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San Gregorio Creek Watershed Management Plan

San Gregorio Creek
Watershed Management Plan

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Prepared for the Natural Heritage Institute

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With an appendix on Groundwater Influences Affecting Aquatic Habitat Potential,
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1 INTRODUCTION

1.1 Goal and Objectives of the Watershed Management Plan

The San Gregorio Creek Watershed Management Plan (San Gregorio WMP) is motivated by the importance and restoration potential associated with the San Gregorio Watershed, as well as the need for a strategic assessment and planning process to ensure efficient and wise use of resources.

The San Gregorio Creek is listed as a high priority creek by various state and federal agencies in California for a range of reasons. San Gregorio Creek is considered a Critical Coastal Area (CCA) by the California Coastal Commission (CCC 2006).[1] Of the 101 CCAs in California, San Gregorio Creek is one of the ten highest priority watersheds based on existing water quality conditions, value and sensitivity of coastal resources, new or expanding threats to beneficial uses, and degree of local support for watershed-based planning efforts. While the completion of watershed-based assessment and management plans is a priority for all CCA watersheds, San Mateo County watersheds have been specifically identified as having declining levels of salmonid habitat and a lack of watershed assessment data.

In addition, the San Gregorio Creek watershed with ~45 miles of blue line streams is one of nine creeks identified by the California Department of Fish and Game (CDFG) for coho salmon reintroduction (CDFG 1998). Further, pursuant to Public Resources Code Section 10004, CDFG prioritized 22 streams in the state in which CDFG intends to determine and recommend the amount of instream flows necessary for aquatic habitat. The list was based on: 1) presence of anadromous species, 2) likelihood that CDFG flow recommendations would provide a high level of improvement, 3) availability of recent flow studies or other relevant data; and 4) the possibility of partners/willing landowners. San Gregorio Creek was ranked third in the State of California for CDFG to develop instream flow requirements.

Although the Surface Water Ambient Monitoring Program (SWAMP) found that San Gregorio Creek Watershed was among the highest in water quality and most intact in benthic

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[1] State of the CCAs Report 26 January 2006

macroinvertebrate communities out of nine San Francisco Bay region watersheds (SFBRWQCB 2007) that were considered, San Gregorio Creek was placed on Clean Water Act 303(d) List in 1998 (SWRCB 2003). The pollutant/stressor was listed as "sediment / sedimentation" and considered an "impairment to steelhead habitat".

San Gregorio Creek Watershed is also a federal conservation priority. The Draft Recovery Plan for Central California Coast Coho Salmon recently released by the National Marine Fisheries Service (NMFS) identifies the San Gregorio Creek Watershed as one of the 28 focus watersheds for recovery of the critically endangered species. Additionally, the mouth of the watershed is protected by a seasonal 25-acre lagoon, which was proposed as critical habitat for the tidewater goby by the U. S. Fish and Wildlife Service (USFWS) in 2005 and again in 2008.

Although there have been a few publicly available studies in the San Gregorio Creek watershed, including: 1) a sediment study in several tributaries (Balance Hydrologics Inc. 2006); 2) an inventory of roads and trails in the El Corte de Madera Preserve (Best 2002), La Honda Creek Open Space Preserve including the recent Driscoll Ranch addition (Best 2007), and the Russian Ridge Open Space Preserve (Best 2005) which have evaluated the road and trail network utilized within the Preserves that cover over 10,000 acres in the watershed; and 3) a study entitled: "Fluvial Geomorphology, Hydrology and Riparian Habitat of La Honda Creek Along the Hwy 84 Transportation Corridor" (SFEI 2003), there has not been a comprehensive assessment and planning effort associated with this critical watershed.

The overarching goal of implementing the WMP is to improve ecological conditions in the San Gregorio Creek watershed to provide multiple benefits, such as protecting and enhancing native fish and wildlife populations, increasing ecosystem functioning, and maintaining the rural quality of life in the watershed. Objectives of the WMP in support of this goal include:

- Compile and analyze existing data regarding status and trends in the watershed;
- Determine current significant factors limiting the populations and habitats of four focal species, including Coho salmon (*Oncorhynchus kisutch*), steelhead (*O. mykiss*), California red-legged frog (*Rana draytonii*): and tidewater goby (*Eucyclogobius newberryi*).
- Make recommendations for management strategies that 1) address critical downward trends associated with natural resources in the watershed: 2) address limiting factors associated with focal species; and 3) to extent possible, meet multiple objectives (i.e., promote both ecological and agricultural security).

Although the San Gregorio WMP addresses some upland issues, the main focus is on protecting and restoring river health.

1.2 Limiting Factors and Watershed Approach

The San Gregorio WMP was designed to quantitatively assess factors limiting native focal species habitats and populations. Rather than responding to symptoms of ecosystem problems, the approach takes a watershed perspective to identify the root cause of ecosystem problems so that comprehensive and effective management and restoration actions can be developed and prioritized. Given limited resources, this watershed-wide approach is not only robust, but prudent.

1.3 Funding

The California State Water Resources Control Board funded[2] the development of the plan through their 2005-2006 Consolidated Grants Program which was designed to integrate and coordinate related grant programs for Watershed Protection, Water Management, Agricultural Water Quality, Drinking Water, Urban Stormwater, and Non-Point Source Pollution Control. Approximately $143 million was made available from six interrelated grant programs administered by the State Water Board's Division of Financial Assistance. The 2005-06 Consolidated Grants were funded using Proposition 40, Proposition 50, and federal appropriations. This project was funded by Proposition 40, the California Clean Water, Clean Air, Safe Neighborhood Parks, and Coastal Protection Act of 2002, under the Integrated Water Management Program: Planning. The purpose of the Integrated Watershed Management Program was to improve water quality, protect and restore habitat and fisheries, reduce flooding, control erosion and sedimentation, and improve local water supply reliability through better groundwater monitoring, river corridor recreation, forest land and fuel management, and hydropower management.

Additional support was provided by a variety of sources including volunteer time, citizen donations of cash, and the Berkeley Water Center.

1.4 Technical and Stakeholder Process

This WMP was developed through the collaboration of a broad spectrum of participants. Project partners include: Natural Heritage Institute (NHI), San Gregorio Environmental Resource Center (SGERC), Cuesta La Honda Guild, San Mateo County Resource Conservation District (SMCRCD), Stockholm Environment Institute, (SEI), California Water Science Center (USGS), Midpeninsula Regional Open Space District (MROSD), Robert Zatkin, and Stillwater Sciences.

In addition, the plan was advised by a Technical Advisory Committee (TAC) consisting of: Joyce Ambrosius (NOAA Fisheries), Kristine Atkinson (California Department of Fish and Game), Matt Baldzikowski (MROSD), Joanne Kerbavaz (California State Parks), Jill Marshall (Regional Water Quality Control Board), Allan Richards (Stetson Engineers), and Tim Frahm (San Mateo County Farm Bureau). The TAC met as a group five times over the life of the project. The acknowledgement listed above does not imply endorsement or approval of this document in its entirety or in part by those individuals or their organizations. Further, the plan proceeded with input from a Watershed Working Group that consists of community members and other interested parties that attended any of four public meetings.

1.5 Geographic Setting of the Watershed Management Plan

The San Gregorio Creek watershed is the second largest drainage in coastal San Mateo County, with approximately 45 miles of blue line streams.[3] Originating in the Santa Cruz Mountains, tributaries to San Gregorio Creek generally drain to the southwest through steep canyons and redwood-Douglas Fir and tanoak forests. The tributaries join in the valley floor, where San

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[2] Funding for this project has been provided in full or part through an agreement with the State Water Resources Control Board. The contents of this document do not necessarily reflect the views and policies of the State Water Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

[3] A blue-line stream is one which flows for most or all of the year and is marked on topographic maps with a solid blue line. It is important to note, however, that the blue lines on USGS maps often under-represent stream length and drainage area.

Gregorio Creek flows through rolling grasslands, coastal shrub, and agricultural areas before emptying into a coastal lagoon at the Pacific Ocean.

The watershed includes the small unincorporated communities of La Honda, San Gregorio, Redwood Terrace, and Sky Londa, and California State Highway 84 traverses the watershed from the eastern boundary with the San Francisco Bay area to the Pacific Ocean at California State Highway 1 (Figure 1-1). A portion of San Gregorio State Beach, Sam McDonald County Park, and several open space preserves are located in the watershed. El Corte de Madera Creek Open Space Preserve (2,821 acres), under the management of MROSD, is located in the upper watershed. La Honda Open Space Preserve (over 5,800 acres) contains portions of La Honda, Harrington, and Bogess Creeks, while Russian Ridge Preserve (1,822 acres) includes the upper reaches of Mindego and Alpine Creeks.

The watershed is largely undeveloped with approximately 50% percent of the land area held in the public trust. The watershed naturally supports cool, low-salinity, alkaline waters, and its fractured mudstone geology offers a more resilient environment for salmonids than the sandy or decomposed watersheds elsewhere in the Santa Cruz Mountains. As CDFG has already recognized, these traits make the watershed an appropriate venue for investing time and effort to improve water quality and habitat conditions for native species.

