survey. Surveys of the channel bed from the mouth along the sand bar after winter storms showed localized bed incision, as well as deposition, of 1 to 7 feet. The greatest bed elevation fluctuations occurred within the breach channel and immediately upstream, while at the southern end of the sandbar the channel aggraded 1 foot over the study period. Maximum scour during large runoff events was not documented, but is assumed to be several feet.

In the lower reach the deepest areas are found along the entire south side of the channel from the bridge to the beach. Elevations along the thalweg range from 1 to 2 feet NGVD, producing pool depths of 4 to 7 feet during summer lagoon periods. The channel shallows on the north side where large amounts of sediment are deposited during storm events. Local residents have noted that the estuary has been gradually filling in over the last 30 years, with the January 1982 storm contributing a substantial volume of sediment to the estuary. Repeat surveys during this project indicate that the bed aggraded 1 to 2 feet over a two year period.

In addition to bed elevation, the composition of the bed in this reach appears to have changed in the last 30 years. Sediment sizes generally found in estuary/lagoon systems and coastal floodplains are sand, silt, and mud. The floodplains adjacent to the channel adhere to this convention. In 1970 the channel substrate through this lower reach appears to have been the typical fine-grained size distribution (Friese, 1971). Today the bed sediments are composed primarily of sand and gravel—a significant coarsening.

Tall dunes are located on the outer bank where the channel bends and begins to parallel the beach. The dunes and sand transition upstream to vegetated, high banks demarcating a stable floodplain. Repeat photography since the early 1970s (Figure 3.1.1), as well as aerial photographs from 1941, 1960, and 1980, show that the dunes and floodplain area on the south bank were once much more extensive. These high dunes would have provided protection from wind and wave washed sand. They also show a small island/side channel complex on the south bank. Since the 1970s the side channel has filled in with sediment, and the banks and dunes have retreated (Figure 3.1.1). Five to 10 feet of lateral bank retreat occurred downstream of the bridge over the project period, the majority taking place during the storm of December 31st, 2005. While the south bank and barrier beach has gone through cycles of deposition and erosion over the past 60 years the area of stabilized wetlands on the north bank has increased by 60% since 1941.

Early historical photos from the 1920s and accounts from the 1940s and 50s describe the lower estuary as deep and wide, with extensive tidal wetlands and channels. A snapshot of what this looked like in the 1920s is seen in Figure 3.1.2. Remnants of the tidal wetlands are still present in 1941 (Figure 3.1.3), but have disappeared by the early 1950s in the lower estuary. By the 1980s the channel-margin wetlands had aggraded to the extent that they are rarely inundated and are no longer connected to the channel. Increased sediment delivery from intensive land use and channel clearing practices in the upper watershed likely led to infilling of the wetlands and transition to upland habitat. Complex wetlands such as these provide diverse, important habitat for foraging, rearing, and high flow refugia. Loss of this habitat has reduced the ecological value of the system and has likely contributed to the degradation of the salmonid fishery.

Spring 1972

October 1979

June 1987

November 2002

March 2006

Figure 3.1.1 *Sequential photos of the lower Salmon Creek estuary. (1972-2002 photos: Copyright © 2002-2006 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.Californiacoastline.org)*

Figure 3.1.2 *1920s photo taken from the first Highway 1 Bridge looking downstream at the lower estuary. Note the extensive tidal wetlands (dark area) covering much of the area in front of the high dunes. This diverse, productive habitat was quickly disappearing by the 1940s and completely gone from the system by the 1960s. (Photo provided by Charles Beck)*

Middle Estuary

Upstream of the bridge the channel narrows and is bordered by high, steep, heavily vegetated banks. Two deep pools (-1.0 feet NGVD) have formed at bedrock-controlled meander bends. Long, shallow runs connect the pools. Broad floodplains have developed on either side where small drainages enter the valley. Currently, seasonal freshwater ponds and wetlands develop in winter and spring along the valley walls, fed by overbank flows and tributary drainage. A larger, perennial pond is found on the south floodplain immediately upstream of the Highway 1 Bridge. Historically this pond area was connected to Salmon Creek by a tidal channel (Figures 3.1.3). A new bridge abutment constructed in the late 1940s filled a portion of the floodplain and effectively disconnected the pond from the mainstem. Evidence of small drainage channels in the north-bank floodplain were observed during the study, and were documented as active in 1971 (Friese, 1971).

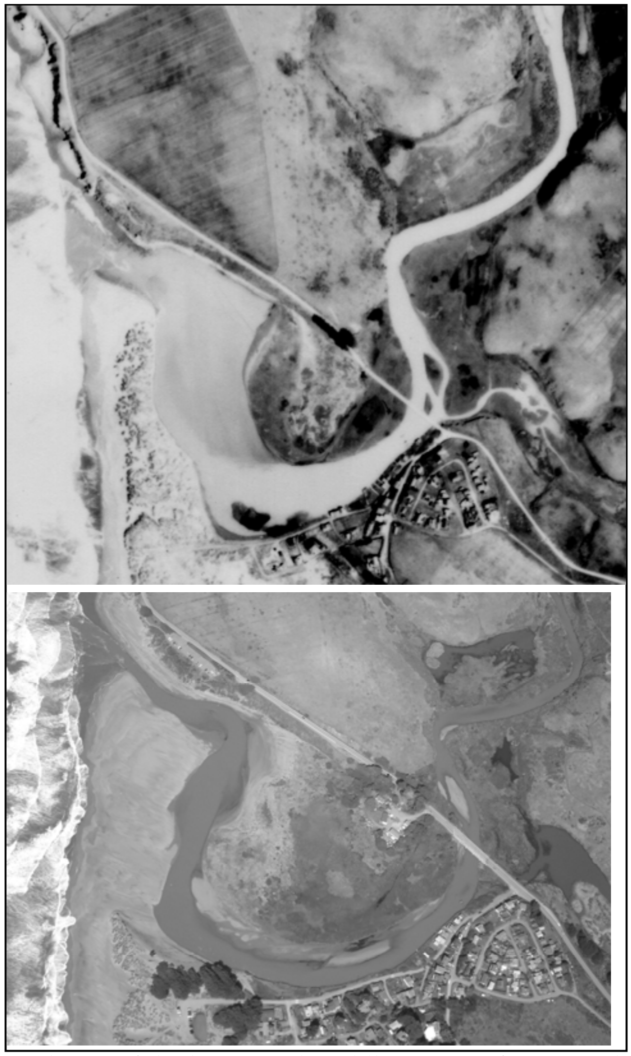


Figure 3.1.3 *Comparative photos of the lower and middle estuary from April 1941(upper) and March 2006. In 1941 several vegetated islands were upstream of the bridge and a tidal channel network was formed in the southern tributary valley. This area was disconnected from the main channel by the new bridge construction in the late 1940s.*

Maps from the late 1800s show the area of open water in the estuary to have been much larger, extending into what are now floodplains (Figure 3.1.4). If these maps are accurate representations of the estuary during the early settlement period the tidal prism was more than twice the current volume. The floodplain dimensions seen today were formed by the early 1940s (Figure 3.1.3). An exception is upstream of the bridge, where, in the early 20th century the estuary was wider with two islands and multiple side channels (Figure 3.1.5). By 1950 a new bridge was built, the channel had narrowed, and the floodplain resembles the current form.

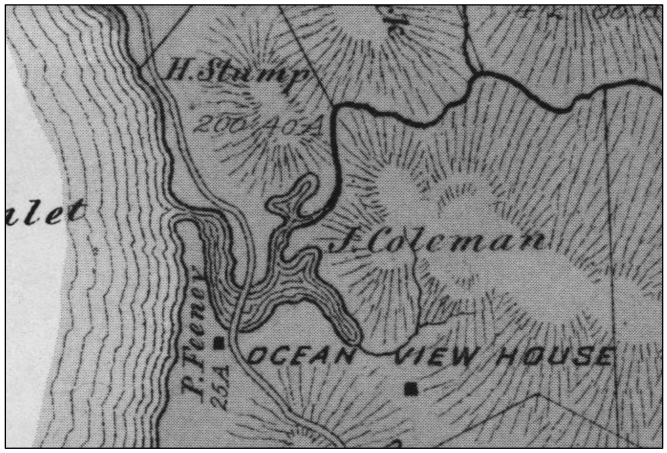


Figure 3.1.4 *1877 map of the Salmon Creek estuary indicating a large, open body of water. Southern and northern branches of the estuary shown in this map are now extensive floodplains and the lower estuary has narrowed.*

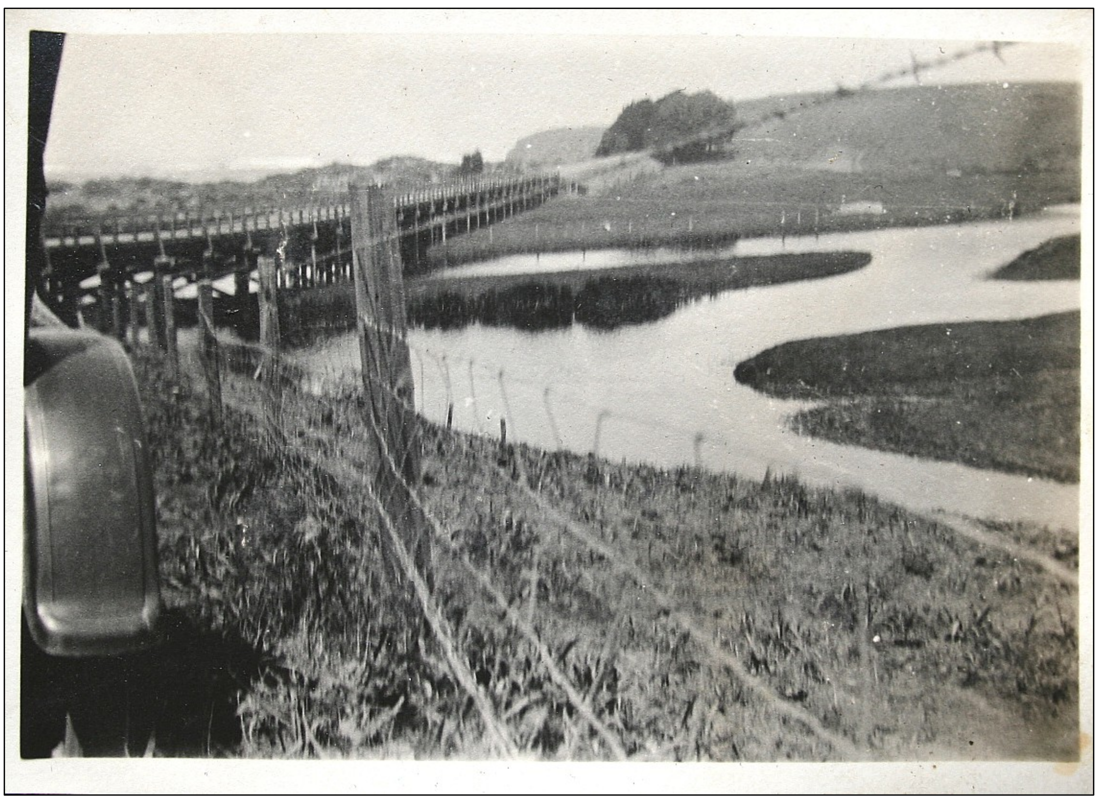


Figure 3.1.5 *1920s photo taken from Highway 1 looking south across the estuary. Note the vegetated islands, side channels, and bank elevations that are at the water surface elevation. All of these features provide complex habitat that supports a healthy ecosystem and strong salmonid population. (Photo provided by Charles Beck)*

The floodplain sediments in the middle reach appear to be similar to those in the lower estuary—fine-grained, interlayered silts and sands. Bed sediments are coarser and are composed primarily of gravel and sand. Gravel point bars are developing on inside meander bends and a large mid-channel bar has formed upstream of the bridge. This gravel bar aggraded two feet during the project period. As in the lower estuary, bed composition has coarsened from the sand and mud deposits described by Friese (1971).

Upper Estuary

The upper estuary is the transition zone from freshwater stream channel to estuary/lagoon system. In late summer freshwater flows into the lagoon near river mile 1.1, while during full lagoon conditions and high flow periods slow, saline water extends approximately 2 miles upstream. Pool/riffle sequences, alternate gravel bars, and low elevation floodplains characterize channel form in this reach. Several deep, bedrock controlled pools are found in this reach. Bed material ranges from silt to coarse gravel and cobble.

Lagoon Formation and Breaching

The timing, intensity, and volume of rainfall in the late spring (April-June) strongly influences barrier bar development and lagoon conditions. A detailed description of the interactions between rainfall, beach channel scour and deposition, and estuarine tidal action during the study period is found in the Water Quality Chapter. In 2004 the barrier bar closed in May after a very dry spring (1.9 inches, 35% of average) and conversion to a freshwater lagoon did not occur. In contrast, spring rainfall in 2005 was 220% of average (11.6 inches). The bar did not close until early August and streamflows were still adequate to largely convert the lagoon to freshwater. Implications of this for water quality and fisheries habitat is discussed in subsequent sections. The two extreme hydrologic conditions resulted in very different lagoon water surface elevations in the late fall. During the drought year of 2004 the lagoon water surface was 2 feet lower than in late summer/early fall 2005. In Figure 3.1.6, rainfall data from the period of record (1948-2005) shows the variability and distribution of spring rainfall totals.

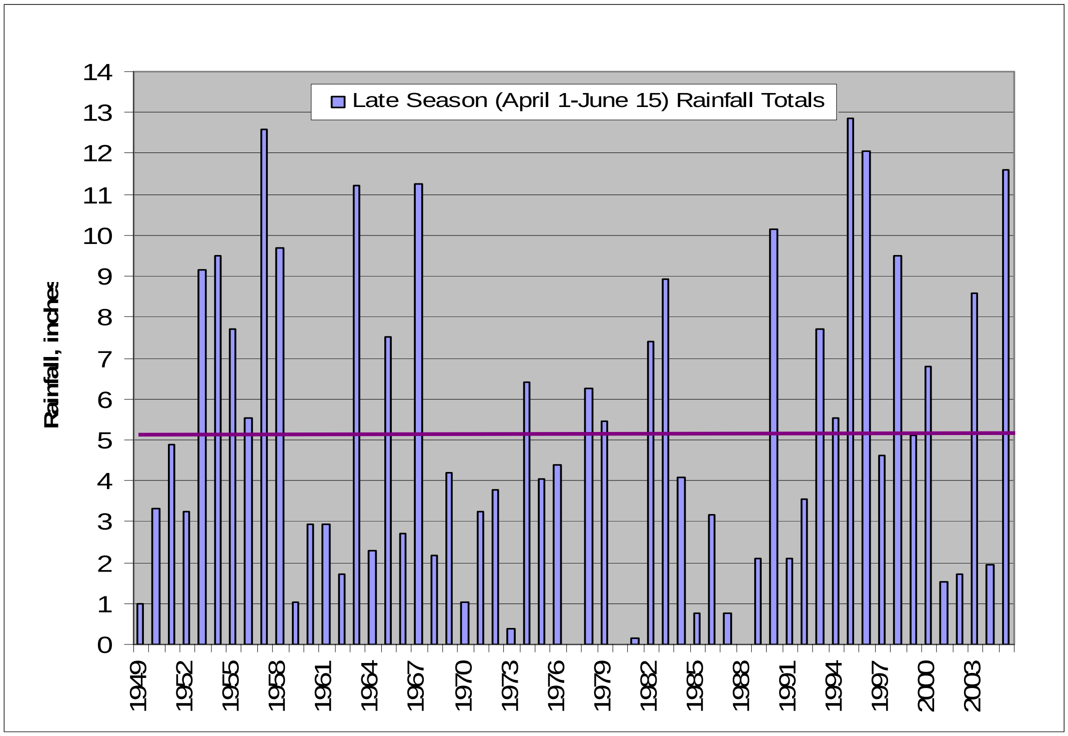


***Figure 3.1.6** Spring rainfall totals for the period of record. Higher rainfall during this part of the year translates to longer bar-open conditions in the estuary, higher lagoon elevations in the fall, and sustained summer streamflows in the upper watershed. Conversely, low rainfall during the spring means exacerbated summer drought conditions and poor in-stream and estuarine habitat.*

Fall sandbar breaching is governed by antecedent lagoon conditions and rainfall/runoff intensity and timing. Lagoon water surface elevation prior to the first rains influences the amount of streamflow required to raise the lagoon level to the barrier sandbar elevation for breaching. In fall 2004 and 2005 the barrier sandbar elevation was at approximately 11 feet. The volume of water in the lagoon at a water surface elevation of 11 feet is approximately 200 acre-feet. This represents the volume of water needed in the lagoon to breach the barrier sandbar. Under the drought conditions of 2004 the late summer lagoon volume was approximately 30 acre feet, thus 170 acre feet of additional water was necessary to raise the water surface to the sandbar crest. In 2005 the antecedent lagoon volume was 65 acre feet, requiring an additional 135 acre feet to breach.

The breaching conditions were reconstructed for fall 2005 using estuary stage data, daily streamflow at the estuary as estimated (watershed area ratio) from discharge at Bodega, rainfall, and an approximation of loss through the barrier beach. Loss from evaporation and sandbar seepage was estimated to be 5 acre feet per day. This was based on the daily inflow volume during a three week period of stable lagoon elevations, and is comparable to flow rates calculated using standard groundwater formulas. Figure 3.1.7 illustrates the inflow/lagoon volume/breach relationship for fall 2005. It appears that the sandbar breached after approximately 180 acre feet of water had accumulated in the lagoon from rain induced streamflow increases.

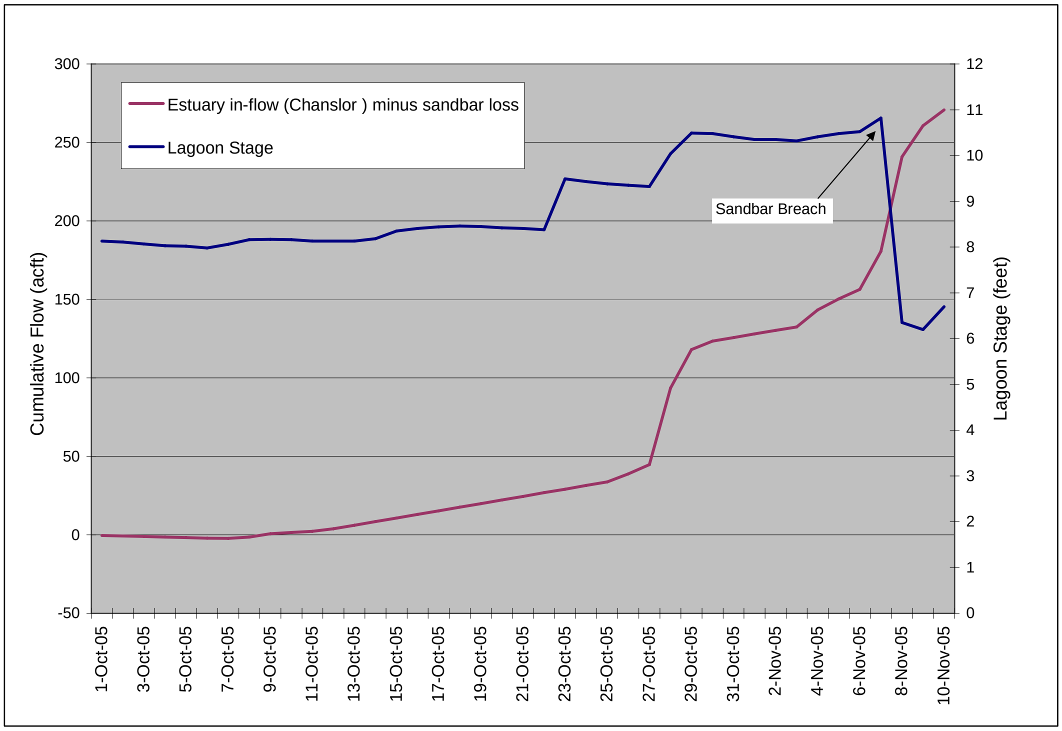


Figure 3.1.7 *Lagoon water surface elevations pre- and post-breach 2005 as they relate to stream flows. The sandbar breached on November 8th. Cumulative inflows were calculated to be approximately 180 acre feet at the time of breach. Given the level of approximation in these estimates, this correlates well with the volume of 135 ac ft needed to fill the lagoon.*

Historical early-season streamflow accrual in the lagoon from October 1st to December 15th was calculated for 1962 through 1974 using flow records at Bodega (USGS Station 11460920 SALMON CREEK AT BODEGA CA). As for the 2005 data, the Bodega streamflows were ratioed by watershed area to reflect the additional contributing tributaries between Bodega and the estuary. Cumulative runoff minus the daily sandbar seepage loss was plotted for each of the eight years of record along with daily rainfall totals (Figure 3.1.8). From these graphs the amount of rainfall that produced runoff conditions required to breach the barrier sandbar was ascertained. Seasonal rainfall totals that produced a minimum of 200 ac ft of storage in the lagoon (the generalized breaching volume) ranged from 9 to 13 inches, with an average of 10 inches. This rainfall value also appears to represent the soil saturation point for the watershed, in that streamflow increases rapidly with any subsequent rainfall.