1.6 Supported Agency Goals and Objectives

Several state and federal agencies and programs have also developed goals and objectives related to the San Gregorio Creek watershed. Many of these goals and objectives have, and will continue to direct future planning and restoration implementation in the watershed. Agency goals and objectives that are shared with this WMP are listed below.

California Coastal Commission

- Complete a watershed management plan to facilitate the management of the watershed as a CCA.
- Identify strategies to protect/restore coastal waters to support CCC's priorities on the Central Coast.

California Department of Fish and Game

- Review new diversions related to the protection and enhancement of steelhead populations.
- Identify the extent of non-native invasive species and develop plans for control/eradication.
- Develop strategies to restore/protect riparian areas from livestock.
- Support coho reintroduction in the watershed and CDFG (2003) recovery strategies for California coho salmon by preparing a comprehensive watershed assessment and restoration plan that includes assessing stream flow, water quality, sediment sources, fish barriers, and instream habitat.
- Support CDFG (1996) steelhead restoration and management plan for California by prioritizing projects that identify and correct problems most limiting the target population.

State Water Resources Control Board

- Enhance beneficial uses, reduce erosion, and restore hydrologic regimes.
- Conduct critical analyses to restore anadromous salmonid habitat.
- Address watershed-scale water quality issues, establish watershed data management capacity, and increase/build capacity for watershed monitoring.
- Provide physical, hydrologic, and biological data pursuant to the development and implementation of a TMDL standard; in particular, inventory and map all major sediment sources and determine the role of large woody debris in sediment retention, and measure bedload and sediment discharges to develop a sediment budget for the watershed.
- Monitor, collect, and analyze water quality and pollutant transport in surface water.
- Provide comprehensive capability for monitoring, collecting, and analyzing ambient water quality data based on standardized protocols that will be entered into a statewide information base.
- Identify and design management measures and strategies to reduce and prevent runoff.
- Identify strategies to protect/restore coastal waters, including application of NPS management measures and development of land use regulations protecting coastal water quality.

U.S. Fish and Wildlife Service

- Support USFWS California red-legged frog and tidewater goby recovery planning.
- Support NOAA Fisheries Central California Coast Coho Recovery Plan by: 1) inventorying impediments to movement of adult and juvenile salmonids and developing/maintaining a database of barriers; 2) ensuring minimum instream flows are maintained; and 3) inventorying water use and availability in streams with coho salmon, and require gauging on coho salmon streams.

NOAA's National Marine Fisheries Service

- Increase the frequency and functionality of off-channel habitats.
- Implement, via technical assistance and/or regulatory action, the flow bypass requirements sufficiently protective of all freshwater life stages.
- Promote efforts to protect riparian and floodplain areas.
- Promote supplemental programs to increase LWD recruitment to improve stream complexity, gravel retention, and pool frequency and depth.
- Promote restoration projects designed to create or restore alcove, backchannel, ephemeral tributary, or seasonal pond habitats.

1.7 Other Programs in the Watershed

The WMP and the recommended management strategies are designed to be coordinated with other resource conservation or restoration efforts in the watershed, including: Trout Unlimited's Coastal Streamflow Stewardship Project; CDFG's on-going research and proposed instream flow study; UC Berkeley's hydrology study and proposed lagoon study; projects and programs of the Local Partnership Office of the San Mateo County Resource Conservation District and Natural Resources Conservation Service; and the Land Use Committee of the San Mateo County Food Systems Alliance. The TAC has been instrumental in making recommendations on how this integration and coordination should proceed.

1.8 Updating the Management Plan

The San Gregorio WMP is meant to be a “living document.” A living or dynamic document is a document which may be continually edited and updated. Living documents are particularly useful for subject matters that change over time or that are sufficiently complex as to warrant ongoing data collection, analysis and refinement, such as the management of San Gregorio Creek.

It is the intent that in the short-term, updates will be in the form of Appendices that are attached to the document. Each new appendix will reference the original document and any previous appendices. As a significant number of appendices are added to the plan and/or significant time passes (5 or 10 years), the plan will be fully revised incorporating all additional information. The TAC will be reconvened and have the opportunity to review any new Appendices to this document, as well as a full revision of it.

Of particular importance is the need to update the plan as more information becomes available regarding climate change. Many studies predict current and potential impacts of climate change on water supplies, including changes in precipitation, sea level rise, warming surface waters and air temperatures, and changes in water demand. How these projections play out along the Central Coast of California is still unknown, however, many of the expected changes are likely to further degrade salmonid habitat by, for example, reducing stream flows during the summer and raising summer water temperatures. These uncertainties call for an emphasis on long-term resource system adaptability - rather than historic verisimilitude – in restoration targets, and major commitments to long-term monitoring.

2 WATERSHED CHARACTERIZATION

2.1 Physical Setting and Location

San Gregorio Creek is the second largest watershed in coastal San Mateo County, draining an area of approximately 33,290 acres in five primary sub-basins[4] (Figure 2-1) comprising approximately 45 miles of stream channel. The watershed originates at an elevation of 2,700 ft above sea level in the Santa Cruz Mountains, part of the southern Coast Ranges, and generally drains to the southwest through steep canyons and redwood, Douglas-fir, and tanoak forests. Mainstem San Gregorio Creek flows 12 mi from its origination point at the confluence of Alpine and La Honda creeks, through rolling grasslands, coastal shrub, and agricultural areas before discharging into a seasonal coastal lagoon at the Pacific Ocean.

The watershed is bounded by Pomponio Creek to the south, Tunitas Creek to the north, State Route 35 (Skyline Boulevard) to the east, and State Route 1 (Coast Highway) to the west, and is traversed from the eastern boundary to State Route 1 by State Highway 84. It includes the small unincorporated communities of La Honda, San Gregorio, Redwood Terrace, and Sky Londa. A portion of San Gregorio State Beach, Sam McDonald County Park, and several open space preserves (OSPs) are located in the watershed (Figure 2-2).

2.2 Sub-basins

The San Gregorio Creek watershed is composed of five sub-basins, which include 13 major tributary streams (Figure 2-1, Table 2-1). These sub-basins, and several of the major tributary streams within them, are described below as available existing information allows. Additional

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[4] CalWater planning basins were used to delineate sub-basins in the watershed. CalWater is an interagency watershed mapping committee whose planning basins are used by the California Department of Water Resources, California State Water Resources Control Board and Regional Water Quality Control Boards, California Department of Forestry and Fire Protection, and California Department of Fish and Game. CalWater planning basins do not always represent true hydrologic sub-basins (e.g., Bogess, Harrington, and Kingston creeks compose the Harrington Creek CalWater planning basin).

information on instream conditions in these sub-basins is also provided in Sections 2.5 (Geology and Geomorphology) and 4 (Limiting Factors Analysis).

Table 2-1. Sub-basins of the San Gregorio Creek watershed.

Sub-basin	Area (ac)
Harrington Creek	8,274
La Honda Creek	7,327
El Corte de Madera Creek	6,333
Mindego Creek	5,978
Clear Creek	5,381
Total	**33,293**

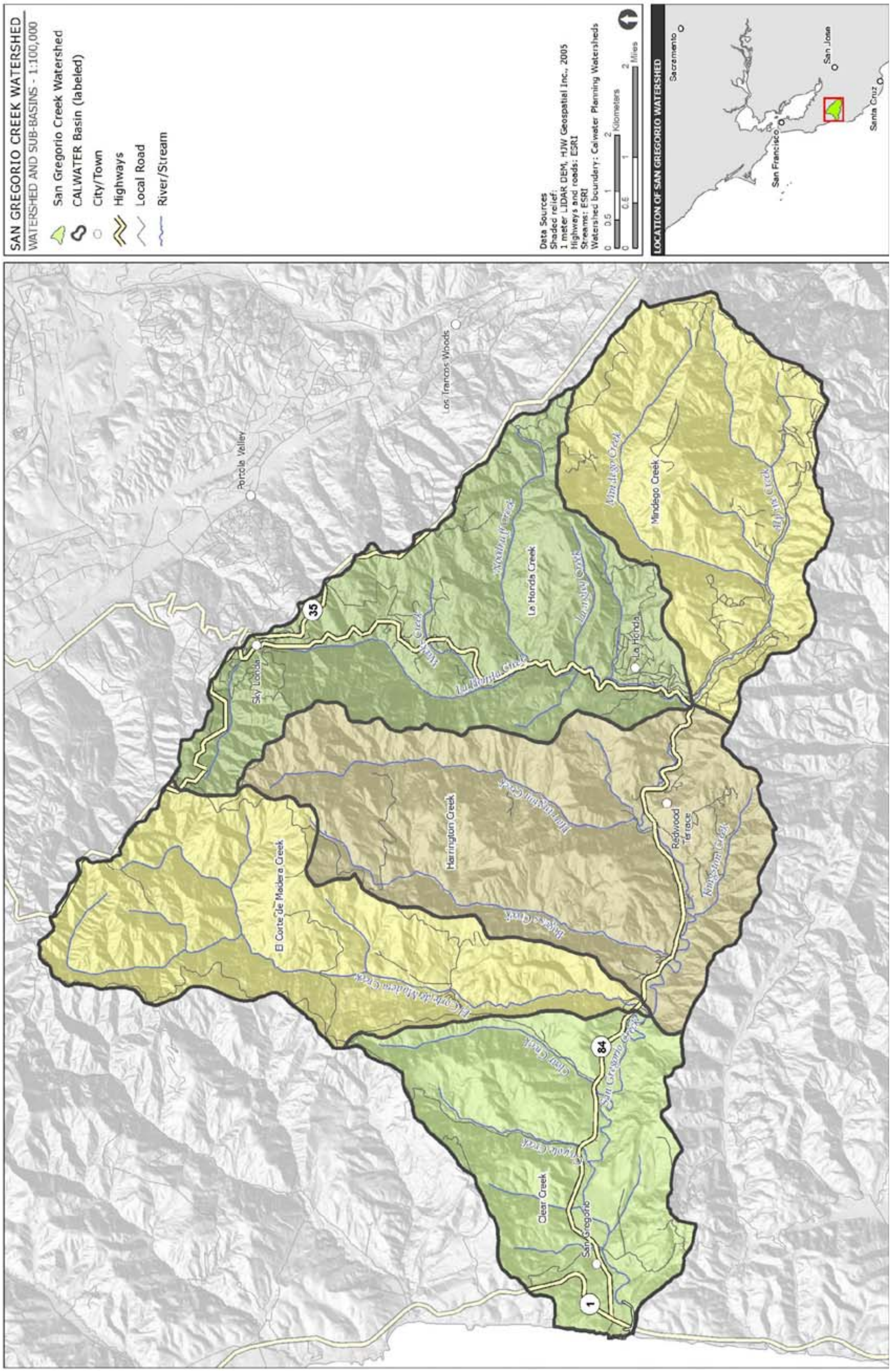
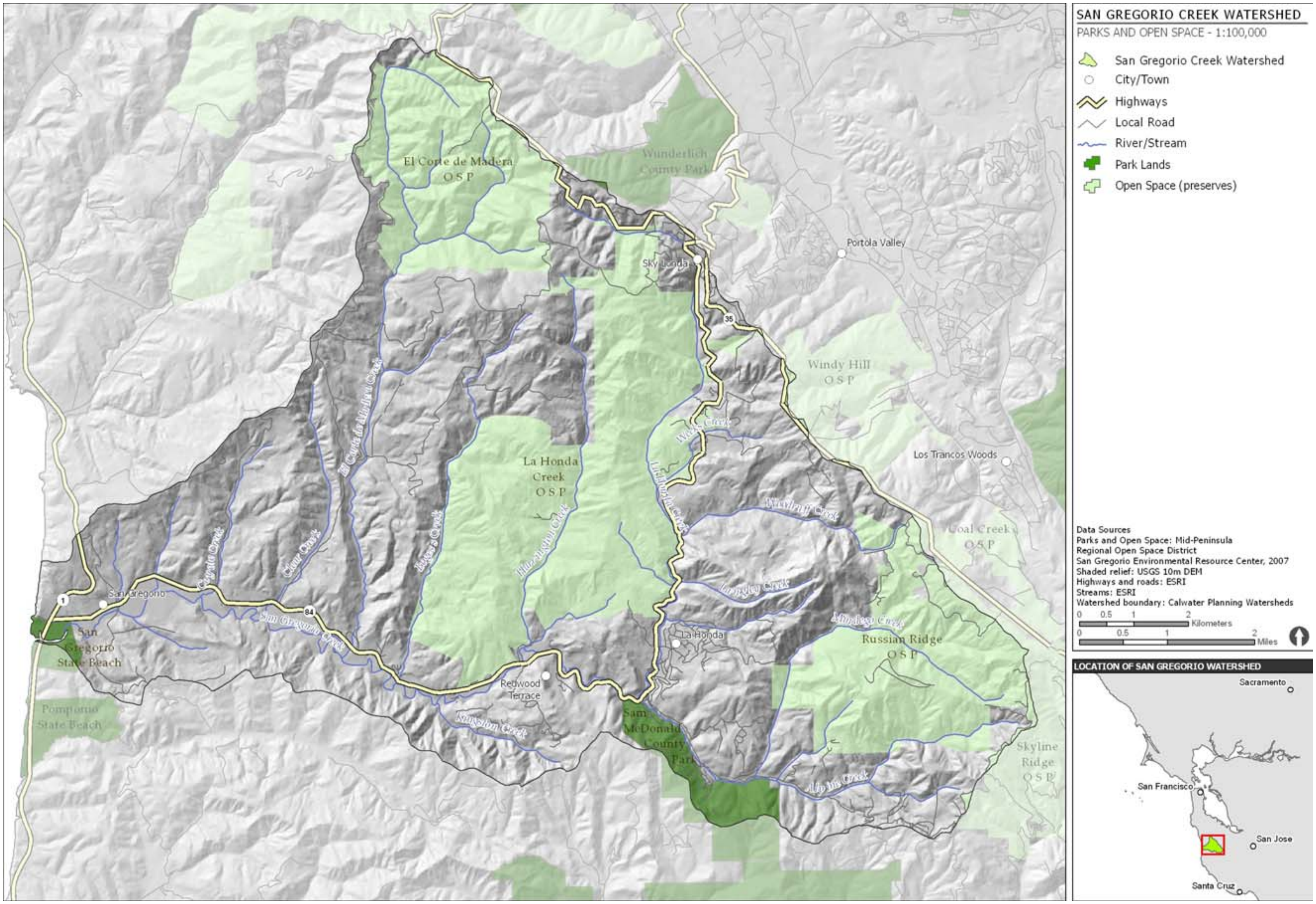


Figure 2-1. The San Gregorio Creek watershed and its sub-basins.



Data Sources
Parks and Open Space: Mid-Peninsula Regional Open Space District
San Gregorio Environmental Resource Center, 2007
Shaded relief: USGS 10m DEM
Highways and roads: ESRI
Streams: ESRI
Watershed boundary: Calwater Planning Watersheds

Figure 2-2. Park lands and open space preserves in the San Gregorio Creek watershed.

2.2.1 Mindego Creek

The Mindego Creek sub-basin is the easternmost sub-basin in the San Gregorio Creek watershed and includes Alpine Creek (Figure 2-1). Elevations in the sub-basin range from 320 to 2,400 ft, with coastal redwood forest and oak woodlands at higher elevations (California Department of Fish and Game [CDFG] 1996a, 1997a). Dominant soil types include stony loams and clay-loams (Sweeny and Mindego series) on moderate to steep slopes, with landslide-prone areas at mid elevations (NRCS 2009) (Figure 2-3). Due to its underlying geology, the Mindego formation (the Mindego Creek sub-basin, along with parts of Alpine Creek) supplies much of the durable and semi-durable clasts, or large sediment, to the watershed (Brabb et al. 1998). Low-density rural residential development occurs along the lower 2.5 mi of Alpine Creek (CDFG 1997a). Midpeninsula Regional Open Space District (MROSD) owns and maintains the Russian Ridge OSP in the headwaters, which amounts to nearly 40% of the sub-basin (Figure 2-2). A portion of Sam McDonald County Park is also located in the Mindego Creek sub-basin (Figure 2-2).

Mindego Creek drains the northern half of the sub-basin and is a tributary to Alpine Creek (Figure 2-1). The creek is a meandering low-gradient stream with boulder and cobble dominated pool-riffle habitat, and ends with a short reach (approximately 3,800 ft) of sand-dominated, moderate-gradient stable, entrenched channel (CDFG 1996a). A 1996 stream survey by CDFG identified a lack of habitat complexity and in-stream cover related to the absence of large woody debris (LWD) and suggested that a lack of summer and winter rearing habitat, in addition to unsuitable spawning substrates, are limiting coho salmon and steelhead spawning and juvenile rearing success.

Alpine Creek runs along the entire length of the southern margin of the sub-basin (Figure 2-1). The creek is somewhat entrenched but stable, with low to moderate gradients. Cobble is the dominant substrate, although significant silt deposits in pools and substrate embeddedness has been noted and may limit salmonid spawning success (CDFG 1997a). Alpine Creek Road parallels much of the creek, and it is likely that landslides and road-maintenance activities contribute fine sediment to the channel. The junction of Alpine Creek and La Honda Creek forms the beginning of mainstem San Gregorio Creek.

2.2.2 La Honda Creek

The La Honda Creek sub-basin includes Weeks, Woodruff, Woodhams, and Langley creeks in addition to La Honda Creek (Figure 2-1). Elevations in the sub-basin range from approximately 360 to 2,320 ft, and vegetation communities include coastal redwood forest and grassland with patches of chaparral scrub (Pearce et al. 2007). Dominant soil types include clay loams (Mindego series) on moderate to steep slopes (NRCS 2009) (Figure 2-3), with notable sandstone formations which contribute unique weathering and sedimentation patterns (Balance Hydrologics 2007). The community of Sky Londa is located just inside the northeast boundary of the sub-basin (where Highway 84 meets Skyline Boulevard), and the community of La Honda is located near the southern boundary of the sub-basin (Figure 2-1). Approximately 30% of the sub-basin (2,260 ac) is owned by MROSD, which maintains areas that are both open for recreational use and closed for preservation and watershed protection (Figure 2-2). The remainder of the sub-basin is privately owned, and managed for activities that include timber harvest, agricultural, and rural residential land uses.