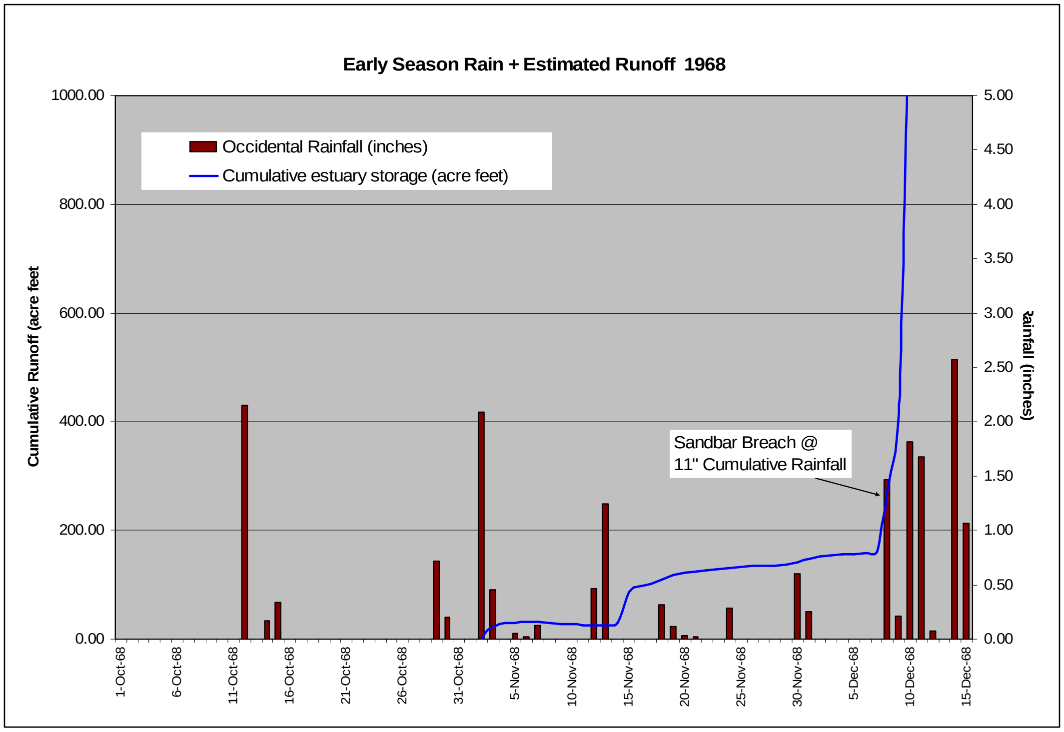


Figure 3.1.8 *Example of rainfall/runoff graph used to determine the cumulative rainfall preceding lagoon breaching. As illustrated in this example, runoff during the first rainfalls of the season is minimal, as the majority of the water infiltrates the soil. When the ground reaches saturation, streamflows respond and the flow volumes entering the estuary increase exponentially. Thus, any significant rainfall after the watershed is saturated will likely initiate breaching, regardless of variation in estuary size or antecedent lagoon conditions.*

Early season daily rainfall was cumulated for each year of record for the watershed (1948-2005 @ Occidental) to determine the date on which 10 inches of rainfall was reached. Four years during the period of record have incomplete datasets (1977, 1978, 1980, and 1999). The estimated breaching dates based on watershed saturation of 10" of rainfall are plotted in Figure 3.1.9. During the past 58 years the Salmon Creek lagoon breached on average by December 3rd (median date is November 30th). October 10th, 1957 is the earliest opening on record, and February 21st, 1976 the latest. These are approximate dates of breaching, as the system is driven by the complex interactions of antecedent hydrologic conditions, date of lagoon closure, summer lagoon volume, and changes in estuary size over time. The breaching dates in the figure can only be considered an indicator of the initial breach date. The barrier sandbar may reform after initial breaching depending on rainfall patterns and watershed conditions. An example of this was the winter of 2004/2005; initial breaching occurred on December 8th after a cumulative 14 inches of rain. The bar closed again two days later and did not reopen until December 27th when an additional 4 inches of rain fell.

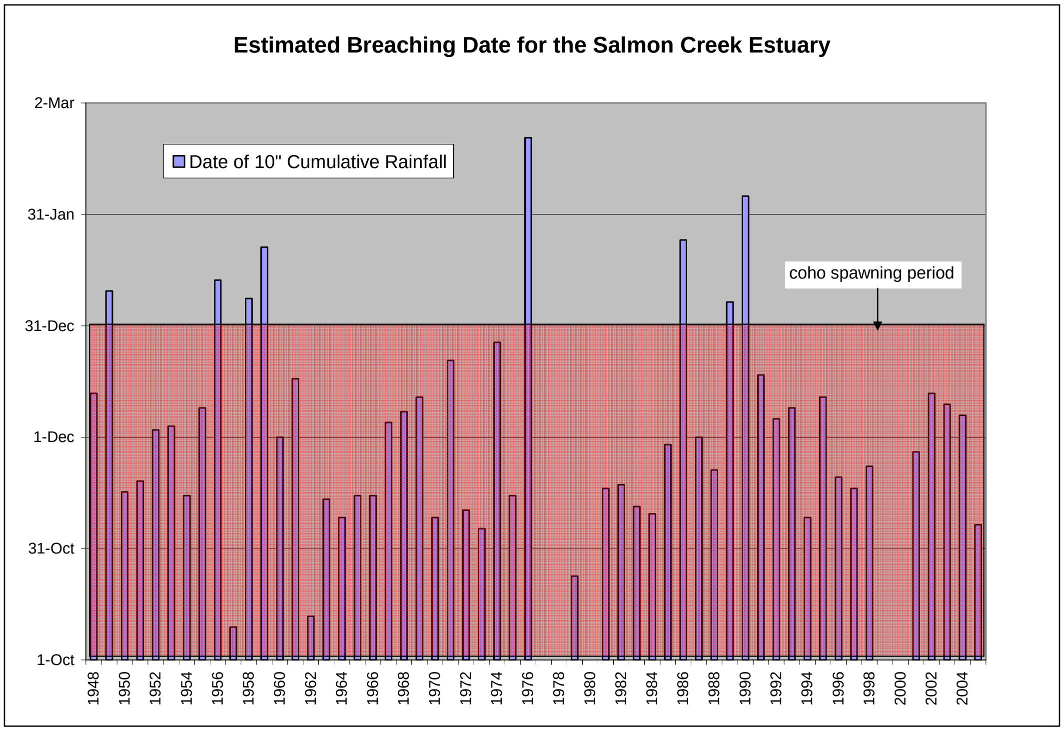


Figure 3.1.9 *Dates of initial sandbar opening each fall from 1948 through 2005. It does not appear that the average timing or variation in estuary breaching has changed significantly in the last 60 years. In half of the years there is at least a one month window for coho to enter the watershed for spawning. Occasionally the bar does not open during the coho run period.*

The sandbar breaching analysis, as shown in Figure 3.1.9, is based on a rainfall/streamflow/lagoon-form dynamic that is present under today's conditions. Using the data available, timing of initial sandbar breaching varies annually within a five month period. There are no observable, significant shifts in the timing of the breach over the period of record (as based on 10" rainfall accumulation date). The average annual breach date (December 3rd) does not change from first 30 years of record to the last, while the median date shifts 4 days; from December 2nd to November 28th.

Have the breaching dynamics changed in the last 30 years? Historical anecdotal stories say that prior to the 1970s the locals would manually breach the sandbar to let in the salmon that were gathering off shore, and that "they always had Salmon for Thanksgiving". It is likely that the summer lagoon water surface was higher than we see now because of higher summer inflows, and thus would require less rainfall-augmented streamflows to initiate breaching. It is also possible that today's smaller tidal prism does not initially flush a deep enough breach channel to allow migratory passage; creating a half-closed, overflow mouth instead of a deep, sustained channel.

3.2 *Upstream Factors* *(prepared by Lauren Hammack)*

Introduction

Streamflow and turbidity in the upper watershed, and their influence on estuary habitat conditions, were assessed during this study. The quantity of freshwater entering the estuary is the primary factor determining habitat quality and dynamics of lagoon formation and breaching. Local memories of the system in the 1950s, 60s, and 70s suggest that summer freshwater flows were much higher than typically occur today, and that even during drought years there was sufficient inflows to keep lagoon levels high (interviews w/ Charles Beck and Dr. Cadet Hand, 2006). Population growth in the watershed, and associated increases in water consumption, has likely reduced dry season flows. Adequate streamflow in the lower watershed, immediately upstream of the estuary, is critical for providing fresh, cool, oxygenated water to upper pools and the lagoon. The local community and government agencies have expressed concern over private and public water supply wells located adjacent to the creek throughout the watershed. Observers have noted that the streambed near Bodega Bay's public supply well, located ~ upstream of the estuary often goes dry in late summer while other reaches still have flow. The effect, if any, of groundwater pumping on streamflow was investigated.

In addition to decreased summer flows, increased sediment loads from the upper watershed have contributed to reductions in summer rearing habitat. As discussed in Chapter 3.1, the areal extent of the estuary has dramatically decreased since the mid 1800s. By the 1940s the estuary had narrowed considerably since historic times, with the northern and southern branches transitioning to marsh and floodplain features. Up until the 1950s and 60s the channel, however, was still deep; with depths of 6 to 12+ feet during summer lagoon conditions (interviews w/ Charles Beck and Dr. Cadet Hand, 2006). Annual winter storm events transport gravels and sand from the upper watershed, gradually filling in the upper and middle estuary. Over the study period 2+ feet of sediment was deposited upstream and downstream of the Highway 1 Bridge. Summer lagoon depths now range from 2 to 6 feet, with a few deeper pools.

While coarse sediment delivery has caused aggradation of the estuary bed, fine sediments suspended in the water can impair juvenile salmonid growth, feeding, and territorial behavior. Excessive turbidity in the system can delay upstream migration of adults and impede spawning behavior. Turbidity levels in the watershed were documented and analyzed for salmonid impairment.

Methods

Initial plans to document streamflows entering the estuary and the effect of well pumping on those streamflows involved monitoring of surface flows at multiple sites in the vicinity of the Bodega Bay Public Utility District (PUD) groundwater wells. By mid July 2004 it became apparent that streamflow was going to drop below easily measurable levels. An alternative method was devised. Water table monitoring wells were installed at four locations within a 1000 foot reach of channel adjacent to the PUD wells (Figure 3.2.1). Perforated PVC pipe was installed to a depth of 8 feet in the gravel bars and pressure transducers were dropped down the observation well. The water surface level loggers recorded water depths at 30 minute intervals. In 2004 the level loggers were installed on July 30th and removed on October 29th. The wells were sealed for the winter. Three loggers were reinstalled in July of 2005 and ran from July 13th through November 2nd. Topography of the study reach was surveyed, and included elevations of the wells in relation to important channel features.

Figure 3.2.1 *Location of observation wells in relationship to the Salmon Creek estuary.*

Higher in the watershed rainfall, streamflow, and turbidity was monitored with continuous loggers. Flow and turbidity monitoring equipment was installed in early December 2004 in Freestone and Bodega. Flow stage was recorded at these sites at half hour intervals through December 2005. Discharge measurements were taken at both Freestone and Bodega over a range of flows and a stage/discharge rating curve was produced for Bodega. The compilation and use of the discharge and rainfall data is described previously in more detail (Chapter 3.1).

The turbidity sensors experienced catastrophic failure due to a manufacturers defect. Thus, continuous turbidity was not collected. To compensate for this loss of data a hand-held turbidimeter (Hach 2100P) was used to collect longitudinal profiles of turbidity at single points of time during storm events. Volunteer water quality monitoring data at discrete locations throughout the watershed was also examined.

Groundwater Withdrawals

Severe drought conditions were present in the summer of 2004. Spring rainfall totals were 35 percent of normal. Streamflows declined rapidly throughout the watershed. Continuous monitoring of the water table elevation captured the decline over a 3 month period (Figure 3.2.2). By mid August the riffles were dry, disconnecting the pools. In early September the pools in this reach dried completely. At its lowest point in the season, the water table was a foot below the channel bed. Stream and water table levels were very different in 2005 after a very wet spring (4th highest on record). The water table remained at a stable level throughout the season (Figure 3.2.3). In both years the first significant rainfall event produced a noticeable change in the water table—in 2004 it brought the level up 3 feet.

Additional observation wells were installed 350 ft upstream and 450 ft downstream of the PUD water supply well (Figure 3.2.1). In 2004 the water table decline pattern was consistent in all three observation wells, with maximum water surface lowering over the study period of 2.5 ft at the upstream and middle wells and 2.0 ft at the downstream well. In 2005 the shallow water table remained relatively stable at the three observation wells over the measurement period, similar to what is seen in Figure 3.2.3.

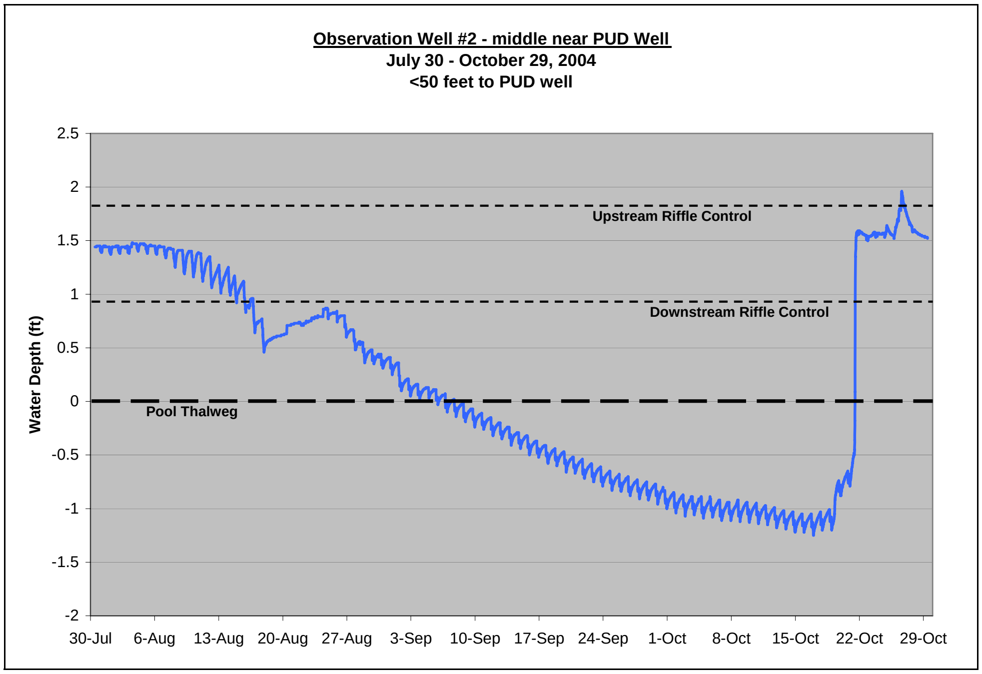


Figure 3.2.2 *Water table levels upstream of the estuary in late summer 2004. Timing of pool disconnection and drying is shown when the water levels go below the feature elevations, as well as water table response to the first rain of the season. Daily fluctuations appear to be responses to periods of well pumping.*

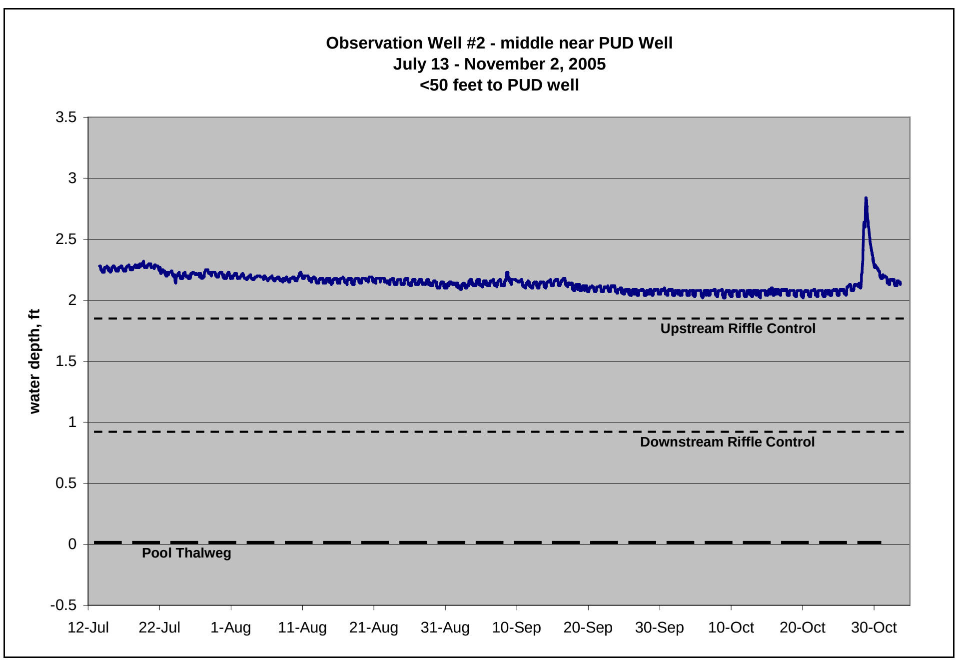
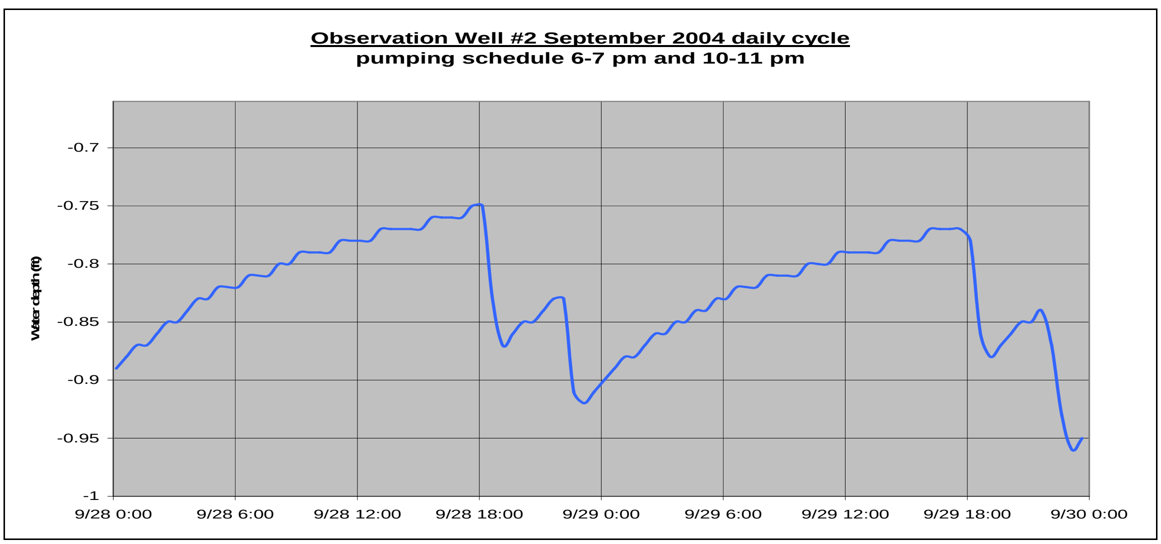


Figure 3.2.3 *Water table levels in summer 2005. A wet spring kept the stream and shallow groundwater levels high and consistent through the season. Flows remained well above pool and riffle elevations. Daily pumping of the wells is detectable in the daily fluctuations.*

Daily fluctuations in the water table are observable in the recordings. The daily patterns are very different between the two years (Figure 3.2.4) and were analyzed against possible fluctuations due to water uptake from the riparian vegetation for photosynthesis, tidal cycles, and groundwater pumping from the adjacent well. Lowering of the water table during daylight hours would be expected if the pattern was due to photosynthesis activity of the riparian willow and alder community. In both years the water table declined only at night. Nor were the patterns consistent with tide cycles. The periods of decline and recovery do correspond closely to the PUD well pumping schedule and are illustrated in Figure 3.2.4.