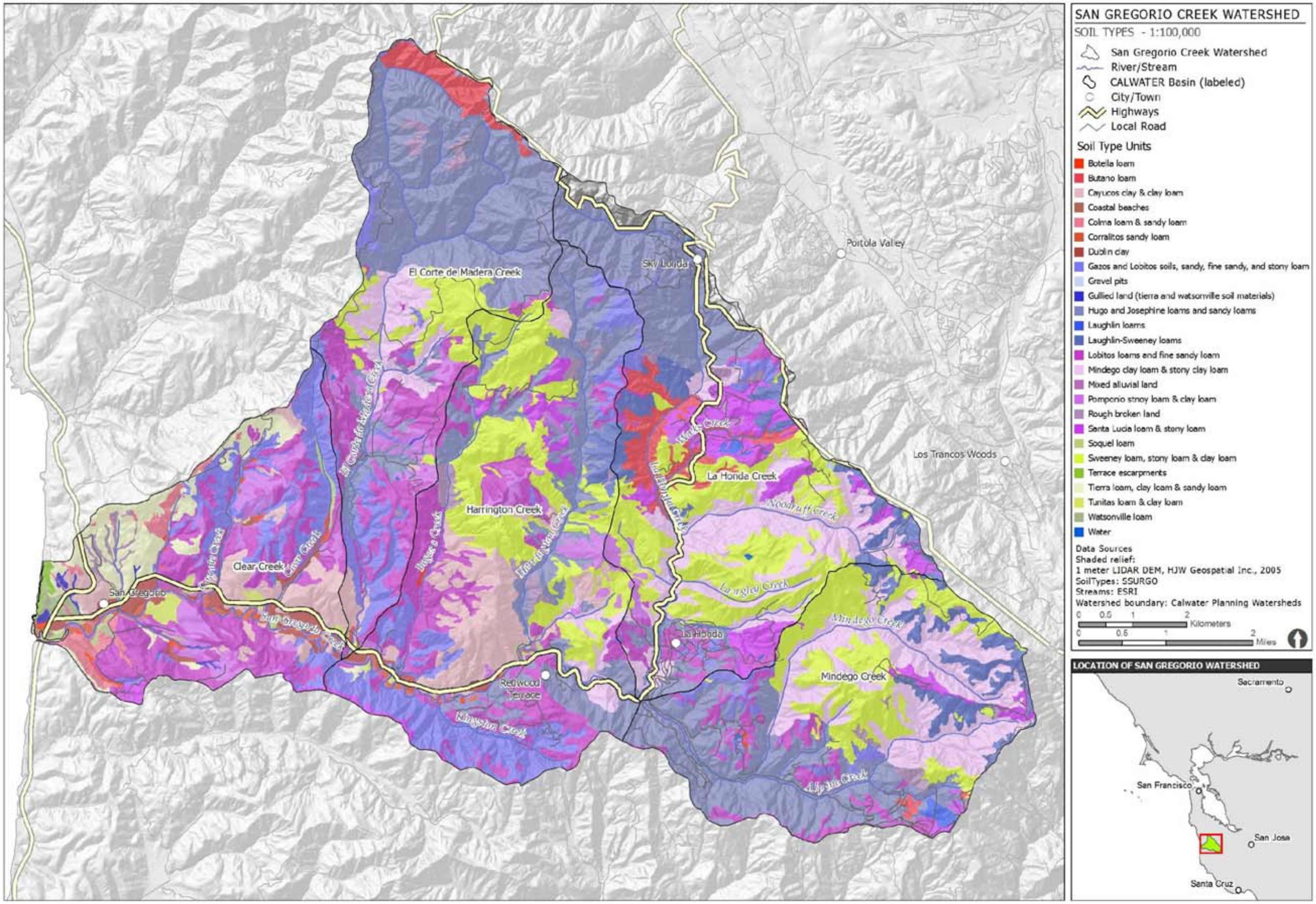


Figure 2-3. Soil types in the San Gregorio Creek watershed.

La Honda Creek flows north to south along the entire western margin of the sub-basin and receives input from Weeks, Woodruff, and Langley creeks (Figure 2-1). In its upper reaches, the creek is confined and characterized by narrow step-pools (primarily formed by LWD) and high-energy flows, which likely limits the availability of salmonid spawning and rearing habitat (Pearce et al. 2007). The lower reaches support a moderate-gradient entrenched channel with cobble dominated substrates. A 2007 stream survey noted significant substrate embeddedness in pool tails throughout the creek and suggested that it may limit salmonid spawning success (Pearce et al. 2007).

Weeks Creek crosses Highway 84 before the confluence with La Honda Creek, and Woodruff Creek drains north and south-facing slopes in the east central portion of the La Honda Creek sub-basin (Figure 2-1). There is little information available on these creeks, although surveys from 1978 and 1979 noted good spawning and rearing habitat for steelhead and an abundance of invertebrate species in Woodruff Creek (CDFG 1978, McKenzie 1979).

Langley Creek drains a small (approximately 0.5 mi^2), steep, southeastern section of the La Honda Creek sub-basin (Figure 2-1). The entire Langley Creek basin is privately owned with some rural residential development (CDFG 1996b). The creek is moderately entrenched with primarily gravel and cobble substrates (CDFG 1996b). A 1996 stream survey noted shallow pools, cobble-dominated riffles, and high water temperatures, and suggested that spawning and rearing habitat for steelhead and coho salmon may be limited in Langley Creek.

2.2.3 Harrington Creek

Harrington Creek is the largest sub-basin of the watershed and includes Harrington Creek, Bogess Creek, Kingston Creek, and the upstream half of mainstem San Gregorio Creek (Figure 2-1). Elevations within the Harrington Creek sub-basin range from approximately 130 to 1,800 ft. Riparian vegetation is predominantly mixed hardwood forest with some Douglas fir and redwood, and upland areas consist of grassland, coastal scrub and oak woodland (Baglivio and Kahles 2006a, 2006b). Dominant soil types include moderately sloped to steep, eroded, loam or clay-loam soils (Lobitos-Gazos series) derived from shale and mudstone with some landslide-prone areas at middle elevations (NRCS 2009, Best 2007) (Figure 2-3). Nearly half of the sub-basin is owned by MROSD and managed as rangeland, although the community of Redwood Terrace is located in the southeast portion of the sub-basin near the confluence of Harrington and San Gregorio creeks.

Bogess Creek drains the western half of the sub-basin north of San Gregorio Creek (Figure 2-1). The lowermost and uppermost reaches of the creek are alluvial channels with well-defined floodplains, with a steeper, higher gradient segment in the middle. Boulder and cobble are the dominant substrate, and the creek is thought to provide abundant spawning and rearing habitat for steelhead and coho salmon (Baglivio and Kahles 2006a).

Harrington Creek drains the eastern half of the sub-basin north of San Gregorio Creek (Figure 2-1). It is primarily an alluvial channel, with well defined floodplains, and bedrock and gravel substrates (Baglivio and Kahles 2006b). Harrington Creek provides steelhead and coho salmon spawning and rearing habitat up to a bedrock waterfall at stream mile 2.5 (Baglivio and Kahles 2006b).

Kingston Creek is the only major channel that drains the generally north-facing slopes in the southern portion of the watershed (i.e., that portion of the watershed that lies to the south of mainstem San Gregorio Creek) (Figure 2-1). In 1985, the creek was described as a narrow channel with a resident rainbow trout population, but that a series of passage barriers likely limit anadromous fish in the creek (CDFG 1985).

A 1996 survey of the upper half of San Gregorio Creek described it as an entrenched, meandering, riffle/pool channel, with a low gradient, high width-to-depth ratio, and a gravel-dominated substrate (Hicketheir et al. 1996). A dense riparian corridor and moderate levels of embeddedness were measured, and a lack of large and small woody debris was noted. In 2005, the National Marine Fisheries Service (NMFS) found coho salmon rearing in upper San Gregorio Creek (M. Baldzikowski, pers. comm., 2009).

2.2.4 El Corte de Madera Creek

El Corte de Madera Creek is the only major tributary stream in the El Corte de Madera Creek sub-basin. The creek drains a relatively narrow, north–south trending corridor and ends at mainstem San Gregorio Creek (Figure 2-1). Elevations within the sub-basin range from 100 to 2,400 ft. Mixed conifer forest, grassland, and scrub are the dominant vegetation communities (CDFG 1996c). Similar to other sub-basins in the watershed, eroded loam soils (Gazos series) underlie much of the sub-basin (Figure 2-3). There are also notable outcroppings of (Butano) sandstone which contribute unique weathering and sedimentation patterns (Balance Hydrologics 2007). Over 40% (2,651 ac) of the watershed is publicly owned by MROSD and designated for multiple-use recreation (MROSD 2009a); the remainder is privately owned. El Corte de Madera Creek is an entrenched, low-gradient, meandering channel (CDFG 1996c). CDFG surveys of the creek (1996c) noted very little spawning habitat and high water temperatures.