The daily response of shallow groundwater levels to the PUD pumping cycle (Figure 3.2.4) is also observable in the upstream and downstream wells in 2004; indicating that shallow groundwater flow in the area was very low, and thus the water supply withdrawals had a large area of influence during this drought season. In 2005 the downstream observation well was not reoccupied and an additional well was installed 1100 feet upstream of the PUD supply well. The daily pumping cycle is not observable in the 2005 upstream well logs. Shallow subsurface flow was strong throughout the summer, as it was able to maintain a stable water table and nullify the effects of local groundwater withdrawals.



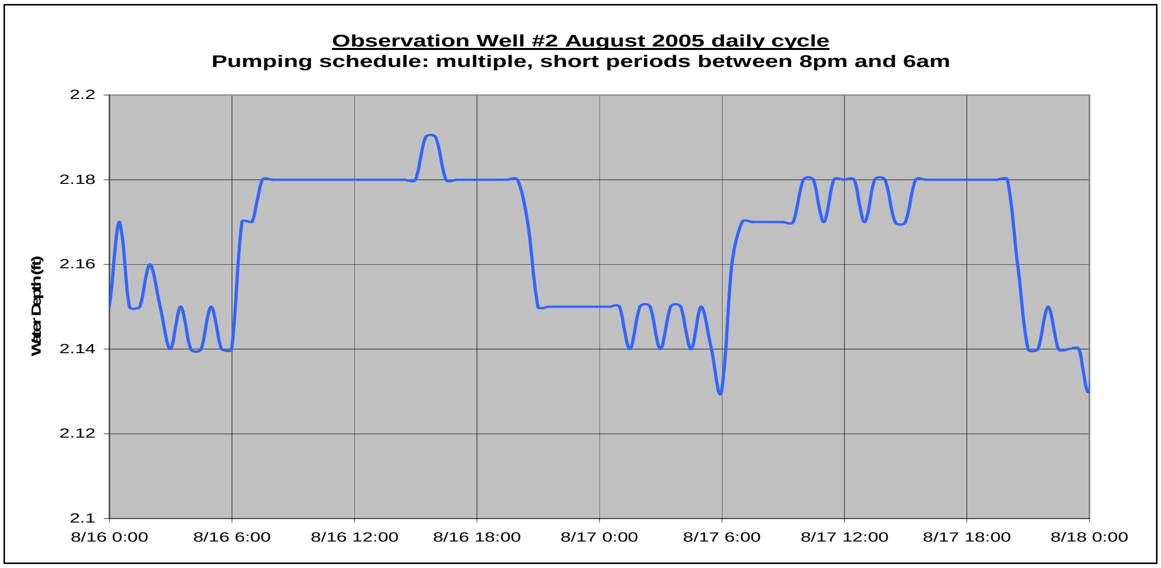


Figure 3.2.4 *Examples of daily water table fluctuations in 2004 and 2005. Pattern differences are related to changes in water supply well pumping routines between the two years. Note that in the drought year (2004) the fluctuations were over 2 tenths of a foot, while in the wet year (2005) the fluctuations were only over 6 hundredths of a foot.*

These results indicate that the groundwater well adjacent to the creek does have an effect on local water table levels during pumping. The drawdown and inability of the water table to recover appears to be more pronounced during drought years when groundwater recharge volumes and head is significantly decreased. Streamflow levels at any point in the stream network are determined by surface flows from upstream and the groundwater conditions locally. Shallow groundwater flow rates and volume is a function of topography, bedrock type, and depth and composition of the alluvial fill in the valley. During drought years the groundwater conditions along the channel are such that a large cone of depression and zone of influence forms around the water supply wells. Groundwater flow is not sufficient to recharge the system after pumping and the water table elevation gradually declines over time. This reduces the amount and quality of water available for habitat in the immediate area of the wells as well as downstream to the estuary.

The study site is at the bottom of the watershed, directly upstream of the estuary. Adequate freshwater flows in this reach are critical to summer rearing habitat in the downstream pools and lagoon. Streamflows at this point are a result of all the water diversions and extractions occurring in the whole watershed, as well as the adjacent well withdrawals. This shallow groundwater investigation was limited in extent, and a quantitative analysis of the effects of the groundwater pumping at this site cannot be made. However, the data does show that the aquifer that the well is withdrawing from is connected to the shallow groundwater and that the water table is highly responsive to extractions. During low flow, or drought, conditions the streamflow is highly dependent upon local groundwater contributions, while in wet years the in-channel flow and shallow groundwater will sustain some instream flow.

Turbidity

Base-flow turbidity during the summer and between winter storms is typically below 10 NTUs throughout Salmon Creek. This is well within the levels considered to be beneficial for juvenile and adult salmon. During storm events turbidity increases appreciably, with watershed-averaged turbidities ranging from 150 to 400 NTUs (Figure 3.2.5). Instantaneous peak turbidity values often go above 1000 NTUs and have sustained periods of 150 to 600 NTUs. Measurements of turbidity at fourteen sites within the watershed during high runoff indicate that there are extended periods of "significantly impaired" conditions for Salmonids during storm events in both the mainstem and tributaries.

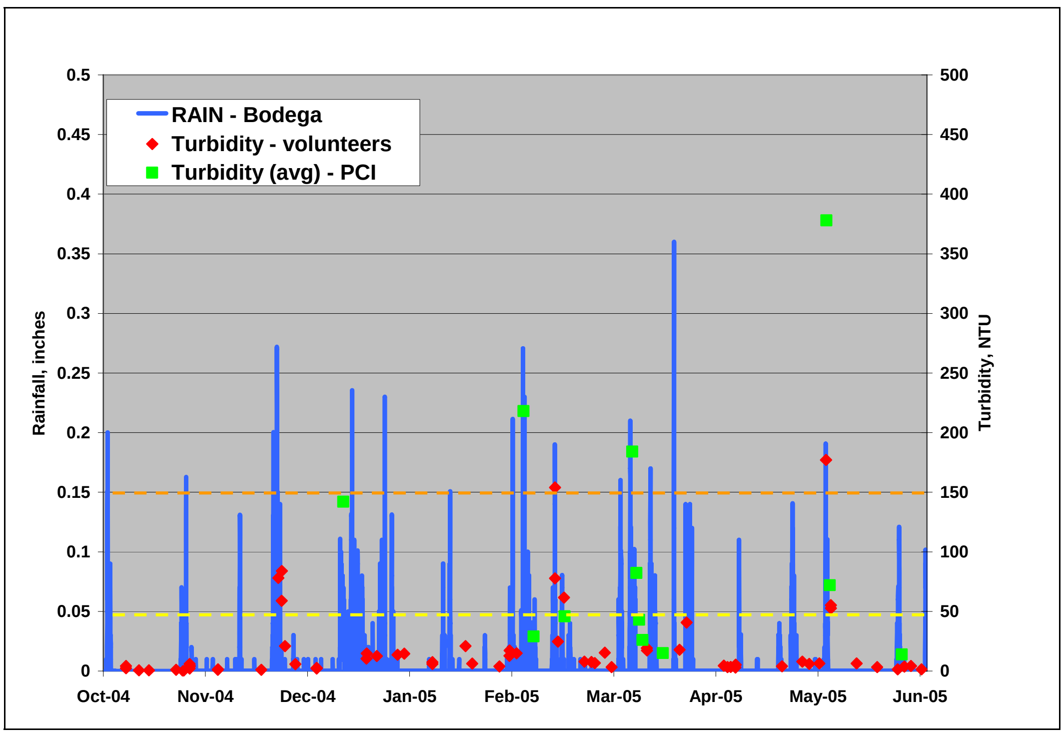


Figure 3.2.5 *Turbidity in relation to rainfall in the Salmon Creek watershed. Slight impairment of salmonids occurs under turbidity conditions above the yellow line and significant impairment occurs above the orange line (see Figure 3.2.6)*

Newcombe (2001) has developed an empirical model to assess the severity of impacts caused by increasing the duration and concentration of suspended sediments (Figure 3.2.6). He found that the longer fish are exposed to high concentrations of fine, suspended material that reduces clarity of the water, the greater the ill-effects. Chronic mid-level turbidity (50-100 NTUs) can have much the effect on the fishery as a short period of very high turbidity (1000 NTUs). Suspended sediment in the water can contribute to marked declines in the entire aquatic ecosystem. Direct effects include mortality, reduced physiologic functioning, and habitat alienation. Decreased growth rates (from reduced food supply) and reproduction are indirect effects of high turbidity.

Figure 3.2.7 shows turbidity levels and their approximate duration in the lower estuary during three storm events in spring 2005. Widespread erosion from roads, slides, gully, and channel banks in the upper watershed produces high turbidity in the stream and estuary. The elevated turbidity during storm events may contribute to reductions in the fishery by indirect or direct impairment of juvenile and adult salmonids. Adults may wait to enter the estuary and watershed until the waters clear to more favorable levels, thereby reducing the time and opportunities for spawning. Juveniles entering the estuary to feed and prepare for transition to the ocean will experience reduced feeding opportunities and potential physiologic impairments that will lessen their survivorship. No turbidity refuges currently exist within the estuary or upper watershed.

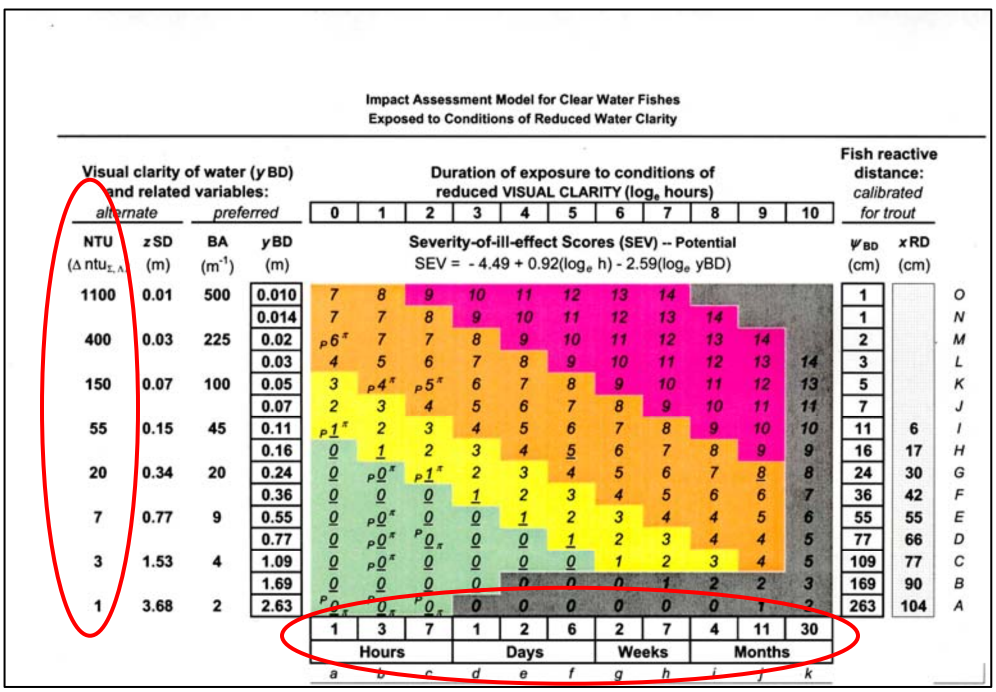


Figure 3.2.6 Newcombe's (2001) turbidity impact model. Severity of impact to salmonids and other clear water fishes increases with NTU (y axis) and time (x axis). Green indicates ideal conditions, yellow slightly impaired, orange significantly impaired, and red is severely impaired. Increasing severity leads to reduced growth and habitat, and/or physiologic impairment.

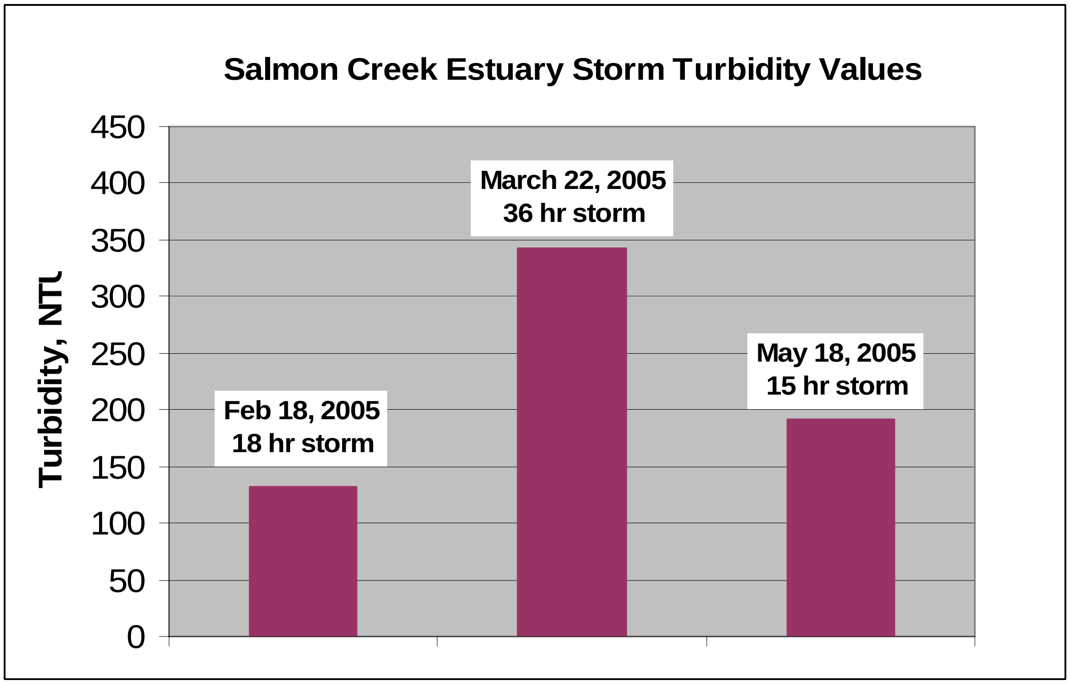


Figure 3.2.7 *Examples of turbidity values and durations during three storm events in 2005. Conditions within the estuary during these periods were slightly- to significantly impaired for Salmonids. Habitat alienation and physiologic impairment occurs at these levels.*

3.3 *Water Quality* *(prepared by James C. Roth)*

Note: Complete figures for Section 3.3 are located in Appendix B

Introduction

Water quality in the Salmon Creek estuary was studied intensively for one year beginning in June 2004. Monthly profiles were made of temperature, salinity, and dissolved oxygen at six sampling stations between the estuary mouth and the upstream limit of tidal action near the Chanslor Ranch. Continuously-recording datasondes placed at three stations logged the time course of signal water quality events in the near-bottom environment. The first data were collected on 3 June 2004, shortly after the growing beach berm closed the estuary mouth, and monthly cruises were made thereafter. Regular monthly sampling ended on 1 June 2005, at which time datasondes and tidbit recorders were removed. Stage recording was continued through the summer of 2005, however, and this report includes stage data through 22 September 2005, as well as water quality profiles made on that date. Water quality sampling stations were located in deep pools, and ranged from the estuary mouth upstream to near the observed upstream limit of seawater excursion.

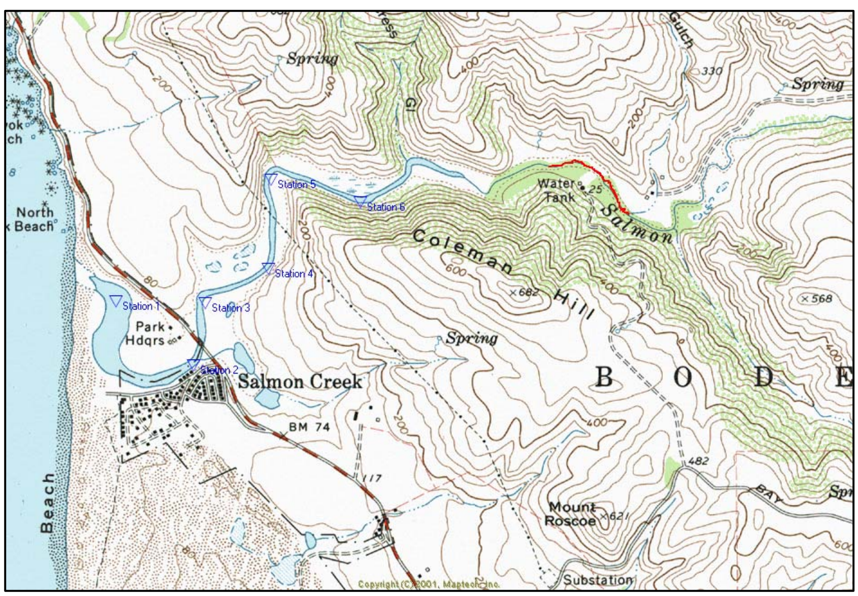


Figure 3.3.1 *Study area with sampling stations indicated by blue triangles. Red track indicates the freshwater study reach near the off-channel well.*

Methods

On each sampling date profiles of temperature, salinity, and dissolved oxygen were made at half-meter intervals from the surface to just above the bottom, using YSI meters. Profiles were made at each of six sampling stations. Recording datasondes (Stations 1-3) or Tidbit temperature recorders (Stations 4-6) were deployed on 3 June at each station, logging hourly data. The datasondes (Hydrolab Datasonde 3) recorded temperature, salinity, and dissolved oxygen just above the bottom. They were downloaded and serviced on each subsequent monthly visit. The water level in the estuary was measured relative to an arbitrary mark made on one of the Highway 1 bridge piers. These levels were later converted to stage data when a stage recorder was installed. Stage data are roughly equivalent to feet above Mean Lower Low Water (MLLW). Rainfall in the Salmon Creek watershed is based on data from gauges in Bodega, Willow Creek Road, and Freestone. For dates when data are available from more than one of these stations, the daily means have been used.

Results

Based on the station locations and the water quality results, the estuary can be divided into three habitat zones:

- The lower estuary (Station 1)
- The middle estuary (Stations 2 and 3)
- The upper estuary (Stations 4, 5, and 6)

Because the condition of the sandbar or beach berm located at the mouths of small estuaries in California is a major determinant of water quality conditions in the estuaries, the results of this study are presented in terms of the alternating states, bar-open (i.e., mouth open) vs. bar-closed (mouth closed).

Water Quality in the Salmon Creek Estuary during Bar-Closed Conditions, June 2004 through November 2004

<u>The Lower Estuary</u>

The lower estuary is the broad and relatively shallow area adjacent to the beach berm. This section is exposed to the wind—brisk most afternoons—which keep it unstratified when the berm isolates it from tidal action. Sampling station 1 was located in the deepest part of the lower estuary (~ 2 m deep on 3 June 2004). On 3 June the water column was stratified, and the profile represents conditions established before the beach berm closed: warm fresh water overlying cool salt water, with dissolved oxygen near saturation from top to bottom. By early July most of the water column had mixed, and surface salinity was around 7 ppt.

Profiles made in August, September, and October show a well-mixed system, with cool (15-20 °C), brackish (~ 7 ppt), and well-oxygenated water from surface to bottom.

Datasonde records at Station 1 show the time course of signal events in the lower estuary. In June and early July on at least four occasions, seawater (high salinity and low temperature) spilled over the berm. These dates coincide with the highest (spring) tides, and probably also with high surf events. None corresponded to neap tides.

After 4 July the beach berm had achieved sufficient height to prevent additional seawater incursions. By 10 July the lower estuary was well-mixed, and it remained so all summer and fall. During this period the salinity was constant, and the temperature showed a diel variation of about 2-3 °C. Dissolved oxygen ranged from around 5 ppm at night to around 10 ppm during the day. The lower estuary in summer had cool temperatures, moderate salinity, and adequate dissolved oxygen. It was thus a relatively benign habitat for fish in terms of water quality.

Salmon Creek flows were very low in the summer of 2004, and the water level in the estuary in the summer of 2004 fell steadily after the berm closed. At Station 1 (the deepest part of the lower estuary) the maximum depth from August through early October was only 1.5 m. On 1 November the beach berm was intact and its crest was ~ 2 m above the water level in the lower estuary. On that date, near-bottom waters at Station 1 showed increased salinity, as well as higher temperatures and dissolved oxygen values. The October datasonde trace shows that the warm, salty water entered the system on 20 October and 27 October. These came immediately following the first two rainstorms of the season, which occurred on 19 October and 26 October (Figure 3.3.2). Salinity increases in the bottom of the lower estuary in October resulted not from seawater incursions over the berm, but from high salinity water being flushed from stratified pools upstream following rains. The water level rose over 0.5 m following the October rains, but did not breach the berm. Saltwater was also flushed down following rains in mid-November, but the berm was not breached until early December.

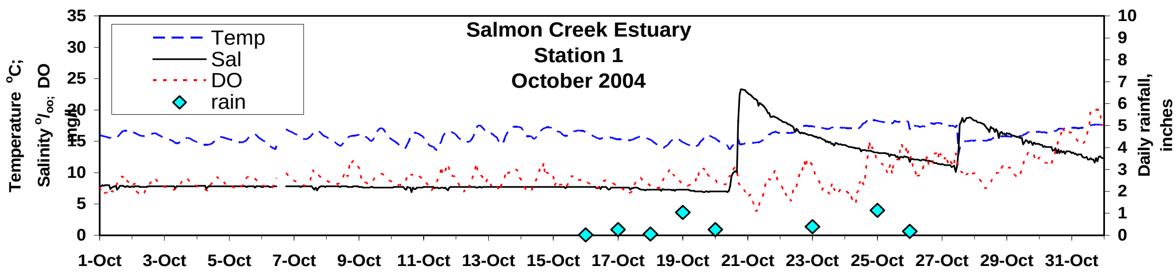


***Figure 3.3.2** October, 2004 records show two peaks of saline water entering the lower estuary from upstream. These peaks followed rain events; the beach berm has not been breached to allow tidal waters to enter the estuary.*

The Middle Estuary

The middle estuary is the relatively narrow section just upstream of the broad lower estuary. Being narrow it provides less fetch to the wind, and in summer growth of the pondweed *Ruppia spp.* (ditch grass or wigeon grass) is much more extensive than in the lower section. *Ruppia* in the middle zone in summer fills the entire water column. These features combine to prevent vertical mixing in middle zone pools, and they remained strongly stratified throughout the summer and fall. Sampling stations in the middle zone were located near the old piers on the south side just downstream from the bridge (Station 2, 2.5 m deep on 3 June 2004), and on the north side near the bend with willows ~ 60 m upstream of the bridge (Station 3, 3.5 m deep on 3 June 2004). Conditions at Stations 2 and 3 proved to be substantially similar; the following discussion is based primarily on data from Station 3.

On 3 June 2004 most of the water column was salty (~ 25 ppt), with a layer of relatively fresh water in the near-surface meter of the water column. The bottom waters were cool (17.5 °C) and dissolved oxygen levels were high. This represents conditions established while the berm was still open and tidal exchange occurring. The salinity gradient provides a large resistance to mixing, and conditions in the salty layer soon developed in a striking manner. The lower layer began to heat up, so that temperatures as high as 30 °C occurred after only 1 month of stratification, and reached 31.6 °C by September. The mechanism of heat accumulation in salty water overlain by a freshwater layer is well known and is the principle behind the "solar pond," which has been used as an alternative energy source in hot climates. The freshwater layer acts like a lens, which focuses solar radiation to the salty layer where heat accumulates because the stratification prevents exchange with surface layers. Concomitant with this heating of the saline layer, the near-bottom dissolved oxygen became reduced, and was depleted for most of the summer and fall. However, dissolved oxygen in the upper part of the salty layer was extremely high, due to photosynthesis by *Ruppia* and algae growing in and on it. On several occasions dissolved oxygen levels in the warm, salty layer were highly super-saturated—off-scale on the meter (> 20 ppm)—during daytime profiles.

Datasonde records from Station 3 clearly show the steady increase in near-bottom temperature from ~ 16 to 28 °C during June. The datasondes were deployed on racks which were intended to place the probes close to, but not in contact with the bottom (within 15 cm). However inspection of the datasonde rack after the 1 July to 11 August deployment indicated one end of the rack had been exposed to anoxic sediments and the other was not so exposed. This indicated that the rack was standing on end during that period, and the probes were therefore located about 75 cm above the bottom, not closer to it as had been intended. The high density of the *Ruppia* probably played a role in maintaining the vertical position of the rack. Although deployment of the probes 75 cm above the bottom was inadvertent, it proved to be serendipitous in that it illustrated how greatly the dissolved oxygen levels can vary within a few vertical centimeters in the salty layer. On several occasions during the first half of July the dissolved oxygen within 75 cm of the bottom was off-scale (>20 ppm; these are plotted as 20 ppm). After the datasonde was redeployed on 11 August (now weighted to insure probes were 15 cm above bottom), the records indicate that the water near the bottom was anoxic, and it remained anoxic or nearly so for the rest of the bar-closed period. There was a slight increase in near-bottom dissolved oxygen (to ~ 2 ppm) in September, which was probably due to photosynthesis, since it appeared to have a diel component. The datasonde records for Station 3 do not show when the near-bottom water became anoxic because this occurred while the probe was higher in the water column. However, based on events at the other stations, anoxia probably occurred sometime in July.

These data indicate that pools in the middle estuary do not provide much reliable habitat for fish. Much of the water column is too warm, and furthermore, is either anoxic or so high in dissolved oxygen that it may become toxic to fish. Only a relatively narrow zone about one meter thick near the surface is suitable for occupation by fish. However, *Ruppia* provides some cover for fish in this zone.

Increases in salinity in the lower zone following rainstorms in October evidently eroded the upper part of the salty layer in the middle zone, but the runoff was insufficient to overcome the stratification in the middle zone.

<u>The Upstream Estuary</u>

Upstream from Station 3 the estuary is quite shallow in summer but a few pools scoured in bends are deeper, and the upper stations (Stations 4, 5, and 6) are located in such pools. The development of stable stratification in upper estuary pools in the summer of 2004 was similar to that found in the middle zone in that a lower layer of salty and very warm water developed which is anoxic at the very bottom but very high in dissolved oxygen just above the bottom. However, pools in the upper zone differ from those in the middle zone in that the bottom salinity is lower and the salty layer is not as thick. The maximum salinity in the bottom layer at Stations 4, 5, and 6 was ~ 23, 14, and 10 ppt, respectively. This discussion will focus on conditions at Station 6, the uppermost station. Station 6 is located on the north side of the channel just upstream of the gravel beach on the Chanslor Ranch (Figure 3.3.1). The channel just downstream of the gravel beach became very shallow and narrow by September, and was dry by October.

On 3 June the temperature and dissolved oxygen were uniformly distributed from top to bottom, at 20 °C and ~ 10 ppm. A thin freshwater layer occurred over a saline bottom. This represented conditions established while the system was tidally influenced (bar open). The maximum salinity observed on 3 June was 5.4 ppt. It is possible that the profile on 3 June was not taken in the deepest part of the pool, because subsequent profiles there showed a deeper column and a maximum salinity of 10-13 ppt. After only one month of stratification, the inverse temperature stratification was well established, with temperatures as high as 29 °C near the bottom. As was the case in the middle stations, dissolved oxygen concentrations were very high in the salty layer but away from the bottom, sometimes > 20 ppm.

Tidbit temperature recordings made on the bottom at Station 6 show that the temperature increased from 20 to 29 °C in the first two weeks of June. A diel temperature fluctuation of up to 2 °C was apparent in the first 3 + months, but was less apparent after mid-September. There was also a longer-term undulation in the temperature record with a range of ~ 25 to 29 °C in August. Bottom temperatures showed a steady decline in September and October, from ~ 26 to 22 °C by mid-October. There was a sharper temperature decrease recorded in the last week of October, but profiles made on 1 November still showed a bottom temperature of 22 °C. (Profile bottom temperature on 1 November was 24 °C.) The Tidbit may have been buried in the sediments or displaced to a shallower depth by the runoff from the rainstorms during that period. (The tidbit recorder placed at Station 5 was pulled up and left out of the water, evidently by a curious or malicious person. It appeared to be logging air temperatures for most of November 2004.)

Storm runoff in October and November 2004 did not overcome the stratification at Station 6, which still had near-anoxic, salty water near the bottom. The loss of heat in the near-bottom water occurred during stratified conditions. The most likely explanation for the heat loss would be that shorter days reduce heat inputs, so that there is a net loss of heat to the sediments. This may also be partly an artifact of the sensor being buried in the sediments, which are cooler than the near-bottom water in summer. This may also be the mechanism for near-bottom heat losses observed at middle estuary stations.

Water Quality Profiles at Sites Between the Primary Stations

Data based on profiles at Stations 2 through 6 in summer 2004 showed that unrelieved stratification limited the available habitat for fish. The primary stations were located in deep pools. In order to determine whether conditions in 2004 were equally severe in shallower parts of the estuary, additional profiles were done on 29 November 2004 at four extra stations, located between Stations 1 and 2 (Station 1.5); between Stations 2 and 3 (Station 2.5); between Stations 3 and 4 (Station 3.5); and between Stations 4 and 5 (Station 4.5). Most of these stations were less than 2 m deep when sampled. These profiles showed that the shallow stations had only slight salinity and temperature increases near the bottom, and were generally well-oxygenated. There was a significant increase in salinity (to 15 ppt) and decrease in dissolved oxygen (to 0.8 mg/L) near the bottom only at the deepest of these extra sites (Station 2.5).

Water Quality in the Salmon Creek Estuary During Bar-Open Conditions, December 2004 through May 2005

The Lower Estuary

The beach berm at the estuary mouth was breached on 8 December 2004, and except for a few days in late April 2005, the berm remained open until after the last set of monthly profiles were made on 1 June 2005. The interplay between tidal action and rainfall in determining estuary stage heights and bar closure in the estuary is discussed in a separate section below.

Bar-open water quality profiles in the lower estuary were of two types. Profiles made following flushing flows after rains show a water column uniformly fresh, with temperature and dissolved oxygen uniformly distributed from top to bottom. A second type of profile was observed after winter base flows returned. Such profiles show a surface freshwater layer overlying a saline bottom layer of varying thickness. During these situations, stream flows were inadequate to repel the entrance of seawater at high tides. Temperature and dissolved oxygen were relatively uniform vertically.

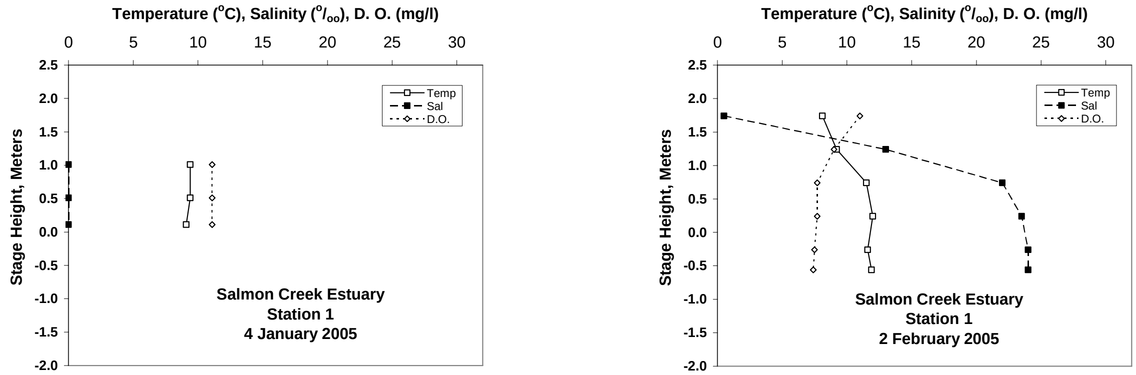
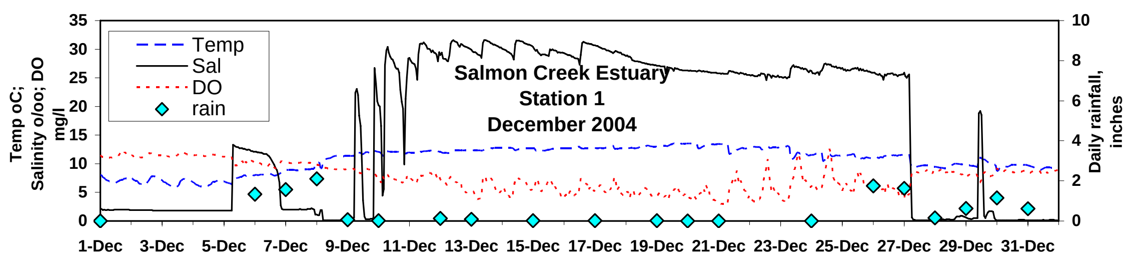


Figure 3.3.3 *Bar open water quality profiles. Storm flows sufficient to flush out saltwater are shown on the left and saltwater intrusion after normal base flows return is shown on the right.*

Datasonde deployment in the estuary during bar-open conditions is fraught with hazards, especially in the lower estuary where sediment erosion and deposition extensively re-arrange bottom contours after storms. Datasonde records from Station 1 are incomplete after 5 March 2005. The instrument was not lost, but was buried in fine sand on two occasions, which eventually rendered the unit inoperative. The December data clearly show that the water column went fresh on 8 December 2004 following a total of 5 inches of rain which fell during the previous 3 days. Seawater soon entered the near-bottom layer as the system was once more open to tidal action. The saline bottom layer persisted until 27 December after which a series of rainstorms kept seawater out—except for isolated spikes associated with high tides—until 19 January 2005. (Figure 3.3.4.) The saline bottom layer then persisted for a month, when rains in mid-February flushed seawater out for the next 5 days. The saline layer returned on 23 February and persisted until 28 February 2005.



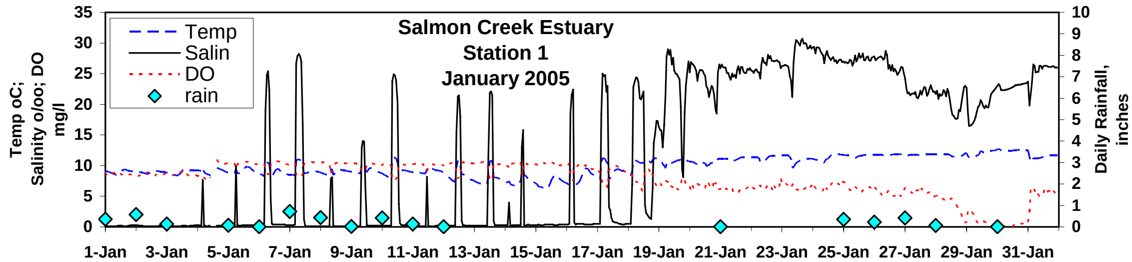


Figure 3.3.4 *Records show the influence of tidal and freshwater (rainfall) influx as the estuary mouth is breached.*

Near-bottom dissolved oxygen in the lower estuary was generally high during tidal conditions. The role of tidal action in maintaining dissolved oxygen levels adequate for fish is illustrated by the records for the period 11-19 February 2005 (Figure 3.3.5.), when dissolved oxygen decreased from ~ 8 mg/L to <1 mg/L. This was a period of neap tides, during which seawater did not reach into the estuary. Another low-dissolved oxygen episode occurred around 29-30 January 2005, which was also during neap tides, but since estuary stage data are unavailable for that period, it is not known if tidal exchange was occurring then.

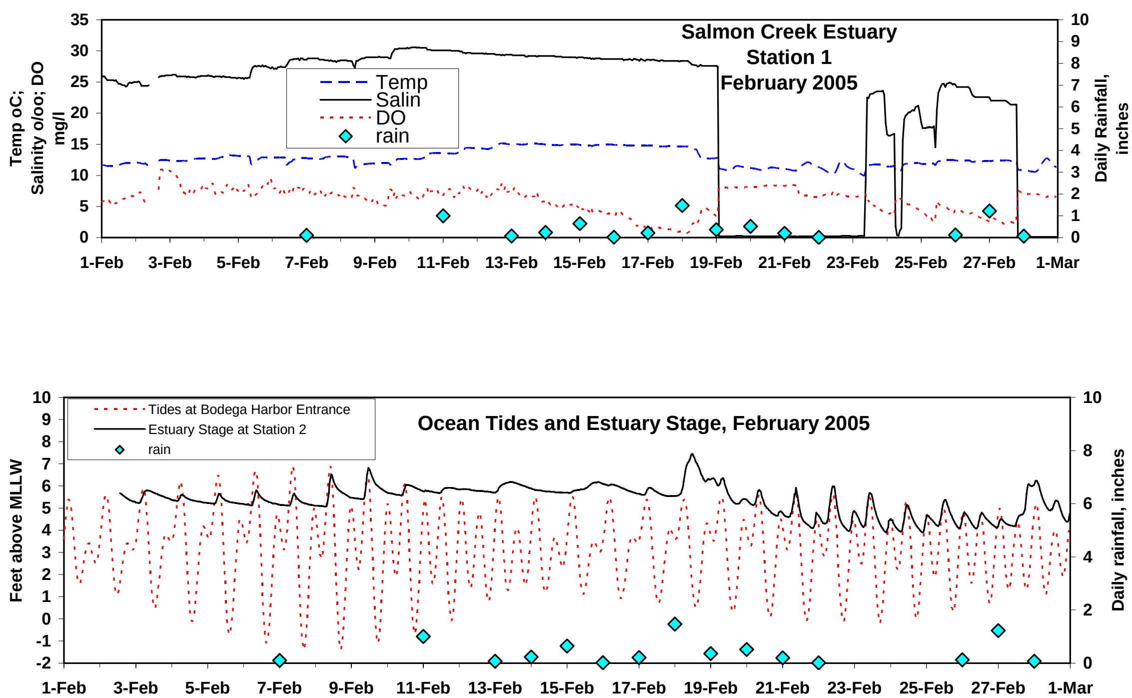


Figure 3.3.5 *Water quality and water surface elevation conditions shown with corresponding tidal and rain records.*

The Middle Estuary

Water quality profiles in the middle estuary during bar-open conditions were similar to those in the lower zone: fresh and unstratified during flushing flows, and stratified with saline water overlain by fresh during tidal action.