2.2.5 Clear Creek

The Clear Creek sub-basin includes Clear Creek, Coyote Creek, several unnamed tributaries, and the downstream half of mainstem San Gregorio Creek (Figure 2-1). This sub-basin ends at the Pacific Ocean and technically includes the seasonal lagoon at the mouth of San Gregorio Creek, although the seasonal lagoon is discussed separately and in more detail below. Eroded loam and clay loam (Tierra series) soils underlie the sub-basin with small occurrences of somewhat poorly drained clay soils (Dublin series) on flat outcroppings (NRCS 2009) (Figure 2-3). Dominant vegetation communities include grasslands, mixed willow, and coastal scrub (coyote brush). The community of San Gregorio, with a population of approximately 287, is located one mile east of Highway 1 within the Clear Creek sub-basin.

Although CDFG (1973a, 1973b) surveys indicate that both Clear Creek and Coyote Creek are intermittent seasonal streams that contribute flow to San Gregorio Creek only in the winter, more recent observations indicate that Coyote Creek is generally a perennial stream and that it supports a resident population of *O. mykiss* (J. Smith, pers. comm., 2009; J. Rigney, pers. comm., 2010). Fish passage into Coyote Creek is potentially limited in some years by the culvert under the Hwy 84 stream crossing (J. Rigney, pers. comm., 2010) but apparently steelhead do use the stream (J. Smith, pers. comm., 2009).

2.2.6 Seasonal lagoon

Lower San Gregorio Creek drains into the Pacific Ocean at San Gregorio State Beach, downstream of the Highway 1 Bridge (Figure 2-1). In dry months, low-energy waves deposit sand and build up the sandbar at the beach. After the sandbar forms, water surface elevation rises as the impounded seasonal lagoon fills with freshwater stream flow. Historically the seasonal lagoon likely backed-up into adjacent marsh habitat, but during the construction of the Highway 1

Bridge, the marsh and lagoon were partially filled and the creek was forced to the south under the bridge. The marsh now connects with the lagoon through a culvert, which, likely due to channel incision, effectively drains the marsh into the lagoon (Swenson 1997).

The lagoon is now contained in the large incised stream channel primarily upstream of the Highway 1 Bridge when the sandbar is closed (Smith 1990). At its largest, the seasonal lagoon is approximately 5 ac, with a maximum depth of 6 ft (California Trout 1971). At the beach, the precise size and location of the lagoon vary somewhat each year (Smith 1990). The bed of the lagoon is composed of fine gravel, sand, and silty clay loam, and during the summer, aquatic vegetation is abundant and an algal bloom occurs. After the sandbar forms, stream flow into the lagoon generally results in unstratified fresh water conditions, with relatively cool temperatures, high dissolved oxygen, and high invertebrate abundance (Smith 1990). These are ideal conditions for steelhead to rear in the lagoon (Smith 1990). When stream flow into the lagoon is low, due to late sandbar formation, drought, or upstream diversions, the lagoon stratifies with a layer of warmer, more saline, and lower dissolved oxygen water at the bottom that precludes many native fish species and limits the growth of juvenile steelhead (California Trout 1971, Smith 1990). High lagoon water levels spread over the sandy beach, but seldom flood much land farther upstream outside of the main stream channel (Smith 1987). Despite alterations to the lagoon, it has been shown to support a diversity of freshwater, estuarine, and saltwater fish species, such as tidewater goby, and rearing steelhead (Smith 1990; K. Atkinson, pers. comm., 2009). Coho salmon are not observed to rear in San Mateo or Santa Cruz county lagoons, but do use lagoon habitat to undergo physiological adjustments to prepare for the marine environment during their smolt outmigration (K. Atkinson, pers. comm., 2010).

The sandbar naturally breaches at the onset of fall and winter storms, converting the seasonal lagoon to a flowing river channel. During this period, the lagoon is open to full tidal mixing and once again habitat conditions are suitable for both migrating and rearing steelhead and coho salmon (Smith 1990). Artificial breaching of the sandbar occurred historically (California Trout 1971, Smith 1990) and is still a regular occurrence. In 2005 and 2006, artificial breaching took place throughout the summer, to the extent that the sandbar was rarely in place for more than two to three weeks (K. Atkinson, pers. comm., 2009). Artificial breaching causes the lagoon to drain quickly, drastically altering the habitat for the species that are rearing there, and the lowered water surface elevation further disconnects creek and marsh habitats (Swenson 1997). Preventing artificial summer sandbar breaching, as well as ensuring adequate freshwater stream flow to create freshwater seasonal lagoon conditions, have been identified as two key measures to enhance steelhead populations in the San Gregorio Creek watershed (Smith 1990; K. Atkinson, pers. comm., 2009).

2.3 Land Use

2.3.1 Historical land use

Costanoan Indians were the first inhabitants of the San Gregorio Creek watershed, subsisting by hunting, fishing, and gathering native plants (Dougherty 2007). Spanish missionaries led by Don Gaspar de Portola in his search for Monterey Bay arrived in the San Francisco Bay area in 1776, establishing a series of local missions and settlements, laying the foundation for future development that began with small-scale agricultural production (San Mateo County 1986, Dougherty 2007). In 1821, Mexican rule was established and large “ranchos” were delineated and given to the recipients of Mexican land grants. The establishment of large land holdings altered the emphasis of the area's agricultural economy from small subsistence plots to large cattle ranches (San Mateo County 1986). The ranchos were under Mexican rule from 1822 to 1846 and, in addition to cattle ranching, were used as dairies and for farming. Rancho San Gregorio (18,000 ac) encompassed present-day San Gregorio and La Honda and was bounded on one side by Arroyo Honda (Dougherty 2007).

During the Gold Rush in the mid-19th century, California's population boomed and new settlers in the San Gregorio Creek watershed incrementally bought or squatted on portions of the ranchos (San Mateo County 1986). The increasing development of California in general, and the Bay Area specifically, required building materials and prompted the harvesting of timber in the Santa Cruz Mountains. By 1870 most timber had been harvested from the eastern slope of the Santa Cruz Mountains (Dougherty 2007). Logging operations then moved west toward the coast, and numerous logging camps were established in the San Gregorio Creek watershed including the commercial center of La Honda (San Mateo County 1986). Meanwhile, an influx of farmers began developing the flat lands in the lowest portions of the watershed into larger agricultural operations. With the influx of people and industry came an expanding road network fortified by the Redwood City–San Gregorio Turnpike in 1868 and the Searsville-La Honda Turnpike in 1878, which followed the present-day course of Old La Honda Road (Dougherty 2007).

As logging diminished, the area began to be used for recreation and residential uses (Dougherty 2007). Several large lodges were built in the 1920s to accommodate Bay Area visitors, and plots were subdivided for summer cabins. These early vacation cabins are now, or have been replaced with, year-round residences, while many of the large lodges fell victim to fires (San Mateo County 1986, Dougherty 2007). Many residences have also been constructed since the 1930s–40s, such as those within the Cuesta La Honda Guild (Brady et al. 2004). Parts of the watershed continued to be used for dry farming (e.g., Driscoll Ranch) in the middle of the 20th century (DCE 2007), but many of these areas are no longer farmed. Oil drilling also occurred in the La Honda Creek oil field beginning in the late 19th century, and continues today on a small scale (J. Paulin, pers. comm., 2004, as cited in DCE 2007; DOGGER 2009). Over 80 oil wells occur in the watershed, primarily in the southern portion of the Harrington Creek sub-basin (Figure 2-1), although only five, located between La Honda Road and Kingston Creek near Redwood Terrace, are likely to be active (the remaining wells are either capped or idle) (DOGGER 2009).

2.3.2 Current land use

Overall, land use in the San Gregorio watershed has evolved from subsistence hunting and gathering prior to the 1800s, to ranching (both beef and dairy) and agricultural production. Intensive timber harvest followed through the 1800s and into the 1900s, which saw an increase in residential development and acreage preserved as open space. Current land use is a mix of agriculture and urban/residential uses, and forestland and rangeland that overlaps with designated open space. According to the 2000 census, the population of the watershed is 3,445.

The entire watershed lies in unincorporated San Mateo County and is subject to the County's General Plan (San Mateo County 1986) and Zoning Regulations (San Mateo County 1999). A portion of the watershed also lies in the Coastal Zone and is therefore regulated by the County's Local Coastal Program (San Mateo County 1989). Most of the land in the watershed is zoned Resource Management (RM), Timberland Preserve Zone (TPZ), Planned Agricultural District (PAD), Community Open Space Conservation District (COSC), with some Residential (R-1) (San Mateo County 1999) (Figure 2-4, Table 2-2).

HISTORICAL SNAPSHOT LOOK AT SAN GREGORIO AGRICULTURE

Agriculture, farming and ranching has changed thru the years. During the days of the California Missions, the San Gregorio area was noted primarily for its lamb and sheep production. Much has changed since then. Farming techniques and equipment, crops, roads and transportation, methods of planting and harvesting as well as the size and number of family farms themselves have changed in response to market forces, labor, transportation, infrastructure and land values. They continue to evolve today.

A snapshot of the 1950's farming and ranching in San Gregorio:

As a boy growing up in the early 1950's on a dairy in San Gregorio, John Muller recalls many small 5-10 acre apple orchards in the watershed. These orchards were sprinkler irrigated and were comprised of many varieties of eating and cooking apples. He recalled them as mature, producing orchards which would suggest that they had been present in this watershed for several decades. These orchards were found on both sides of Highway 84 roughly from the Westerly edge of the Redwood forested area to Stage Road.