Datasondes deployed in the middle estuary did not get buried, but continuous dissolved oxygen data could not always be logged because deposition of fine silt following storms sometimes occluded the dissolved oxygen sensors. During December 2004 the datasonde deployed at Station 3 began to experience shortened battery life. The unit was retrieved on 22 February 2005 and was sent away for repairs. The repaired unit was re-deployed on 1 March 2005.

The datasonde records made at Station 2 show patterns similar to those made in the lower zone, with the onset of flushing episodes occurring at about the same time after each storm. (For example, fresh water was first sensed on 8 December between 4 and 5 am at both Stations 2 and 1.) But at Station 2 it took longer for seawater to return after each storm than in the lower zone. For example, following the flushing episode of 19 February 2005, seawater re-entered Station 1 on 23 February, but freshwater persisted at Station 2 for two days longer.

Episodes of flushing flows that repulsed seawater from Station 2 also persisted following storms in March, April, and May. The middle estuary was totally fresh for nearly half of May 2005. Such extended freshwater periods would deter the establishment of marine and estuarine organisms to which fresh water is toxic.

Farther up the middle estuary at Station 3 the datasonde records show that freshwater episodes were of still longer duration than at Station 2. For example, the freshwater episode that lasted at Station 2 from 9 to 13 April 2005 persisted at Station 3 until 17 April. Low dissolved oxygen found at Station 3 around 19-21 April was associated with temporarily bar-closed conditions.

The Upper Estuary

Water quality profiles made in the upper estuary show that on nearly every date from December 2004 through early June 2005 the water column remained fresh. Salty bottom water was found at Station 4 on one date, 2 February. All profiles at Station 5 were unstratified and fresh. At Station 6 the near-bottom layer on 1 June 2005 had 1.5 ppt salinity; on all other dates during bar-open conditions, the water was fresh at all depths.

Temperature records often show an abrupt decrease with the onset of flushing flows and re-opening of the bat to tidal exchange. (See 8 December below.) During bar-open conditions temperatures often allow a diel fluctuation pattern of a few degrees

Celsius. This is typical of an unstratified water column free to exchange heat to the air.

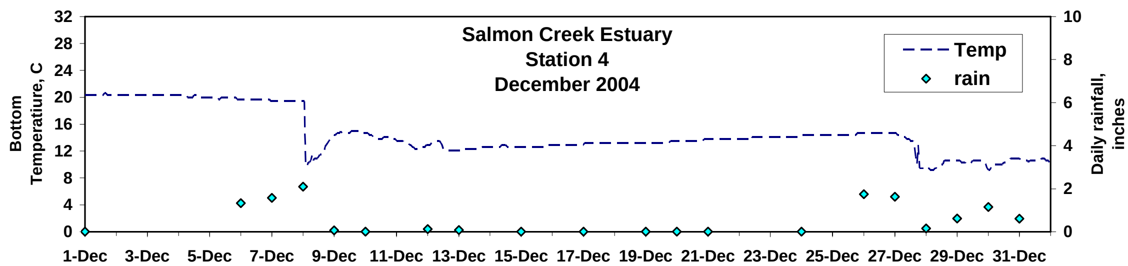


Figure 3.3.6 *Temperature response to rainfall events.*

The Response of Salmon Creek Estuary to Tidal Action and Rainfall, February 2005 though September 2005

Observations made on monthly monitoring cruises in Salmon Creek Estuary during bar-open conditions led to the conclusion that the tidal amplitude inside the estuary is much smaller than the tidal range in the nearby ocean. We have noted that following heavy rains the creek flow cuts deeper into the beach, which results in greater tidal amplitudes inside the estuary. Outflow from the creek when it returns to baseline winter flows after the immediate runoff from storms is too small to keep the beach opening deep, and the tidal amplitude inside the estuary is reduced as the beach cut gets shallower. For example, over 3 inches of rain fell on 26 – 27 December 2004, and direct observations showed that the beach berm was cut to a depth of 8 feet or more immediately thereafter, but the channel was 6 feet shallower by 4 January 2005.

A continuously-recording water level gage was installed at Station 2 in the estuary, and it became operative on 2 February 2005, logging every 30 minutes. With the availability of continuous estuary level data, the roles of tides and rainfall in estuary dynamics can be elucidated in greater detail. The following discussion is based on estuary stage, rainfall and tide data from 3 February through 22 September 2005, and illustrates how the estuary responds to the spring-neap tide cycle during baseline winter flows, and how this is modified by runoff from rainstorms.

Tides at Bodega Harbor Entrance are shown, with the estuary height data superimposed, in Figures WQ-26 (February through May 2005) and WQ-27 (June through September). The stage data have not been surveyed to precisely establish their vertical datum, but are here plotted to the same datum as the tide data (feet above MLLW). That the high tide peaks in the two plots often coincide suggests that the stage gage datum is roughly equivalent to MLLW. Rainfall data are plotted on a separate scale.

The general pattern is that during winter baseflows and spring tides (7-9 February 2005, Figure 3.3.7.) the estuary levels track the higher high tides but do not drop to the level of the lower high tides. During neap tides and moderate runoff (12-17 February), the estuary is not tidal at all because it is higher than the highest neap tides. Larger runoff pulses such as 18 February and 28 February briefly raise the estuary level above the highest tides. Runoff events that flush the estuary (19-25 February) erode the beach channel deep enough to reflect peaks associated with both the higher and lower high tide each day, and the amplitude of the tides in the estuary can then be as high as 2 feet. (During this study period there was never an event that eroded the channel deep enough to reflect ocean *low* tides.) More major runoff episodes eroded the berm deep enough to reflect both daily high tides, but increased outflow prevented estuary water level from reaching tide heights outside the estuary.

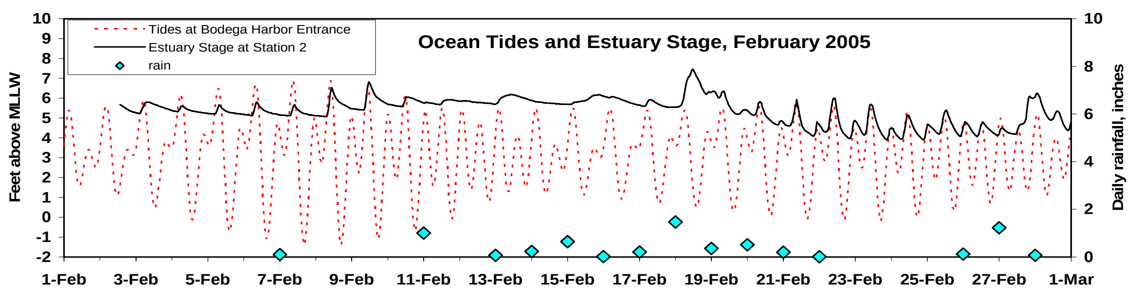


Figure 3.3.7 *Ocean tides, estuary stage, and rainfall*

The beach berm evidently partially closed on 17 April 2005 and appears to have completely closed on 24 April. Water level in the estuary rapidly increased to ~ 9 ft above MLLW before the berm breached itself on 1 May. The breaching was not associated with a rainstorm. The berm appears to have closed briefly again around 4 June but became tidal again following rainfall on 8 June. The estuary was closed again around 8 July and remained so until 20 July 2005. It opened for a few days during spring tides on 20 – 24 July 2005, and then evidently closed for the remainder of the period of record.

September 2005 Water Quality Profiles, With a Comparison Between Estuary Conditions in 2004 and 2005

An additional set of water quality profiles was made on 22 September 2005, to determine whether estuary conditions in summer 2005 were as severe as those observed in 2004. They suggest that conditions in the estuary were more benign in 2005. In the upper estuary there was no saline layer at all at Stations 5 or 6, and at Station 4 the maximum salinity was only 3 ppt near the bottom. Unlike the situation in 2004, the upper estuary habitat in September 2005 was not stratified and the whole water column was suitable for fish.

In contrast to the upper estuary, profiles made in the middle estuary were quite similar to those observed in September and October 2004. Once again there was a stratified system with an inverted temperature curve and a salty anoxic layer near the bottom.

The lower estuary profile on 22 September 2005 was similar to the 1 November 2004 profile. There was an increase in salinity near the bottom, which in 2004 was attributed to warm salty water pushed downstream by rains in October. The September 2005 profile had adequate dissolved oxygen near the bottom (as was the case in November 2004), so it is unlikely that the salinity stratification had been in place for very long. Rain may have played a similar role in the lower estuary in 2005 (0.3 inches fell on 14 – 16 September).

The September 2005 profiles clearly show that the habitat quality was improved in 2005 over 2004, and this was reflected in better survivorship of juvenile steelhead in 2005 than in 2004 (see Fisheries Chapter 3.4).

Discussion

It is apparent that the major difference in the estuary between the two years is the difference in rainfall and resulting flow levels in the creek. Water levels observed in the estuary in the two years are compared in Figure 3.3.8. The bar closed in late May in 2004, and summer creek flows were so low that salinity had already reached the upper estuary stations before the bar closed. The estuary level began dropping as soon as the bar was closed. It continued to drop until rains fell in October. In 2005, in contrast, the bar did not close until late July, and flows were adequate at the time of bar closure to prevent the encroachment of salinity into the upper estuary stations. Estuary levels in 2005 continued to rise for a month after bar closure. September water levels were about 2 feet higher in 2005 than in 2004, which means that a much greater area of suitable habitat was available for fish in 2005.

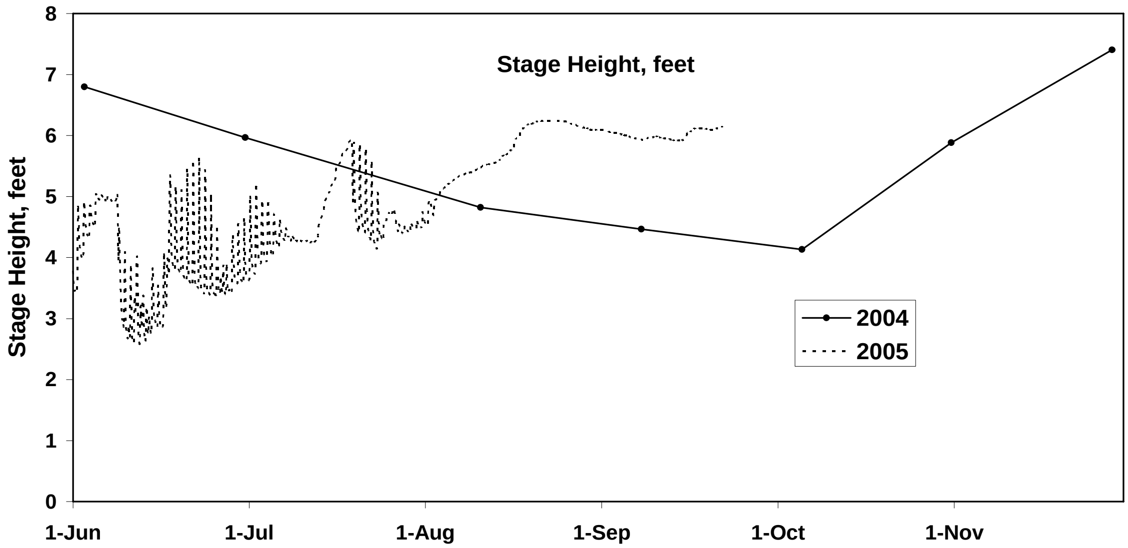


Figure 3.3.8 *Comparison of summer stage heights between 2004 and 2005.*

It is instructive to examine the seasonal rainfall patterns. Long-term rainfall records are available for Occidental, which is located near the headwater area of Salmon Creek. Figure 3.3.9 is a comparison of monthly Occidental rainfall totals in the October-through-June period. Data for 2003-2004 are compared with those for 2004-2005, and to the monthly averages for the previous ten years. It is apparent that the biggest difference between the 2003-2004 year and the following one is not just the total rainfall (50.2 inches *vs*. 56.8—both below average) or winter rainfall (December 2003 and February 2004 had *above* average rainfall), but the amount of rainfall in spring that is different: March and April 2004 had about half of the average rainfall for that period, and no rain at all fell in May or June 2004. In contrast, the spring rains in 2005 were above average in March, and especially so in May and June. Coastal watersheds such as in Sonoma County lack a snowpack storage reservoir, so that rains that fall early in winter do not contribute much to the creek flows in the following summer. A similar conclusion was reached by Fawcett et al (1993) who found that summer juvenile steelhead survivorship in Sonoma County creeks was related to rainfall the previous spring, but not rainfall the previous winter.

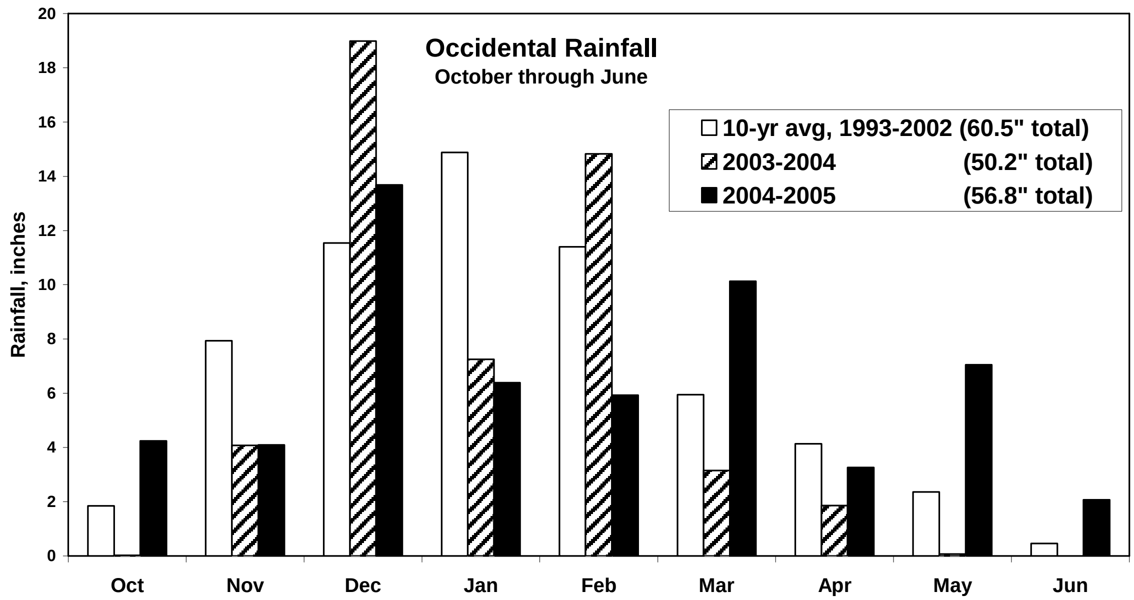


Figure 3.3.9 *October through June monthly rainfall summary, 2003-2004 and 2004-2005 seasons compared with the average rainfall for the 10 previous years.*

3.4 *Fisheries (prepared by Michael H. Fawcett)*

Introduction

The biological monitoring portion of the Salmon Creek Estuary Study was begun in May 2004, with the objective of characterizing existing biotic conditions in the estuary by a program of monthly sampling of biota over a one-year period. During the same period, studies of physical conditions in the estuary, including water quality, hydrologic, and geomorphic processes were also conducted. The monthly biotic sampling was conducted from early June 2004 through early June 2005 in conjunction with monthly water quality monitoring (Chapter 3.3), and with some aspects of the hydrologic study (Chapter 3.2). Since the stage recording (i.e., water level) portion of the hydrologic study continued through summer and fall of 2005, an additional round of biotic and water quality sampling was conducted in September 2005, to provide a basis for comparison between the two years.

A secondary objective of the estuary study was to monitor aquatic biota in the vicinity of an off-channel well located just upstream of the estuary during the observed annual draw-down of surface water at the site, as part of a study to evaluate potential impacts of this and other water diversions (off-channel wells and direct diversions) in the watershed. Seasonal flow conditions at this location just upstream of the upper end of the estuary could be expected to have some influence on dry-season conditions within the estuary. Aquatic habitat within a 447 m. (1,467 ft) reach of Salmon Creek adjacent to the well site (Figure 3.4.1) was characterized, and fish and other aquatic animals were sampled throughout the reach at the beginning of July 2004, and again in August 2004, after surface flow had ceased and most of the water in pools had disappeared.

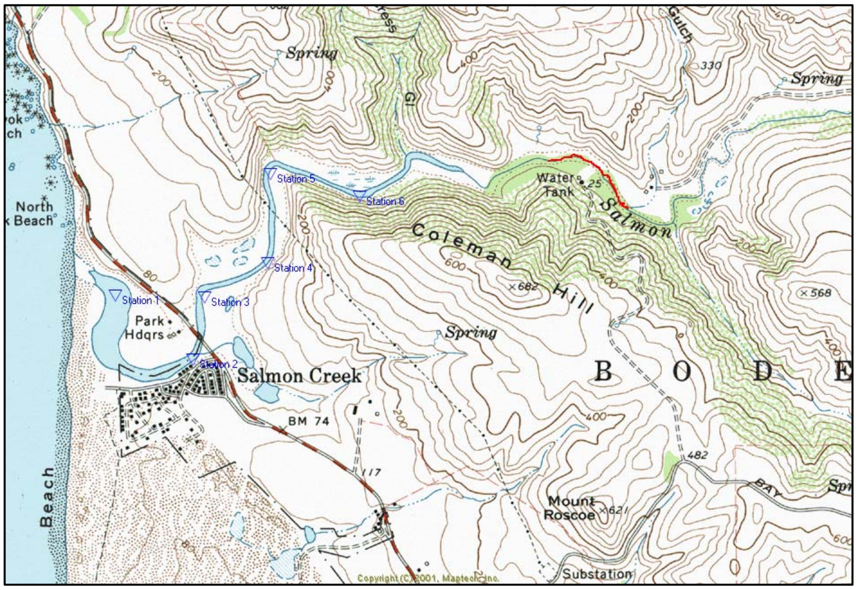


Figure 3.4.1 *Study area with sampling stations indicated by blue triangles. Red track indicates the freshwater study reach near the off-channel well.*

It was expected that the estuary study, in combination with the study of the rest of the Salmon Creek watershed, would lead to identification of processes or habitat conditions in the watershed that may have contributed to historic declines in populations of coho salmon, *Oncorhynchus kisutch* (now extirpated in the watershed) and steelhead (i.e., sea-run rainbow trout), *Oncorhynchus mykiss* (still spawning and rearing in the watershed, but in greatly reduced numbers from those reported in historical times). Coho (Central California Coast ESU) are listed as an endangered species under the federal Endangered Species Act (ESA) and California Endangered Species Act (CESA), and Steelhead (Central California Coast ESU) as a threatened species under the ESA. Salmon Creek, its tributaries, and the estuary are included in critical habitat for both coho and steelhead (NMFS 1999, 2005).