Cattle were also an important agricultural feature in the San Gregorio Valley, both as beef cattle and as dairy cows.

Several of the beef cattle operations included permanent irrigated pastures along Highway 84 in proximity to the creek which was used both as forage, but also for the harvest of "grass hay". These operations also included rangeland for their cattle grazing in the hills.

Several commercial dairies were located in the watershed. Muller recalls 5 commercial dairies. The largest produced 20-30 "cans" of milk a day, which were placed by the farmers along Highway 84 early in the morning and picked up by a truck and delivered to Johanson's Creamery in San Bruno or in some cases to Watsonville every day. These dairies also irrigated pasture for their cows.

Also found in the valley during the 50's were vegetable farms. Crops such as cauliflower, Brussels sprouts, artichokes and seed potatoes were commercially grown. Naomi Patridge (Imamura) recalls her families vegetable farm located between Stage Road and the Coast Highway. Their "specialty crops" included New Zealand spinach and English peas. Many of these vegetables were "varieties" no longer available. In Muller's recollections, all of these crops were irrigated with overhead sprinklers.

In the hills of the lower San Gregorio Valley, annual crops which needed no irrigation such as flax and "dry beans" were grown and harvested each year.

As diverse as the crops were the names and heritages of the farmers. Swiss, Portuguese, Italian and Japanese farmers with names such as Sousa, Takata, Modena, Montevaldo, Tichenor, Andrade, Imamura, Alsford and Muller were the foundations of the farming/ranching community of San Gregorio in the 1950's.

Recollections were provided by John Muller and Naomi Patridge (Imamura).

Rangeland zoned as RM is the dominant land use in the watershed, occurring primarily in the foothill grasslands, although it is not known how much of this is actively being grazed (Figure 2-4, Table 2-2). Timber harvesting primarily occurs in the headwaters of the watershed in fragmented TPZ districts, but it is also allowed in RM districts with proper permits (San Mateo County 1999). Approximately 4,700 ac of the watershed is zoned for timber harvesting, and although it is not known how much of this is actively being harvested, the acreage is likely to be relatively small.[5]

Agriculture historically and currently occurs in PAD, RM, and COSC zoning districts (San Mateo County 1986, 1999). The purpose of the PAD zoning designation is to "preserve and foster existing and potential agricultural operations in San Mateo County in order to keep the maximum amount of prime agricultural land and all other lands suitable for agriculture in agricultural production" (San Mateo County 1999). Aerial Information Systems (2001, 2006) mapping identified 331 ac of working agricultural lands in the watershed (see Section 2.7), although it does not differentiate between types of agricultural lands (nor do any of the other currently available land use mapping datasets). Crops grown in the watershed include apples, cauliflower, brussel sprouts, wine grapes, and artichokes. Agricultural lands are centered along the coastal terrace and river valley.

Urban or built-up land, zoned as COSC and R-1, occurs throughout the watershed, but is focused in and around the towns of San Gregorio and La Honda (Figure 2-4). Aerial Information Systems (2001, 2006) vegetation mapping indicates that urban/built-up lands occupy 1,148 ac in the watershed (Table 2-2). Analysis of San Mateo County and MROSD geographic information system (GIS) data indicates that there are approximately 140 mi of State- and/or County-maintained roads in the watershed, and approximately 47 mi of inventoried roads and trails on MROSD lands.

A significant portion of the San Gregorio Creek watershed is also used as parks and open space preserves. MROSD owns and manages over 10,000 ac, or 33% of the watershed, and San Mateo County and the State of California also have large land holdings (Figure 2-2, Table 2-3). MROSD's purpose is to purchase, permanently protect, and restore lands to form a regional open space greenbelt, preserve unspoiled wilderness and fragile ecosystems, and provide opportunities for low-intensity recreation and environmental education in northwestern Santa Clara County and southern San Mateo County (MROSD 2009b). MROSD's largest land holdings in the watershed include the Russian Ridge Open Space Preserve (OSP), La Honda Creek OSP, and El Corte de Madera Creek OSP (Figure 2-2, Table 2-3).

Russian Ridge OSP is 2,800 ac and includes the upper reaches of Mindego and Alpine Creeks (Figure 2-2) (MROSD 2009b). The preserve has eight miles of hiking, bicycle, and horseback riding trails, and is renowned for its spring wildflower displays.

La Honda Creek OSP is 5,711 ac and consists of working ranch land, grasslands, and forests near the town of La Honda (MROSD 2009c). It is comprised of the upper La Honda Creek Preserve and Driscoll Ranch. La Honda Creek OSP contains redwood and Douglas fir forests to the north, grasslands to the south, and portions of La Honda, Harrington, and Bogess creeks (DCE 2007). MROSD is creating a 30-year Master Plan for La Honda Creek OSP that aims to balance the preservation of viable agriculture, cultural history, and the natural environment with public education and low-intensity recreation (MROSD 2009c).

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[5] Informal communication with CAL FIRE foresters indicates that only one Timber Harvesting Plan (on Harrington Creek) has been filed in the watershed within the last 10 years

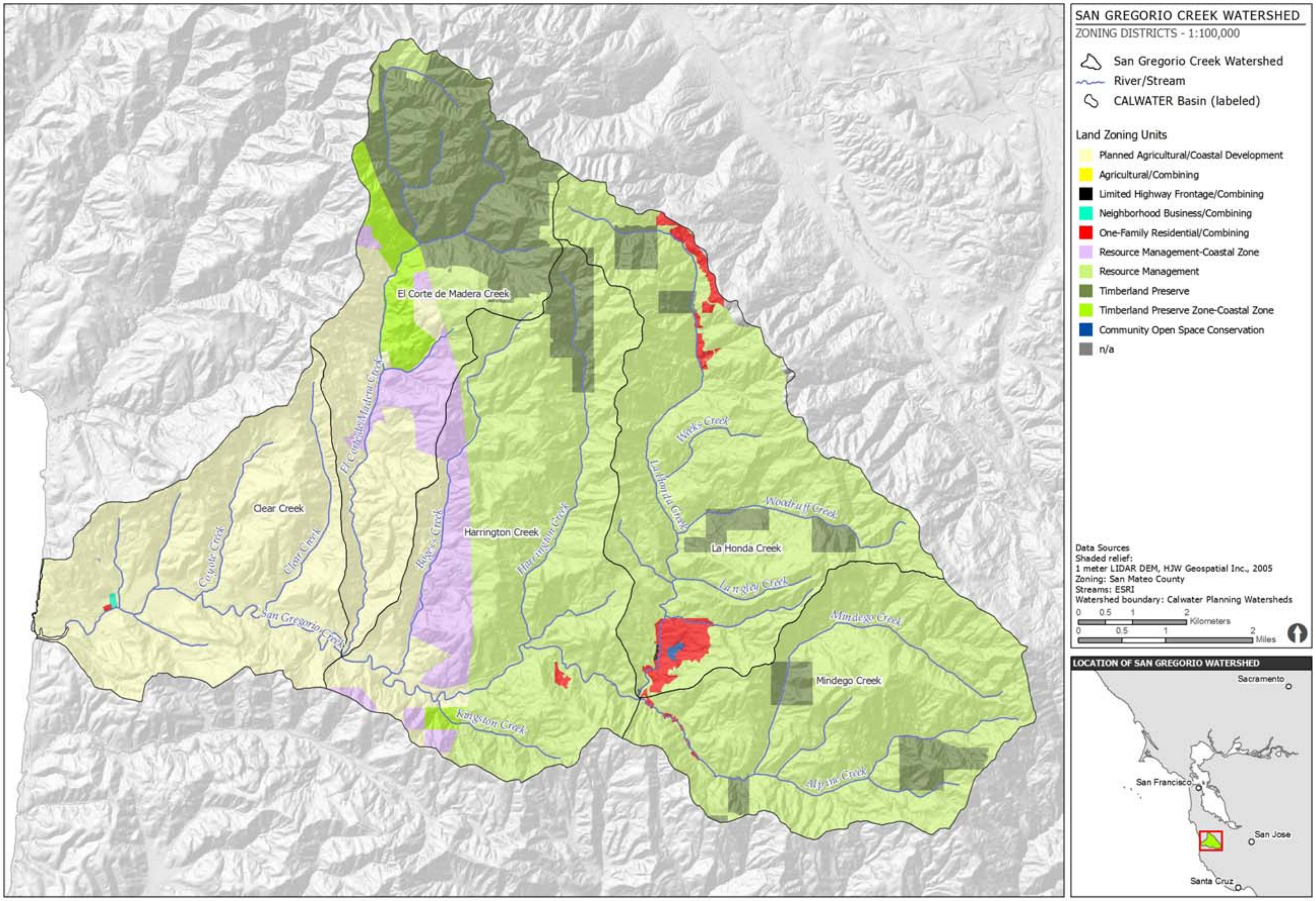

Figure 2-4. Zoning districts in the San Gregorio Creek watershed.

Table 2-2. Zoning districts within the San Gregorio Creek watershed.

Zoning code	Zoning district descriptions	Area (ac)
blank	n/a	4
A-1/S-9	Agricultural/Combining	0.2
C-1/S-7/DR/CD	Neighborhood Business/Combining/Design Review/Coastal Development	8
COSC	Community Open Space Conservation	14
H-1/S-10	Limited Highway Frontage/Combining	4
H-1/S-11	Limited Highway Frontage/Combining	1
PAD/CD	Planned Agricultural/Coastal Development	8,371
R-1/S-10	One-Family Residential/Combining	325
R-1/S-10/DR/CD	One-Family Residential/Combining/Design Review/Coastal Development	4
R-1/S-11	One-Family Residential/Combining	50
R-E/S-10	Residential Estates/Combining	4
R-E/S-11	Residential Estates/Combining	22
RM	Resource Management	18,187
RM-CZ/CD	Resource Management-Coastal Zone/Coastal Development	1,568
TPZ	Timberland Preserve Zone	4,075
TPZ-CZ/CD	Timberland Preserve Zone-Coastal Zone/Coastal Development	638
Total		**33,276**

Source: San Mateo County

Table 2-3. Property ownership within the San Gregorio Creek watershed.

Ownership	Area (ac)	Percent
Private	17,762	53%
MROSD - La Honda Creek OSP	5,711	17%
MROSD - Russian Ridge OSP	2,800	8%
MROSD - El Corte de Madera OSP	2,648	8%
Non-MROSD Easement	1,669	5%
Land Trust	1,205	4%
Sam McDonald County Park	675	2%
Other Public Agency/Institutional Lands	637	2%
San Gregorio State Beach	97	0.29%
MROSD - Skyline Ridge OSP	52	0.16%
Other Public Open Space (County, State, National)	26	0.08%
MROSD - Windy Hill OSP	20	0.06%
Total	**33,301**	**100%**

El Corte de Madera Creek OSP is 2,648 ac and includes 36 mi of hiking, horseback riding, and bicycle trails (MROSD 2009d). MROSD has undertaken the El Corte de Madera watershed protection program to assess road- and trail-related sources of erosion and plan and implement erosion control activities (MROSD 2009d).

2.4 Climate and Hydrology

2.4.1 Climate

As part of the Santa Cruz Mountains, the San Gregorio Creek watershed generally experiences a Mediterranean climate, moderated by the Pacific Ocean marine layer that is responsible for the regular fog conditions along the north-central California coast. Cooler temperatures predominate in winter between November and March, while the warmest temperatures typically occur during late summer. Average annual air temperatures measured in the middle of the watershed at La Honda range from 4°C (40°F) to 22°C (71°F) (Brady et al. 2004).

Westerly precipitation systems deliver rain to the watershed generally between November and April. In contrast, little to no rainfall occurs between late spring through early fall, which is commonly referred to as the dry season. The majority of rain delivered to the watershed falls on west-facing slopes of relatively high relief, where higher elevation areas receive up to 35 inches and lower areas receive 26 inches (Rantz 1971, Saah and Nahn 1989). Winter storms commonly lead to high flow events and increased sediment input to streams (e.g., from overland flow, sheet-wash, and/or splash erosion), and they can promote landslides (Wilson and Wieczorek 1995).

2.4.2 Hydrology

Stream flow within the San Gregorio Creek watershed can be characterized by the U.S. Geological Survey's (USGS) San Gregorio at Stage Road stream gauge (USGS gauge #11162570), which has an incomplete record from 1970 to 2008[6]. The highest mean monthly flows occur in February and are generally high from December to March (Figure 2-5; Table 2-4), typical for watersheds in this geographic area. The highest recorded peak flows at the San Gregorio Creek at Stage Road stream gauge occurred in January 1982, January 1995, and January 1997 (Table 2-5). However, the gauge was not operating during the December 1955 or February 1998 floods that, according to the USGS gauge on nearby Pescadero Creek (USGS gauge #11162500; which is approximately 4 mi south of San Gregorio Creek), were two of the three highest peak flows since 1950 (January 1982 is the other highest peak flow) (Table 2-5). Long periods of high flows are rare, with most winter storms passing through the watershed relatively quickly (Figure 2-6). The lowest flows occur between July and October, and are frequently below 1 cubic feet per second (cfs) in August and September (Figures 2-5 and 2-6). Notable fluctuations in flow are occasionally measured at the USGS San Gregorio stream gauge during low flow periods. For example, flows will drop from approximately 1 cfs to near zero over a period of a few hours and then return to 1 cfs several hours later. The cause of these fluctuations is unknown, and although specific effects on instream conditions have not been determined, they are expected to be detrimental to fish and their habitat.

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[6] The incomplete period of record available for the USGS San Gregorio at Stage Road stream gauge (#11162570) is October 1970 to September 1994, May 2001 to September 2005, and July 2007 to current.

Table 2-4. Average monthly discharge in lower San Gregorio Creek (as measured at USGS gauge #11162570 for the available period of record).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly average discharge (cfs)	92	103	84	39	13	6	3	2	1	3	22	55

Table 2-5. Peak flows recorded at the San Gregorio Creek and Pescadero Creek stream gauges.

San Gregorio Creek at Stage Road (USGS gauge #11162570)		Pescadero Creek at Pescadero (USGS gauge #11162500)	
Date	**Peak discharge (cfs)**	**Date**	**Peak discharge (cfs)**
4 January 1982	7,910	3 February 1998	10,600
9 January 1995	6,600	23 December 1955	9,420
1 January 1997	6,100	4 January 1982	9,400
2 March 1983	5,440	2 April 1958	7,630
12 February 1992	5,200	26 January 1983	7,550

The San Gregorio Creek watershed likely experienced very low and intermittent flows in the later summer and fall on occasion under historical, unimpaired conditions. The San Gregorio Creek stream gauge record shows that near no-flow conditions can be a regular occurrence in the lower watershed in the months of July, August, and September. For example, the creek was dry (zero flow recorded) at the gauge location every day from July 13 to September 30, 1977 and every day from July 26 to September 30, 1988. While the watershed's climate and setting have a significant bearing on instream flow conditions, instream flows could also be affected by riparian water diversions and groundwater pumping. The magnitude of this effect is not currently known, but during below-normal water years the available water supply can be insufficient to meet all the water rights allocations in the watershed and provide instream flows for aquatic species[7]. As a result, the watershed was adjudicated in 1993 (Superior Court of San Mateo, Decree #355792), and the rights of all users to divert water within the watershed have been codified through the court decree. For each water right, the adjudication defines the type of water usage, the priority for delivery, the volume of annual allowable diversions, the time period during which diversions are permitted, and the associated point of diversion. In addition, under the adjudication all new water diversions (or activation of unexercised riparian rights) in the watershed are subject to the maintenance of minimum bypass, or instream flows, as measured at the USGS gauge. These minimum instream flows are:

- 10 cfs from 1 December to 30 April (except the entire creek flow shall be bypassed for 5 consecutive days after a storm causes streamflow to rise above 50 cfs);
- 10 cfs from 1 May to 15 June when the sand bar at the mouth of San Gregorio Creek is open;
- 2 cfs from 1 May to 15 June when the sand bar is closed; and
- 2 cfs or the entire streamflow, which ever is less, from 16 June to 30 November.

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[7] Of the 28 focus watersheds in the draft coho recovery plan, San Gregorio Creek was identified as potentially having the most serious water diversion issues (NMFS 2010).

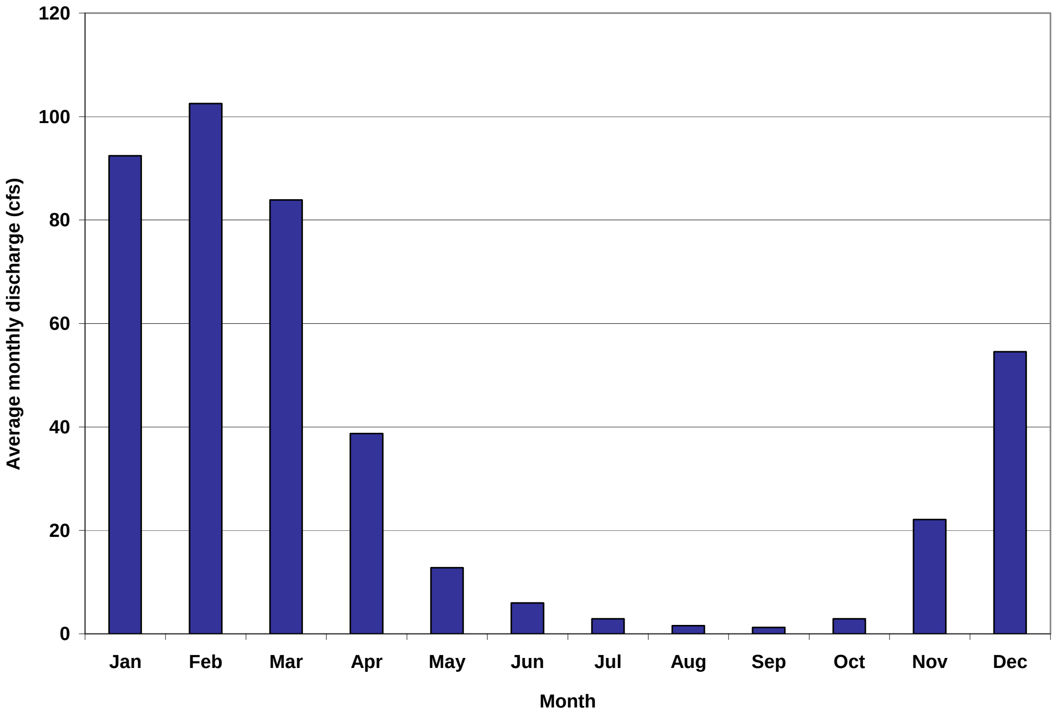

Figure 2-5. Average monthly discharge for the USGS San Gregorio gauge (#11162570) for the period of record October 1970 to September 1994, May 2001 to September 2005, and July 2007 to September 2008.