There are two additional listed aquatic species that currently occupy the estuary: the tidewater goby (*Eucyclogobius newberryi*), and the California freshwater shrimp (*Syncaris pacifica*) are both listed as endangered species under the ESA. The California freshwater shrimp is also an endangered species under CESA. The tidewater goby has been reported throughout the estuary (including this study), and the freshwater shrimp is routinely found near the well site just upstream of the estuary, and occurs seasonally in shallow, freshwater areas within the upper zone of the estuary (Fawcett, *unpublished data*). Biotic sampling conducted for this study was authorized by federal and state *Scientific Collector's* Permits issued to Michael Fawcett (NOAA Recovery Permit No. 1045; USFWS Recovery Permit No. TE027296-

3; DFG Scientific Collector's Permit No. SC-000806) and Jim Roth (DFG Scientific Collector's Permit No. 801036-01).

Methods

Estuary Monitoring

The U.S. Fish and Wildlife Service does not allow active sampling (use of nets or other devices) within habitat known to be occupied by tidewater goby during the months of May and June, so only visual observations were made (by snorkeling) during those months (i.e., if visibility was not obscured by turbidity). Beginning in July 2004, we attempted to use a variety of small beach seines (4-mm delta mesh, 1.2 m deep, 1.2 to 15 m long) and a small otter trawl (2.4 m wide at the mouth, 2 mm mesh) to sample fish and epibenthic (i.e., residing on or above the bottom) invertebrates in the estuary. The smallest seines (1.2 m length) are operated by a single person, who pulls the seine along the bottom by means of a wooden rod attached to each end, then guides the seine onto the shore or lifts it out of the water. Longer seines (5 to 15 m length, with a bag in the center) are pulled by two people along some pre-determined route, and then are pulled up onto a beach (or to the edge of the beach, such that the bag containing the catch remains in the water). We also used a larger seine (9.5-mm mesh, 2.4 m deep, 30 m long), which is deployed in an arc by boat while one person holds onto one end of the net, then both people pull the seine up onto the beach, leaving the bag (which contains most of the trapped fish) in the water; fish are then transferred from the bag to a live car or tub of aerated water for processing. Beach seines can effectively capture a variety of fish, including juvenile and adult salmonids, but are generally limited to use in wadeable depths (i.e., waist- to chest-deep water), and are difficult or impossible to use in situations where the bottom sediments are very soft, making wading difficult.

The otter trawl used in this study is towed at low speed (2-3 mph) behind a boat. Weighted wooden doors attached to a bridle hold the mouth of the net open while it is being towed along the bottom. The trawl can be used in a variety of depths, and is effective at capturing relatively slow-moving fish and macro-invertebrates (crabs, shrimp, etc.) on or near the bottom, but is not effective at capturing fast swimmers such as juvenile or adult salmonids, which simply move out of the way of the net. At the end of a short period (1-2 minutes) of towing, the net is hauled aboard, and animals are quickly transferred from the cod end of the net to an aerated tub of water.

Both trawl sampling and seine sampling disturb benthic habitat each time sampling is conducted. In an estuary as small and narrow as that of Salmon Creek, it is not feasible to conduct a statistically rigorous sampling program effectively covering a variety of species and habitats (with well-replicated sampling among stations and habitats, etc.), without damaging the habitat, harming protected species such as tidewater goby, and/or violating model assumptions such as independence of the samples. Therefore, we did not attempt to design such a program, and the available funding would not support one. Instead, our program was focused on using a variety of techniques to elucidate what species are present in the estuary in different seasons and locations within the estuary, and what is their relative abundance from one season or location to another, and to the physical parameters (water quality, hydrology, channel morphology) simultaneously being studied, all of this subject to the limitations imposed by conducting the study within a single one-year period. Rainfall amount and timing, air temperatures, ocean conditions, and other factors vary hugely from one year to another, and can have enormous impacts on aquatic life—several years of study encompassing a wide range of seasonal variation is usually necessary before one can make reasonable inferences about typical or average conditions affecting fish populations in a particular watershed.

An additional restriction is that, under the rules applicable to our federal recovery permit for tidewater goby, cumulative incidental mortality of five or more gobies caused by our sampling would lead to immediate suspension of further sampling, followed by a lengthy formal review, and possible revocation of, the permit. Because tidewater gobies were very abundant throughout the estuary during the study period (see Results section), were unavoidably captured during efforts to capture other species (e.g., steelhead), and are small and easily harmed by trampling, tumbling within a net, etc., we had to limit the number of attempts at seining or trawling, thereby limiting our ability to effectively characterize steelhead and other species' use of the estuary, in order to avoid harming excessive numbers of gobies.

Stream Monitoring Near the Off-Channel Well

Stream habitat near the well site was characterized in June 2004 by wading through the entire study reach, with one biologist (J. Michaud) sketching diagrams of habitat units (discrete pools, riffles, or glides, and locations of trees and their rootwads, large boulders, and other habitat features, and recording notes, while the other team members measured the lengths, widths, and depths of the units, and described the stream bed, presence of woody debris, riparian canopy, and other habitat features. All the units from a point approximately 217 meters downstream from the well site (i.e., measured along the stream channel from a point adjacent to the well site) to 230 meters upstream of the well site were thus characterized. The reach selected for study was based on previous observations made during the period from 1996-2003 of typical annual summer dewatering of some of the stream habitat adjacent to, and downstream of the well (*personal observation*). For convenience, the study reach was arbitrarily divided into lower, middle, and upper reaches, with 5-7 units lying within each reach. The units were numbered consecutively, from No. 1 (a long pool at the downstream end of the lower reach) to No. 18 (a riffle at the upstream end of the upper reach).

Some sampling by dipnet was conducted in most of the units on 4 June 2004; seining was not attempted on that date, because it was judged that many of the steelhead fry present were too small (ca. 40 mm or less) to effectively capture and safely handle. We returned on 2 July 2004 and seined every unit, attempting through repeated passes to capture all, or nearly all, of the fish within each unit. Captured fish, newts and their larvae, and other animals were temporarily held in aerated, shaded 5-gallon buckets of stream water at ambient stream temperature before processing and while seining continued. California freshwater shrimp were held in a separate bucket, to avoid predation or damage from other captured animals. All captured vertebrates, freshwater shrimp, and crayfish were identified and enumerated. Identification was to the level of species, except for lamprey larvae (known as *ammocetes*), which are difficult to identify in the field (i.e., difficult to distinguish among the three local species). Juvenile steelhead were anesthetized (or, more accurately, calmed) with dissolved carbon dioxide, then measured (fork length), and allowed to recover before being released back into the unit from which they were taken. Each habitat unit was measured again, and seining was repeated on 12 August 2004, by which time considerable dewatering had already occurred (several units were dry). An additional walk-through of the study reach was conducted on 31 August 2004, by which time most of the units were dry or reduced to shallow, exposed puddles, and few aquatic animals remained alive. An additional habitat survey (visual inspection only) and seining of the study reach was conducted at the end of the summer of 2005 (10 October 2005).

Results

Estuary Monitoring

<u>Aquatic habitat</u>

Our assessment of habitat conditions in the estuary was developed through a combination of bathymetry, water quality, and fish surveys conducted throughout the study period at different water-level stages (from bar-open, low tide to high tide and bar-closed conditions). Bathymetry and water quality in the estuary are described in detail in other sections of this report. The sampling stations identified in Figure 1 were selected (based on a bathymetry survey conducted in May 2004) to include the deepest areas in the estuary, because:

a) these were expected to be the locations where salinity stratification and its effects on water quality would be most evident, and
b) these would be locations to which steelhead and other fishes might be expected to retreat when threatened by avian predators such as pelicans, cormorants, and kingfishers, or when disturbed by human activities.

Steelhead, if not already hiding in the deepest water available, usually retreat to the deepest water immediately after being flushed from other shelter or instream cover, such as undercut ledges, rootwads, large woody debris, aquatic vegetation, or terrestrial vegetation trailing in the water (*personal observation)*. In the Salmon Creek estuary, cover is limited in the summer months to beds of ditch grass (*Ruppia* spp.) or floating algal mats in unshaded areas, and to other cover types associated with the few deep pools: bedrock ledges at Stations 3, 4, 5, and 6, trailing vegetation at Stations 3, 4, and 6, and large woody debris and old pier pilings at Station 2.

The deepest part of the estuary during the study period was at Station 3 (3.5 meters). The deepest part of the Station 1 area was only 2.0 m in June 2004, and 1.5 m by September 2004. However, we found that from July 2004 until early December 2004 (when rainfall runoff caused the sand bar at the mouth to open and the estuary was flushed) salinity stratification and the associated "solar pond effect" (the surface layer of freshwater acting as a lens to heat the underlying saltwater layer—see Water Quality report) resulted in all of the habitat in the estuary, with exception of the Station 1 area, below a depth of 1 meter below the water surface, being either too warm for salmonids (25.0-31.6 °C = 77.0-88.7 °F.), or anoxic (in which case it is unsuitable for all native fish and most invertebrates). Therefore, the only habitat available to steelhead and most other aquatic animals in the summer and fall was within the 1-m thick surface layer of freshwater or within the mixed water column at Station 1. The dense mats of *Ruppia* and floating algae present in most of the estuary contributed to the lack of mixing of water layers, and decaying *Ruppia* contributed to the oxygen depletion in the stagnant saltwater layer.

The streambed in most of the estuary, with exception of the bedrock outcrops mentioned above, consists mainly of small gravel, sand, and silt. Close to the mouth (Station 1), sand is the predominant feature. Some fairly large-diameter gravel and cobble bars occur at meanders or streambed-grade changes just downstream of Station 5, just upstream of Station 4, and between Station 4 and the Highway 1 Bridge (Figure 3.4.1). At Station 1 (the reach from the mouth to the base of the tall dunes), fine particles of silt and clay are flushed out of the area during bar-open conditions, leaving mostly sand behind. Thus, turbidity related to suspended fine sediment seldom occurs at Station 1 when the mouth is closed. Wind-driven turbulence apparently inhibits establishment of dense *Ruppia* beds at Station 1, and also inhibits growth of water clarity-reducing phytoplankton prevalent in the rest of the estuary. The result of these conditions is that the water column at Station 1 is usually clear from top to bottom whenever the mouth is closed, and fish have no place to hide from pelicans, cormorants, or other predators. The maximum depth at Station 1 was only 1.5 m in September 2004, making steelhead and other fish easily visible to pelicans and cormorants, which are frequently seen foraging or resting near Station1.

Aquatic Life

No biological sampling was conducted in the estuary during May and June in 2004 or 2005, because of the ban on disturbing habitat occupied by tidewater goby during those months (the main breeding period). Over the ensuing months we used a variety of sampling techniques to document fish and macro-invertebrate abundance and distribution (Table 3.4.1). These efforts resulted in the collection of ten fish species and a few invertebrates (Table 3.4.2) during the study period.

Table 3.4.1 Schedule of biological sampling in Salmon Creek estuary

Date	Location	Sampling methods	Comments
07/01/04	Sta. 1, 5	4-ft seines & direct observation	Confirmed that many tidewater gobies were present throughout estuary, decided against further sampling on this date
08/11/04	Sta. 1, 3-4	Otter trawl	2 tows at Sta. 1, one tow between Sta. 3 and 4
08/11/04	Sta. 1, 5	50-ft and 4-ft seines	50-ft seine used at Sta. 1, single tow
09/08/04	Sta. 1	100-ft seine	Single tow (400 steelhead captured)
09/10/04	Sta. 5, 6	Snorkel survey	
10/06/04	Sta. 1	100-ft seine	2 tows
11/02/04	Sta. 1-2	Otter trawl	1 tow
11/02/04	Sta. 1	100-ft seine	1 tow
11/02/04	Sta. 1, 4, 5, 6	Snorkel survey	
11/30/04	Sta. 1-2	Otter trawl	2 tows
11/30/04	Sta. 1	100-ft seine	1 tow
01/04/05	Sta.1-2	Otter trawl	1 tow
01/04/05	Sta. 1	100 ft seine	1 tow, aborted—water turbid, clogged with debris from recent stormwater runoff
02/02/05	Sta. 1	100-ft seine	3 tows
03/01/05	Sta. 1	100-ft seine	2 tows
04/07/05	Sta. 1	100-ft seine	3 tows
05/10/05	--------	None	No sampling because of tidewater goby restrictions; too windy and turbid for snorkeling
06/01/05	Sta. 1, 4, 5	Snorkel survey	Goby restriction on physical sampling in effect; water clarity poor
09/22/05	Sta. 1	100-ft seine	1 tow
09/22/05	Sta. 5-6	Snorkel survey	

Table 3.4.2 Aquatic species captured or observed in estuary during study period	
Common name	Scientific name
Fishes	
Tidewater goby	*Eucyclogobius newberryi*
Steelhead	*Oncorhynchus mykiss*
Threespine stickleback	*Gasterosteus aculeatus*
Prickly sculpin	*Cottus asper*
Pacific staghorn sculpin	*Leptocottus armatus*
Cabezon	*Scorpaenichthys marmorata*
Starry flounder	*Platichthys stellatus*
Pacific herring	*Clupea pallasii*
Topsmelt	*Atherinops affinis*
Shiner perch	*Cymatogaster aggregata*
Amphibians	
California red-legged frog	*Rana aurora draytonii*
Bullfrog	*Rana catesbeiana*
Reptiles	
Western pond turtle	*Clemmys (=Emys) marmorata*
Invertebrates	
Bay shrimp	*Crangon franciscorum*
Black-tailed shrimp	*Crangon nigrocauda*
Opossum shrimp	*Neomysis mercedis*
Amphipod	Class Crustacea, Order Amphipoda, Suborder Gammaridea (possibly several species)
Mammals	
River otter	*Lutra canadensis*

Because of the concern about causing excessive harm to tidewater goby, our sampling efforts were somewhat inhibited throughout 2004 and early 2005 by the presence of enormous numbers of tidewater goby every place we looked. We repeatedly tried brief tows of the otter trawl because it allowed sampling of bottom areas too soft or too deep for seining, but trawling often resulted in the capture of many gobies (Table 3.4.3), with the risk of some of them being entrained and crushed in the debris collected, or lost and stranded in the bottom of the boat during the process of removing the catch from the net (they are small fish, usually less than

50 mm long). We finally settled on the use of a 30 m long seine of fairly large mesh (9.5 mm) netting as a method that effectively captured steelhead (while allowing most of the gobies and invertebrates to pass through the net), but that particular seine could be used effectively only near Station 1 (Figure 3.4.1), where it could be pulled up onto the sandy beaches (and where net-clogging masses of filamentous algae and *Ruppia* were usually absent). Thus, the fish sampling effort during the study period was inconsistent and strongly biased toward the lower end of the estuary (Station 1). We attempted to compensate by conducting snorkel surveys elsewhere in the estuary, but this was frequently unsatisfactory because of poor water clarity.

Table 3.4.3 Total catch by otter trawl in Salmon Creek estuary

Species	Date (Sta. 1)	Date (Sta. 3-4)	Date (Sta. 1)	Date (Sta. 1)	Date (Sta. 1)
	8/11/04	8/11/04	11/2/04	11/30/04	1/4/05
Tidewater goby	158	167	265	31	18
Threespine stickleback	242	28	117	76	10
Starry flounder	1				2
Prickly sculpin	1		2		1
Bay shrimp	1				
Black-tailed shrimp	1				

Table 3.4.4 Total catch by seine at Station 1											
Species	**Date**										
	7/1/04*	8/11/04**	9/8/04	10/6/04	11/2/04	11/30/04 ξ	1/5/04Φ	2/2/05	3/1/05	4/7/05	9/22/05
Tidewater goby	12	~300 ψ		24			1		4		
Steelhead	1	2	400	2	1				7		167
Threespine stickleback	30	~100	19	390			9		3	7	14
Pacific staghorn sculpin			3						1		
Prickly sculpin			1	1					2		
Pacific herring			46								
Shiner perch			2							5	
Starry flounder				1	1		3		8	6	2
Pacific herring				1							
Cabezon									1		
Topsmelt				1							
Black-tailed shrimp			2								
Bay shrimp				5							

* 25-ft seine, 2 tows
** 50-ft seine
ψ Gobies and stickleback allowed to swim out of net without further handling
ξ Net clogged with woody debris, no fish caught
Φ Net clogged with *Ruppia* and leaf litter, no fish caught

Table 3.4.5 Total catch by seine at Station 5		
Species	Date	
	7/1/04	8/11/04
Tidewater goby	~100	~190
Threespine stickleback		~350
Prickly sculpin		4
California red-legged frog		3

Ten species of fish were collected during the study period (Table 3.4.2); complete catch results by trawl and seine are provided in Tables 3.4.3-3.4.5, visual observations in Table 3.4.6. Steelhead and threespine stickleback are the only anadromous species captured in the estuary during this study. Cabezon are usually found in rocky, nearshore marine areas, but it is not unusual to find a few juveniles among collections made in estuaries, e.g., Estero Americano (Commins et al 1996) and the Russian River estuary (Roth et al 2000). The remaining species listed in Table 3.4.2 (with exception of tidewater goby) are common residents of estuaries along the Pacific Coast, either for all or part of their lives.

Table 3.4.6 Total numbers observed from boat or by snorkel surveys					
Species	Date	Date	Date	Date	Date
	7/2/04	9/8/04	9/10/04 (Snorkel)	11/2/04 (Snorkel)	6/1/05 (snorkel)
Tidewater goby		~350 (Sta. 1-5)	~250 (Sta.5-6)	~40 (Sta. 1) ~30 (Sta. 5-6)	
Steelhead		~50 (Sta. 1-5)	12 (Sta. 5-6)	1 (Sta. 5-6)	
Threespine stickleback		Hundreds		1 (Sta. 5-6)	Hundreds (Sta. 4, 5-6)
Prickly sculpin			1 (Sta. 5-6)		
California red-legged frog	1 (Sta. 5)				
Western pond turtle	1 (Sta. 2) 1 (Sta. 5)				
River Otter				2 (Sta. 3 – seen from boat)	

Few steelhead were captured in the estuary, except on two occasions: 399 juveniles (smolts) and 1 adult were captured at Station 1 on 8 September 2004 in a single tow of the 30-m seine, and 167 juveniles were caught at the same site on 22 September 2005, again in a single tow. In both cases, a large number of steelhead must have been present in the vicinity, because only a small fraction of the area was sampled in each pull of the seine. Only two steelhead were captured at Station 1 in two pulls of the seine in early October 2004, and none in a single attempt in early November 2004 (Table 3.4.4). On the first occasion, the water was too warm (20 °C at the surface at Station 1 — see Water Quality report) to safely subject the fish to the added stress of measurement, so the fish were quickly counted and released while I visually made rough estimates of how many belonged to each of three rough size groupings: 100-130 mm, 50 fish; 130-180mm, 249 fish; 180-260 mm, 100 fish. I assumed that the three size classes probably represented 1, 2, and 3-year old fish. The adult was approximately 450-500 mm long. All the steelhead were in good condition, i.e., fat and healthy-looking. On the second occasion (22 September 2005), we measured all the steelhead--the length-frequency distribution plotted in Figure 3.4.2 also suggests the presence of three size/year classes, with 2-year olds as the dominant class.

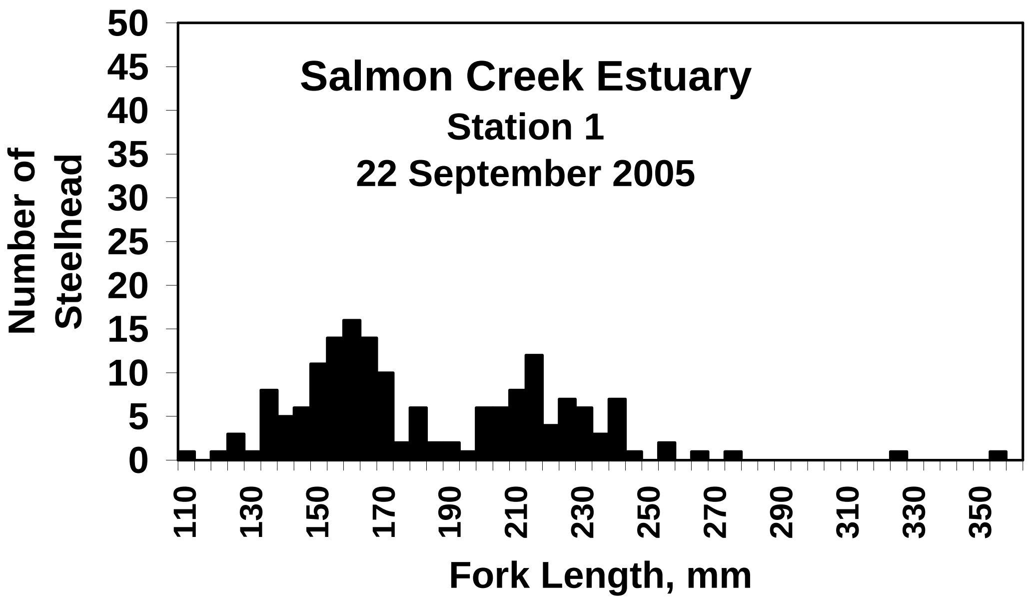


Figure 3.4.2 *Size distribution of steelhead captured by seine at Station 1 in September 2005*

The tidewater goby is currently known to occur in only two localities in Sonoma County (Salmon Creek and Estero Americano), but was historically present in Cheney Gulch as well--the Cheney Gulch population was apparently extirpated (USFWS 2005). Adults of this species rarely live longer than one year, and increases in population density generally occur in spring and summer, although some breeding occurs year-round (Swift, et al 1989; Moyle 2002; USFWS 2005). The tidewater goby can successfully breed at temperatures up to 25 °C (whereas temperatures above 24 °C for more than short intervals are lethal to both coho and steelhead--Moyle 2002). Tidewater gobies undergo "boom and bust" population cycles within occupied localities and do best in shallow coastal lagoons that are "often almost completely choked with aquatic vegetation", including *Ruppia maritima* and *Ruppia cirrhosa* (USFWS 2005), which are the two *Ruppia* species observed to be clogging the Salmon Creek estuary during most of the period of this study. *Ruppia* dies back and largely disappears from Salmon Creek (and other sluggish streams and ponds in the area) with the onset of cold weather in the fall, but the roots do not die, and re-growth begins from the roots in late winter-early spring (*personal observation*).

The Salmon Creek estuary appears to provide good habitat for tidewater goby, as this species has consistently been found there during periodic surveys conducted by Camm Swift and others (cited in Moyle 2002 and USFWS 2005). The Salmon Creek population is recommended as a potential source of tidewater gobies for introduction or re-introduction of the species to Cheney Gulch and Marshall Gulch (a few miles north of Salmon Creek) in the Recovery Plan for tidewater goby (USFWS 2005).

Stream Monitoring Near the Off-Channel Well

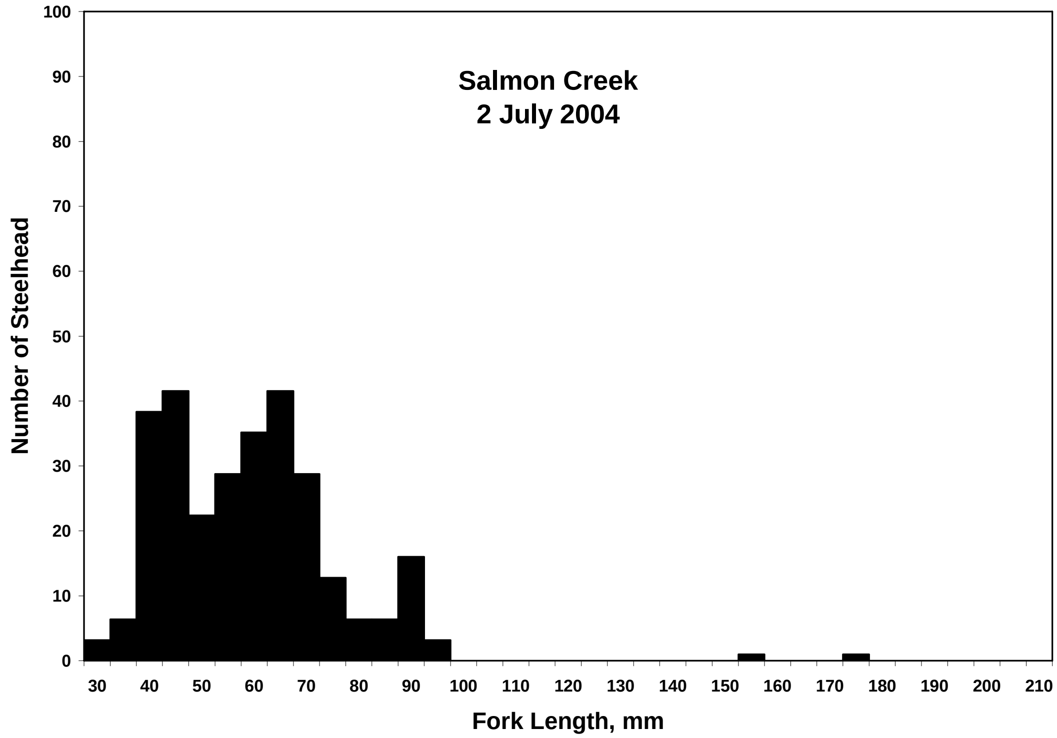
General characteristics of the habitat units surveyed on three dates in summer 2004 in the study reach near the well site are provided in Table 3.4.7. The initial habitat survey was conducted on 4 June 2004, prior to dewatering of the reach. Additional habitat surveys were conducted on 12 August and 31 August, by which time most of the units were dry or reduced to shallow puddles, as shown in two photographs of Unit 10 (Figures 3.4.3 & 3.4.4), which lies directly across the channel from the well site. Detailed analyses of hydrological events accompanying the visible dewatering of the stream during this period are presented in the main report.

Figure 3.4.3 *Unit 10 near well site, 12 August 2004 – considerable dewatering had already occurred since 2 July survey.*

Figure 3.4.4 *Unit 10 near well site, 31 Aug 04 – remaining pool only 4.4 cm. deep, no vertebrates left in the pool.*

Preliminary sampling by seine indicated that most of the steelhead present in the study reach on 4 June 2004 were fry too small (< 40 mm) to effectively capture by seine and safely handle for measurement, so we limited our sampling on that date to brief dipnetting in fewer than half of the units. The resulting catch totals for different species of aquatic animals on that date are included in Table 3.4.8, but should not be taken as quantitatively comparable to the totals presented for 2 July and 12 August 2004—on the latter dates we systematically seined every unit. Steelhead were measured during the 2 July survey; all but two of the 292 steelhead captured appeared to be young of the year (Figure 3.4.5). Considerable dewatering had occurred between the July and August sampling (Table 3.4.7), which meant that the remaining animals were more concentrated within the remaining units, thus more efficiently captured by seining, which partially explains why some species appeared to increase in number during the interval--the other part of the explanation is that increased individual body size (rapid growth rates during summer weather) makes more of the population of each species vulnerable to capture by seining than when the individuals are smaller in size earlier in the year.

All of the species listed in Table 3.4.2 are native to this region, except for bullfrogs (*Rana catesbeiana*), which are native to the eastern United States. Bullfrogs are introduced, invasive pests in the western U.S., implicated as contributing factors in the decline and disappearance of many native frogs and other vertebrates from their native geographic ranges in California (e.g., California red-legged frog, *Rana aurora draytonii*; and foothill yellow-legged frog, *Rana boylii*, both of which are found in the Salmon Creek watershed). Although California red-legged frog is a federally threatened species within most of its range in California, the listing range does not include coastal watersheds north of Walker Creek in Marin County (it is, however, a California species of special concern statewide, as is the foothill yellow-legged frog). Four adult California red-legged frogs were captured during sampling near the well site (Table 3.4.8). As mentioned earlier in this report, both steelhead and California freshwater shrimp are listed under the ESA: Steelhead is a *threatened species*; California freshwater shrimp is an *endangered species.* California freshwater shrimp is also listed as *endangered* under CESA.



Summary Statistics	
total count	293
YoY count	291
YoY m. L.	60.4 (based on 91 individuals measured)
YoY sd	15.1 (“)

Figure 3.4.5 *Size distribution of steelhead captured near the well site on 2 July 2004.*

Table 3.4.7 Stream habitat near well site											
Reach	**Unit No.**	**Length (m.) on Survey date**			**Width (m.) on Survey date**			**Max. Depth (cm.) on Survey date**			**Initial Description**
		6/4/0	8/12/0	8/31/0	6/4/0	8/12/0	8/31/0	6/4/0	8/12/0	8/31/0	
Lower	1	22	22	~18	5.7	5.5	~5.0	90	90	~60	Pool with sand overlying b at base of rock bluff
	2	20	19	1.2	2.6	1.3	1.0	35	24	9.0	Sand-bottom riffle/glide
	3	12	7.8	0 (dry)	3.4	2.3	0	20	8.0	0	Sand-bottom pool
	4	6.1	0	0	2.5	0	0	6.0	0	0	Sandy riffle
	5	8.5	5.8	2.6	4.4	3.1	1.2	51	35	15	Sand-bottom pool
	6	36	19	2.6	13	6.6 *	1.2	48	35	12	Gravel bar at upstream end sandy elsewhere
Middle	7	24	23.5	4.0	3.8	2.5	1.9	55	46	18	Pool/glide with gravel-cob bottom, mostly unshaded
	8	6.3	0	0	1.4	0	0	20	0	0	Riffle, gravel-cobble botton
	9	20	0	0	3.6	0	0	14	0	0	Glide/riffle
	10	62	44	3.0	5.1	2.3	0.9	32	31	4.4	Pool/glide
	11	17.1	10.5	0	6.6	~1.0	0	19	16	0	Pool, gravel-sand-silt botto
Upper	12	22.8	15.5	0	10	2.8	0	40	23	0	Glide/riffle, gravel bottom
	13	71	No dat	~4.0	9.3	9.0	2.5*	50	42	26	Pool/glide with woody del
	14	25	25	3.7	3.6	2.8	0.8	26	16	6.6	Glide
	15	4.7	0	0	3.8	0	0	10	0	0	Riffle
	16	72	70	~4.0	10	6.2	~3.0	68	55	26	Pool/glide with downed w and rootwads
	17	9.0	7.5	~6.0	4.9	4.7	~3.0	48	48	22	Pool, sand bottom
	18	13	13	0	2.0	0.5	0	12	1.0	0	Riffle

*Combined width of 2 smaller pools

Nearly all the animals remaining in the study reach on 12 August presumably died by the time I returned on 31 August, because the units they occupied were already isolated by lack of water between the units on 12 August – there was nowhere for them to go. During the 31 August survey, I found only a handful of sticklebacks still alive in a few of the units. No other fish were seen, and the mud within and around the remaining puddles of water was covered with tracks made by raccoons (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), and large wading birds (herons, egrets, etc.,) indicating that these predators probably ate most of the aquatic animals stranded in the shrinking pools.

Table 3.4.8 Total catch by seine and dipnet near well site

Common name	Scientific name	Date			
Fish		6/4/04*	7/2/04	8/12/04	10/10/05*
Steelhead	*Oncorhynchus mykiss*	24	292	60	34
Threespine stickleback	*Gasterosteus aculeatus*	>300	324	1260	429
Prickly sculpin	*Cottus asper*	4	45	87	21
California roach	*Lavinia symmetricus*	55	56	47	33
Lamprey (ammocetes)	*Lampetra spp.*			5	
Amphibians					
California red-legged frog	*Rana aurora draytonii*	1		3	
California (Coast Range) newt	*Taricha torosa torosa*	4			
Rough-skinned newt	*Taricha granulosa*	1	4	3	
Rough-skinned newt (larvae)	*Taricha granulosa*		1		
Red-bellied newt (larvae)	*Taricha rivularis*	4	51	68	
Bullfrog (larvae)	*Rana catesbeiana*				1
Invertebrates					
California freshwater shrimp	*Syncaris pacifica*	23	12	17	

* Dipnet sampling only
** Only 5 units sampled, all in lower reach

Discussion

Although coho salmon occurred in Salmon Creek in historical times, none were collected during this study, and none have been found in other surveys conducted in the Salmon Creek watershed in many years (Fawcett, unpublished data from occasional surveys from 1996 through 2004; Bill Cox, CDFG, personal communication; P. Adams, NMFS, personal communication). Steelhead still spawn and rear every year in Salmon Creek, although many local people feel that steelhead are no longer as abundant as they used to be. There are good reasons for believing that vast amounts of sediment has accumulated in mainstem Salmon Creek and in the estuary within recent decades, particularly during a couple of severe winters (1982-83 and 1986) when massive slope failures occurred on prominent coastal hillsides, sending vast quantities of material downhill and into nearby streams. In the case of Salmon Creek, it seems that something about the hydraulics near the mouth prevents significant amounts of sediment from completing the journey from headwaters to the sea (i.e., sediment accumulates in the estuary, but not much of it gets swept out to sea during the brief periods when the mouth is open). Depending on the tidal level when the berm at the mouth is breached, a deep and swift outlet channel may be rapidly formed. However, within a day after breaching, the outflow channel has largely filled up with sand again, so that a relatively minor flow of water (and entrained sediment) passes across the beach and out to sea. Questions have arisen about whether or not anthropogenic changes to the Salmon Creek estuary have caused or contributed to the extirpation of coho from the watershed. Information obtained during our brief period of study suggests at least three possible contributing factors:

1. The estuary has become smaller in surface area and volume of water held and shallower on average, than it once was, owing to massive sediment aggradation; much of the aggradation occurred during sporadic major storm events, e.g., the heavy rains, flooding, and landslides that occurred in early 1982 and 1986. Sediment aggradation in the estuary has altered the hydraulic properties of the estuary in ways that have reduced the frequency and magnitude of the tidal excursion, such that access to incoming adult coho on their spawning run is frequently not available (i.e., the bar at the mouth remains closed) until their normal peak entry time (October through December) in the region is passed or nearly so. As an example of this possibility, the mouth of the estuary did not open until the second week of December 8th in 2004, it then closed two days later and did not reopen again until December 27th (Chapters 3.1 and 3.3).
2. Excessive and increasing water diversions in the Salmon Creek watershed have reduced the freshwater input to the estuary, which has negatively affected the suitability of the estuary for salmonid rearing, especially during drought periods such as the area experienced in the nineteen-seventies, and during unusually dry summers, such as occurred in 2004. A dry summer occurs following a shortage of spring rainfall—other studies in the area (Fawcett et al 2003) have shown that the amount of rain that falls after the first of the year is far more important to summer stream conditions than the total amount of rain falling during the water year (July-June). Additionally, when a dry spring-summer occurs, water users tend to start diverting water earlier in the year, and use more water than during an average year, thus

exacerbating the effect of the shortage of spring rainfall. During the period of the present study, rainfall for the 2003-2004 water year was about average for the area, but very little rain fell in the spring of 2004 (Chapter 3.1, DWR and NOAA records). As a result, the berm at the mouth of the estuary closed in late May 2004 and remained closed until 8 December 2004; large areas of the estuary became isolated from the rest (e.g., surface water disappeared between Station 5 and Station 4), and the maximum depths of pools measured in September 2004 was substantially smaller than in the same pools measured in September 2005 (Chapter 3.3)—Spring and summer 2005 was unusually wet (Chapter 3.1), with significant rainfall events occurring throughout April, May, and June; no parts of the study area became dewatered in 2005 (*personal observation*), and the estuary mouth was breached several times during the dry season.

3. The estuary in its present condition lacks sufficient instream shelter to protect salmonid juveniles, smolts, or adults from predators. This shortage of cover became especially apparent in late summer-fall of 2004, when the only part of the estuary that had water quality conditions suitable to keep salmonids alive was at Station 1, where a large school of steelhead present in September in clear water only 1.0-1.5 m deep, was apparently decimated by predators (brown pelican, *Pelicanus occidentalis*, an endangered species) and double-crested cormorant, *Phalacrocorax auritis,* during the interval between the September survey (400 steelhead captured) and the 2 November survey, when only 1 steelhead was captured at Station 1 (Table 3.4.4) Flocks of both of these birds were observed foraging and consuming fish at Station 1 during the September 2004 survey and on other occasions. Throughout the late summer and fall of 2004, steelhead at Station 1 had nowhere to escape—they could not go out to sea because the estuary mouth was closed, and they could not go back upstream because of intolerable water quality conditions upstream of Station 1.

The three factors cited above lead to some obvious management or enhancement plans that could be undertaken, namely: reducing sediment input in the watershed through erosion control measures; reducing water diversions from the watershed during the summer months; and installing some log/rootwad structures in the estuary to improve available cover for fish. However, any attempts at active physical modification of the estuary (e.g., installing logs or channel modification) in the estuary will run into the problem of improving conditions for one group of listed species (steelhead and salmon) at the expense of another (tidewater goby). The estuary appears to be ideally suited for tidewater goby in its present condition, so enhancements made to benefit salmonids would be likely to negatively impact goby habitat. A compromise will require consultation with, and cooperation among several agencies: USFWS, NMFS, U.S. Army Corps of Engineers, and DFG.

CHAPTER 4: SUMMARY AND DISCUSSION

Estuaries and lagoons play a critical role in the life cycle of coho salmon and steelhead trout in the small coastal streams of Northern California. Good water quality, sufficient water quantity, habitat complexity, and ample food availability are the vital components necessary for salmonids to not only survive, but also to thrive. Water quality requirements include water temperatures in optimum ranges, adequate dissolved oxygen levels, and water clarity (turbidity) that does not inhibit feeding, territorial behavior, or physiologic functioning. Juvenile salmonid residence in the estuary or lagoon provides the necessary conditions for them to adjust physiologically from freshwater to saltwater. Estuaries also provide rich foraging opportunities that promote additional growth before heading out to the ocean. Food availability is dependent upon habitat complexity, water quality, and macro-invertebrate populations. Multiple studies on steelhead and other salmonids indicate that rapid growth and greater size upon ocean entry, resulting from estuary rearing, directly relates to higher rates of marine survival and return (Miller and Sadro, 2003).

The estuary and lagoon habitat is particularly important in systems that display absent or degraded summer upstream habitat. During drought years or in areas of poor summer rearing habitat juveniles will emigrate downstream seeking available habitat (Bjornn 1971). Under these conditions significant percentages of a watershed's juvenile population can end up rearing in the coastal lagoons and estuaries (Zedonis 1992, Shapavalov and Taft 1954). If the estuarine lagoon habitat is unavailable, or of poor quality, the annual production of steelhead (and coho) juveniles and smolts may perish. Important habitat features in estuaries for steelhead and coho include side channels, substrate complexity, and adequate woody debris for cover (DFG, 2004).

Elevated sediment delivery to coastal and estuarine habitats often adversely affects the biologic structure and functioning of the ecosystem, and reduces its ecologic, recreation, and aesthetic value (Thrush et al, 2004). In undisturbed coastal systems a dynamic balance occurs between the volume of terrestrial import of sediment to the estuary and export out. Increased rates and volumes of sediment delivered to the estuary from disturbances in the upper watershed (land use changes/practices, catastrophic fires, and extreme flood events) throws the dynamic out of balance and sedimentation of the estuary occurs. High sediment loading smothers macroinvertebrate and benthic faunal communities (Thrush et al, 2004)—an important food source for rearing juveniles. Excessive flood-borne sediments can fill tidal channels and aggrade tidal wetlands; permanently altering ecosystem structure and reducing critical habitat.

Dramatic reductions in the size and depth of the Salmon Creek estuary have occurred since European settlement of the area in the mid 1800s. Areas of open channel have filled in, side channels have disappeared, the channel has aggraded and coarsened, and tidal wetlands have transitioned to upland communities. Photos from the 1920s and 1940s show a wider, deeper estuary with extensive tidal wetlands and slough channels. Successive aerial photographs document the aforementioned physical changes over the next 60 years, many of which occurred by the late 1960s. Several large storm events in the 50s and 60s, combined with widespread channel clearing practices in the upper watershed, likely delivered large volumes of sediment to the estuary—filling in side channels and aggrading wetlands. New Highway 1 Bridges encroached on the tidal wetlands, altering the hydrodynamics of the system. The January 1982 storm mobilized sediment throughout the watershed, delivering coarse material to the mainstem from upper tributary storage. During the '82 storm further aggradation of the floodplains occurred, raising their elevations well above the tidal and lagoon water surfaces. In the subsequent 25 years pools have filled in and the overall bed elevation has aggraded up to 6 feet in some areas with excess sediment moving through the system.

The dynamic equilibrium of the Salmon Creek estuary is out of balance. More sediment is entering than can be transported out. This disequilibrium is likely to continue indefinitely, as large volumes of sediment are mobilized annually, and temporarily stored in the channels throughout the watershed. The incised, morphologically simplified channels of the upper watershed do not provide long-term storage for sediment, thus all the material is being transported to the estuary. This shift in the sediment regime, in conjunction with water quality and quantity issues, has significantly altered the hydrodynamics of the ecosystem and its habitat value.

Water quality and biotic data on the Salmon Creek estuary was collected from June 2004 through December 2005. Monthly profiles of temperature, salinity, and dissolved oxygen at six sampling stations between the estuary mouth and the upstream limit of tidal action near the Chanslor Ranch indicate that, during closed-bar conditions, the lower lagoon near the beach was well-mixed all summer and stations in the middle and upper zones were strongly stratified with near-bottom saline layers that remained anoxic and too hot for salmonid survival. Thus, fish habitat was limited to the shallow surface layer of freshwater in middle and upper zones, and to the well-mixed area near the mouth (which was also shallow and lacking in woody debris for cover).

Good quality rearing habitat in coastal estuaries is achieved in either bar-open conditions with full tidal mixing or if full conversion to a freshwater lagoon occurs after bar closure (Smith, 1990). Incomplete freshwater conversions, such as occurred in Salmon Creek in 2004 and 2005 and in other estuaries along the Northern California Coast (Smith, 1990; Cannata, 1998) produce stratified conditions, which result in limited, restricted habitat and reduced growth and survival. During the drought year of 2004, low flows in Salmon Creek permitted the encroachment of seawater into the upper estuary and were not sufficient to keep lagoon levels high enough for pool connectivity and vital habitat. The areas of adequate water quality were devoid of cover and shade. It is estimated that in 2004 very low, if no, steelhead smolts were produced by the estuary. High spring rainfall in 2005 led to better water quality and higher water levels in the lagoon. Stratification was still present, but limited to a smaller area and depth; resulting in a more benign habitat for fish in summer 2005. Correspondingly, smolt production was significantly greater.

Spring—but not winter—rainfall appears to be a major determinant of estuary habitat quality in the following summer. Late spring rainfall maintains the shallow aquifers and contributes to sustained, higher summer streamflows. Thus, summer streamflow directly correlates to lagoon habitat and juvenile production and survival. Domestic and agricultural water use in the watershed reduces the amount of streamflow available for upstream and estuarine habitat. Direct withdrawals and near-channel wells reduce the fresh water entering the estuary. The consequences of these system-wide withdrawals are more significant in low-water years.

Effects of reductions in streamflow upstream of a lagoon include slower velocities through riffles, diminished dissolved oxygen in pools immediately upstream of the lagoon, and lower water levels in the lagoon (Smith 1994). In nearby Redwood Creek lagoon, Smith (1994) reports that the lowered lagoon depths, shallowing of riffles and runs, and low pool dissolved oxygen resulting from the elimination of surface flow, as a result of daily withdrawals from near-channel wells, significantly reduced steelhead and coho numbers and growth in 1992 and 1993. Groundwater pumping from near-channel, public water supply wells in Salmon Creek during the summer of 2004 and 2005 lowered the water table elevation in the creek. In 2005 (wet year) the water levels recovered quickly and normalized to a stable base level. In 2004 (dry year) there was a slow recovery time after pumping periods and the water level decreased daily. It is unclear whether the steady decline in groundwater levels was due to the localized well pumping or to natural reductions in the groundwater volumes during the drought year; it is likely a combination of factors. During 2004 the stream channel in the vicinity of the wells went completely dry, while in other areas of the watershed flow was unusually low and in some areas pools were disconnected and shallow.

Adult salmonids use estuaries as a resting and feeding place before beginning their upstream spawning migration. Once the estuary mouth is open, movement into the river system is typically timed to high stream flows and high tides. It is critical that the barrier bar breaches in time to allow the adults entrance to the estuary and watershed during their spawning periods. Coho salmon migrate and spawn during the late summer and fall, whereas steelhead spawn in the winter (January- March). The Salmon Creek lagoon breaches on average in late November, with a range from early October to mid February.

Late summer lagoon volume governs the quality and extent of rearing habitat for juvenile salmonids, as well as the rainfall necessary to breach the barrier bar in the fall. The quantity of streamflow entering the estuary after bar closure determines whether there is sufficient freshwater to provide quality habitat. Low lagoon water depths, in combination with a lack of structure for cover and protection, lead to high predation losses in the late summer. High rates of sediment delivery to the estuary are contributing to depth and volume reductions. Without significant increases in summer freshwater flows, channel depths, and side channels and large woody debris for cover and predation protection the Salmon Creek estuary/lagoon will continue to be marginal salmonid habitat.

CHAPTER 5: ENHANCEMENT RECOMMENDATIONS

The following recommendations are based on the study results and are intended to improve aquatic habitat conditions in the Salmon Creek estuary. Short-term actions that would implement components of these recommendations are listed in the following chapter.

1. **Enhance habitat diversity in the estuary to provide cooler temperatures, more foraging areas and cover for young steelhead.**

   Historic maps and photographs show that the estuary included a network of small side channels and ponds that would have created excellent rearing conditions for salmonid fish, especially steelhead trout. In addition, the water quality and fisheries reports (Section 5.3 and 5.4) describe that when the mouth is closed, salinity stratification, oxygen depletion in the saline layer and the "solar pond effect" (in which the surface lens of freshwater heats the underlying saltwater layer) combine to restrict fish either to the top 1 meter freshwater or to the 1.5-2.0 m. deep, well-mixed reach directly behind the sandbar at the estuary mouth. In the well-mixed area, the fish are very vulnerable to predation from pelicans, cormorants and other birds because this area lacks ditch or wigeon weed (*Ruppia spp.)* or other cover, and water clarity is usually good. Installation of large woody debris structures, similar to those used in the Mattole River estuary, would provide instant cover. We recommend using an adaptive management process in which a small number (3-5) structures would be installed and then monitored for steelhead use as well as impacts to other species before a larger scale effort is undertaken.

   Longer term solutions would include re-creating side channels and reconnecting existing ponds. Significant additional assessment is needed before pursuing these alternatives. One important question to be answered is their effect on the tidewater goby population which appears to be thriving under current conditions.

2. **Maintain sufficient freshwater flows to provide upstream rearing habitat, keep the sandbar open longer, and moderate salinity, temperature and dissolved oxygen.**

   The amount of freshwater flow is a critical factor in determining when the sandbar will form and how long it will last. Low flows also result in shallower pools and isolation of large areas of the estuary. In fall of 2004, surface water completely disappeared between Stations 4 and 5. Low summer flows also reduce habitat available to steelhead in the upper watershed, and drive them into the estuary where they encounter poor water quality and hungry pelicans.

An action essential for sustaining beneficial flows is to reduce the reliance of local domestic water providers on summer withdrawals from Salmon Creek through increasing storage capacity, developing offstream water sources, and encouraging conservation. Salmon Creek Watershed Council, other local organizations and residents, and agencies can affect this change through helping the suppliers secure grants and educate their customers, and by developing and rigorously promoting a water conservation program.

Domestic water providers are not the only users of summer flow. Agricultural and private domestic users also divert stream water throughout the watershed. Attempts were made in this study to assess diversions, but little official data is available on how much water is being taken and where the withdrawals occur. Completion of a water budget would allow predictions on how varying water years would impact stream conditions, and provide an important tool for managing the timing and amount of water withdrawn from the Salmon Creek system by all users. It would also provide information on water availability that is essential for sound planning and growth decisions.

We strongly recommend that USGS install a stream gage at the upstream end of the estuary and that additional flow meters be installed at 2-3 stations in the upper watershed. Without ongoing monitoring, it is very difficult to assess when additional water is being withdrawn and when conservation measures are making a difference.

Other actions include encouraging the use of practices to increase infiltration and reduce stormwater runoff, particularly in new residential and agricultural development, and supporting projects that demonstrate rainwater catchment and other alternatives to ground or surface water withdrawals.

3. **Reduce the amount of sediment entering estuary.**
The estuary has become smaller because of sediment deposited from major storm events, such as the one in January 1982, and land use changes in the watershed over the past 150 years. Sediment volumes and sizes delivered from the watershed on an annual basis have increased dramatically from pre-European levels, altering the hydrodynamics of the estuary. As the volume of water held by the estuary decreases, the force of the outgoing water is reduced and the sandbar at the mouth forms earlier and remains in place longer. The length of the estuary closure is a significant factor in the loss of the Salmon Creek's coho salmon run. With the bar frequently remaining closed well into December, coho who usually enter streams from October through December, have little chance of

getting into Salmon Creek. The increased sediment also affects habitat for steelhead and other aquatic wildlife by filling in pools and gravels, and increasing turbidity.

Implementation of Best Management Practices (BMPs) for vineyards and livestock operations, repair of accelerated channel and upstream erosion, and sound management of unsurfaced roads and driveways will help reduce sediment entering the estuary. A thorough geomorphic assessment is needed to determine which erosion sites are having the most impact on instream and estuarine conditions, and how best to address them to achieve lasting, cost-effective repairs.

The recent exponential rise in numbers of dead tanoaks and other trees, victims of Sudden Oak Death (SOD), has created dangerous fire conditions in many parts of the watershed. Management to reduce this risk could help avert significant erosion.

4. **Maintain high quality of incoming freshwater.**
Turbidity and high temperature are the greatest water quality issues in Salmon Creek. Turbidity, or fine sediment suspended in the water, is addressed above under sediment reduction. Temperature in the estuary is largely controlled by the amount of entering freshwater, but high water temperatures upstream can also affect estuary temperature. Most of Salmon Creek is well vegetated, but efforts should continue to protect and replant grazed riparian areas. Riparian pastures with carefully managed seasonal grazing have been effective where complete, year-round livestock exclusion is not feasible.

5. **Continue monitoring programs.**
This study allowed for one year of monthly biological and water quality sampling plus continuous datasonde monitoring, and an additional one-day survey in fall 2005. That duration is barely enough to establish workable protocols, and certainly insufficient to detect trends in salmonid use of the estuary and how they adapt to changing conditions. At a minimum, an additional five years of biological and water quality monitoring in the estuary is needed. Securing assistance from area colleges and universities could help sustain the monitoring and incorporate it into more comprehensive studies.

6. **Enhance upstream salmonid rearing habitat**
Although this recommendation does not directly impact estuarine habitat, providing better rearing habitat upstream could allow some steelhead to stay in the upper watershed longer before migrating into the estuary. A healthy estuary can provide excellent rearing conditions; however current conditions in the Salmon Creek estuary as described above can imperil fish. Maintaining

beneficial flows, as described in Recommendation 2 will help sustain pools and high water quality. Instream structures, such as carefully placed large woody debris, can trap sediment, create or enhance pools and provide shade and cover.

7. **Implement compelling education and outreach programs.**
With nearly the entire Salmon Creek watershed in private ownership, education is a primary means of implementing changes in how people manage their property and their water use. Opportunities for synergy and cooperation among the many active groups in the watershed abound. The Salmon Creek Watershed Council, the Occidental Arts and Ecology Center and the Bodega Land Trust are well suited for developing and delivering community-based education programs. Gold Ridge RCD and UC Cooperative Extension have already successfully offered workshops and demonstration programs and have ready access to many of the larger landowners in the watershed. Salmon Creek School is in the process of building an environmental education center that will serve the entire community, not just area students.

Community education is particularly needed in the following areas:
- water conservation
- BMPs for sediment control on ranches, horse facilities, vineyards and rural homes
- reduction of stormwater runoff from roofs and other hard surfaces
- stream dynamics—how stream channels adapt over time and how landowners can anticipate changes in the shape and location of their creeks
- habitat needs for steelhead and coho salmon
- Sudden Oak Death and land management to reduce fire danger
- a primer on the Salmon Creek watershed for new residents

Community members also have plenty to teach researchers and land managers. Oral history was a part of this project and of Gold Ridge RCD's planning work in the upper watershed. As little previous scientific study or monitoring has been conducted on Salmon Creek and the estuary, memories and inherited stories provide critical information to understanding how the Salmon Creek system has reacted to weather conditions and changes in land use. Although extensive and invaluable information was collected in the two efforts, there is much more to gather and to collate into usable documents.

8. **Integrate watershed planning and restoration efforts.**
This effort, the Gold Ridge RCD/Salmon Creek Watershed Council assessment and planning work in the upper watershed, UC Cooperative extension research into how pathogens are transported and stored by sediment and the estuary, and

other studies and planning efforts should be integrated into an overall strategy for managing the Salmon Creek watershed and guiding salmonid restoration.

A watershed GIS (Geographical Information System) was initiated as part of this project. A GIS allows land managers to correlate layers of information, such as an erosion inventory with instream habitat conditions, to better understand and predict how changes in the watershed will impact habitat. Continuing to update it with new information will provide an excellent tool for ongoing assessment and management.

CHAPTER 6: ACTION PLAN

Short Term Action Plan.

The following actions can be completed or well-underway within the next one to three years. Since most will require funding, an action common to each category is the ongoing submittal of grant proposals to agencies and foundations.

ACTION	INITIATING ORGANIZATIONS AND/OR AGENCIES	STATUS AND COMMENTS
Enhance Estuary Habitat		
Install large woody debris structures in the lower estuary to enhance cover for out-migrating steelhead.	Salmon Creek Watershed Council, State Parks	Agency coordination and initial planning underway.
Continue biological monitoring in the estuary for at least five more years to gather better information on how salmonids are using estuary. Include effectiveness monitoring of enhancement projects.	Salmon Creek Watershed Council, area colleges and universities, State Parks	
Organize volunteer events to remove and manage exotic invasive plants on State Park estuary property.	State Parks, Salmon Creek Watershed Council, Bodega Land Trust	
Maintain Beneficial Streamflow		
Support local domestic water providers in securing off-stream water storage and/or new water sources to reduce summer withdrawals from Salmon Creek.	Local water providers, Salmon Creek Watershed Council	Request assistance from the Regional Water Quality Control Board and NOAA to find and secure funding.
Continue to monitor streamflow entering the estuary. Include monitoring stations at several upstream sites.	Salmon Creek Watershed Council, area colleges and universities	

Install USGS stream gage upstream of estuary.	USGS, Salmon Creek Watershed Council with support from all involved agencies	
Support the Bodega Volunteer Fire Department and other community projects in developing effective strategies to increase infiltration and reduce stormwater runoff from new construction or expansion projects.	Salmon Creek Watershed Council, Bodega Land Trust	
Develop a water budget to better manage water diversions in order to maintain sufficient baseflow in Salmon Creek and its estuary to support an anadromous fishery.	Salmon Creek Watershed Council, area colleges and universities	
Manage Sediment		
Repair priority sediment sources as identified in Gold Ridge RCD Erosion Site Inventory.	Gold Ridge RCD	RCD and partners are seeking grant funding.
Complete geomorphic and additional sediment source assessment to better target and appropriately repair those erosion sites that are most impacting salmonid habitat.	Gold Ridge RCD	RCD is submitting a proposal under the SWRCB Consolidated Grant Program.
Continue the road assessment and improvement program. Include long driveways. Assess impact of raised private roads and driveways in floodplain.	Gold Ridge RCD, Salmon Creek Watershed Council	
Encourage the use of Best Management Practices (BMPs) on vineyards and ranches. Demonstrate appropriate BMPs in Salmon Creek and neighboring watersheds.	Gold Ridge RCD, Bodega Land Trust, UC Cooperative Extension, NRCS	Bodega Land Trust is submitting a proposal under the SWRCB Consolidated Grant Program for demonstration of agricultural BMPs.

Maintain High Water Quality		
Continue to fund and coordinate volunteer water quality monitoring.	Gold Ridge RCD, Salmon Creek Watershed Council, Community Clean Water Initiative, Bodega Land Trust	Sonoma County Fish and Wildlife Commission recently granted funding for monitoring equipment and supplies.
Promote the fencing and management of riparian areas in grazing lands to reduce stream temperature and turbidity.	Landowners, Gold Ridge RCD, NRCS	
Enhance Upstream Salmonid Rearing Habitat as Alternative to Estuary		
Continue large woody debris (LWD) placement projects to trap sediment, create pools and provide cover for rearing steelhead.	Landowners, Gold Ridge RCD, Bodega Land Trust, DFG	
Remove barriers or impediments to upstream salmonid migration.	Landowners, Gold Ridge RCD, Bodega Land Trust	
Provide Community Education and Outreach		
Develop a watershed information packet for local real estate agents to distribute to new residents.	Salmon Creek Watershed Council, Occidental Arts and Ecology Center, Bodega Land Trust, Salmon Creek School	
Implement a Water Conservation Campaign.	Salmon Creek Watershed Council, Occidental Arts and Ecology Center, Bodega Land Trust, Salmon Creek School	

Implement a Fuel Management/Sudden Oak Death Awareness Program.	West County Fire Safe Council, Salmon Creek Watershed Council, Occidental Arts and Ecology Center, local fire departments, CDF	
Continue to collect and document oral history.	Salmon Creek Watershed Council, Gold Ridge RCD, Bodega Land Trust	
Develop an educational trail system around estuary.	State Parks, Salmon Creek Watershed Council, Bodega Land Trust	
Coordinate Watershed Planning and Restoration Efforts		
Incorporate various assessments and studies into an Integrated Watershed Management Plan	Salmon Creek Watershed Council, Gold Ridge RCD, Bodega Land Trust	Included in the Gold Ridge RCD and Bodega Land Trust proposals to the SWRCB Consolidated Grant Program.
Continue to develop a Watershed GIS (Geographic Information Service).	Salmon Creek Watershed Council, Gold Ridge RCD	Included in the Gold Ridge RCD proposal to the SWRCB Consolidated Grant Program.

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APPENDICES

Appendices include historical background and oral histories by Kat Harrison, water quality graphs by James C. Roth, and data files. These files may be viewed electronically on the supplemental CD.