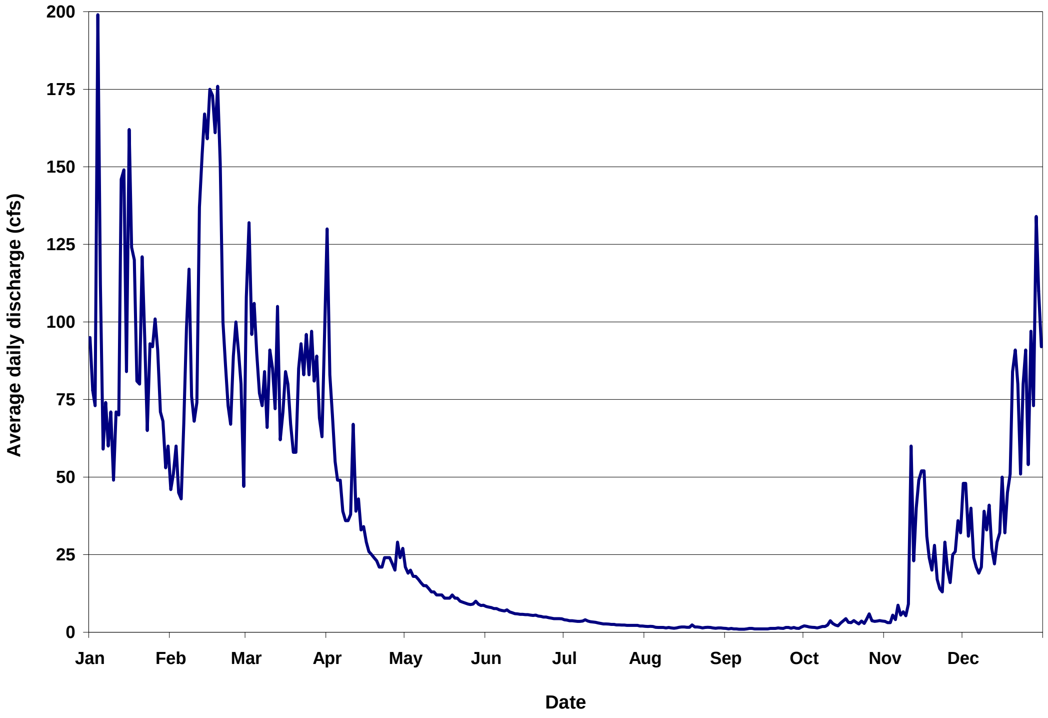

Figure 2-6. Average daily discharge for the USGS San Gregorio gauge (#11162570) for the period of record October 1970 to September 1994, May 2001 to September 2005, and July 2007 to September 2008.

A water master has been appointed, and receives limited funding, to assist the Court in its enforcement of the adjudication, including assessment and inventorying of existing water diversions, working with riparian diverters to monitor their diversions, and implementing diversion priorities during dry water years. Further, pursuant to Public Resources Code Section 10004, CDFG recently ranked lower San Gregorio Creek as its third highest priority in the state for assessment of flow conditions in order to develop recommendations on the quantity and timing of necessary instream flows for fisheries protection (Wilcox 2008). A more detailed discussion of hydrology and water use in the watershed is provided in Section 3: Hydrologic Assessment.

2.4.3 Groundwater

This section summarizes conditions of the San Gregorio groundwater basin based on the more detailed assessment prepared by Zatkin and Hecht (2009) (see Appendix A) unless otherwise cited.

The San Gregorio Creek valley is a recognized groundwater basin (#2–24), with the designated beneficial uses of municipal and agricultural water supply (San Francisco Bay Region Water Quality Control Board [SFBRWQCB] 2007b). In upper watershed areas, groundwater storage may also exist in substantial quantities within large landslide masses and within localized, often discontinuous bedrock aquifers. Fractures in bedrock and/or the concentration of groundwater in a shallow aquifer (i.e., bounded at depth by an impervious layer, such as bedrock or a clay lens) can result in the appearance of springs, or seeps, at the ground surface. Several groundwater seeps are located within the La Honda Creek OSP (DCE 2007), and the USGS has mapped groundwater seeps along San Gregorio State Beach, where groundwater that seeps from the cliff face softens and loosens otherwise resistant bedrock material and contributes to coastal erosion processes (Lajoie and Mathieson 1998). Recharge of the groundwater basin, or the refilling of the aquifer with percolated surface water, is thought to occur primarily in the wetter eastern and southern portions of the watershed.

The number of individual landowners in the watershed who maintain groundwater wells for residential and irrigation water supply is not known. The total number of wells in the watershed between 2006 and 2008, as contained within San Mateo County Environmental Health Division (EHD) records, was estimated at 311 (Table 2-6). The vast majority of these (79%) are situated in the eastern half of the watershed, which primarily acts as an area of groundwater recharge to the basin aquifer in the valley.

Table 2-6. The number and general location of groundwater wells in the San Gregorio Creek watershed.

Area of watershed	Number of wells
Woodside	76
La Honda	169
San Gregorio	66

Source: San Mateo County EHD; see Appendix A

Because the water rights within the watershed are adjudicated, riparian diversions have been allocated to specific users. Accordingly, new water users will likely rely on other water sources, such as groundwater. Applications for new wells are made with the San Mateo County EHD, who typically reviews approximately 20 applications for new wells in the watershed every year

(A. Richards, pers. comm., 2009). While Section 4.68.250 of the San Mateo County Ordinance Code requires meters on all permitted groundwater wells used for domestic water supply (San Mateo County 2009), this is rarely enforced or monitored in the County (Kleinfelder 2008). It is suspected that groundwater withdrawals may have an effect on instream flows during low flow and dry periods (A. Richards, pers. comm., 2009), but there is no information available on groundwater conditions, patterns, or the interaction between groundwater and streamflows in the watershed.

Information on groundwater quality is also relatively sparse compared with other coastal watersheds. However, mineral concentrations and related salinity levels in the groundwater basin are thought to be high as compared to other basins in San Mateo County. Overall, water quality in the watershed can be affected by geologic unit properties, resident time in storage, land use practices, and saltwater intrusion from ocean waters (Fetter 2001). The county is presently compiling water quality data, including concentrations of chloride, nitrate, bacteria, and salinity, which will be useful for watershed management in the future.

2.5 Geology and Geomorphology

2.5.1 Geology and tectonics

The San Gregorio Creek watershed lies adjacent to the San Andreas Fault Zone, a geologically active area of strike-slip (transverse) movement between the Pacific and North American tectonic plates (Figure 2-7). The occurrence of distinct geologic rock units and the position of San Gregorio Creek, its tributaries, and un-channeled valleys are strongly influenced by the geologic structure and the location of the active faults in the watershed. In general, the watershed is underlain by folded, massively bedded sedimentary rocks of Pliocene to Eocene age (2–50 million years ago [Ma]) and more recent Holocene to Pleistocene (0–2 Ma) stream-terrace and alluvial deposits. The main trace of the San Andreas Fault Zone lies approximately three kilometers to the east of the watershed boundary, while associated faults orientated parallel or subparallel to the primary fault zone cut through the watershed, including the San Gregorio, La Honda, and Wood Haven faults (Brabb et al. 1998). The largest of these local faults is the San Gregorio Fault, which crosses the creek at its downstream end. Movements along these active faults, coupled with saturated soils following large winter storms, have historically triggered debris flows in the watershed (Wieczorek 1982, Wieczorek and Keefer 1984).

Lateral offsets along the predominately strike-slip faults in the watershed are clearly demonstrated by the juxtaposition of various rock units, each with unique stratigraphic histories and physical properties. Accordingly, the watershed overlays four fault-bounded geologic assemblages—Pigeon Point, Montara Mountains, Sky Londa, and Mindego Hill—each containing a stratigraphic sequence marked by unique variations in depositional conditions (Brabb et al. 1998). The sedimentary rock units contain varying amounts of sandstone, siltstone, and shale having moderate to very high erodibility (Table 2-7) (Brown 1973). Nearly all major tributaries to the San Gregorio—El Corte de Madera, Harrington, La Honda, and Alpine creeks—drain through these rock units in the three upper assemblages. Highly erodible units, particularly the Lambert Shale and Vaqueros Formation in the Sky Londa and Mindego Hill assemblages, are present in the steeper areas of the upper watershed. Also present in this portion of the watershed are relatively resistant shales and claystones of the Monterey Formation, in addition to the only non-sedimentary rock unit in the watershed, the Mindego Basalt (Brabb et al. 1998).

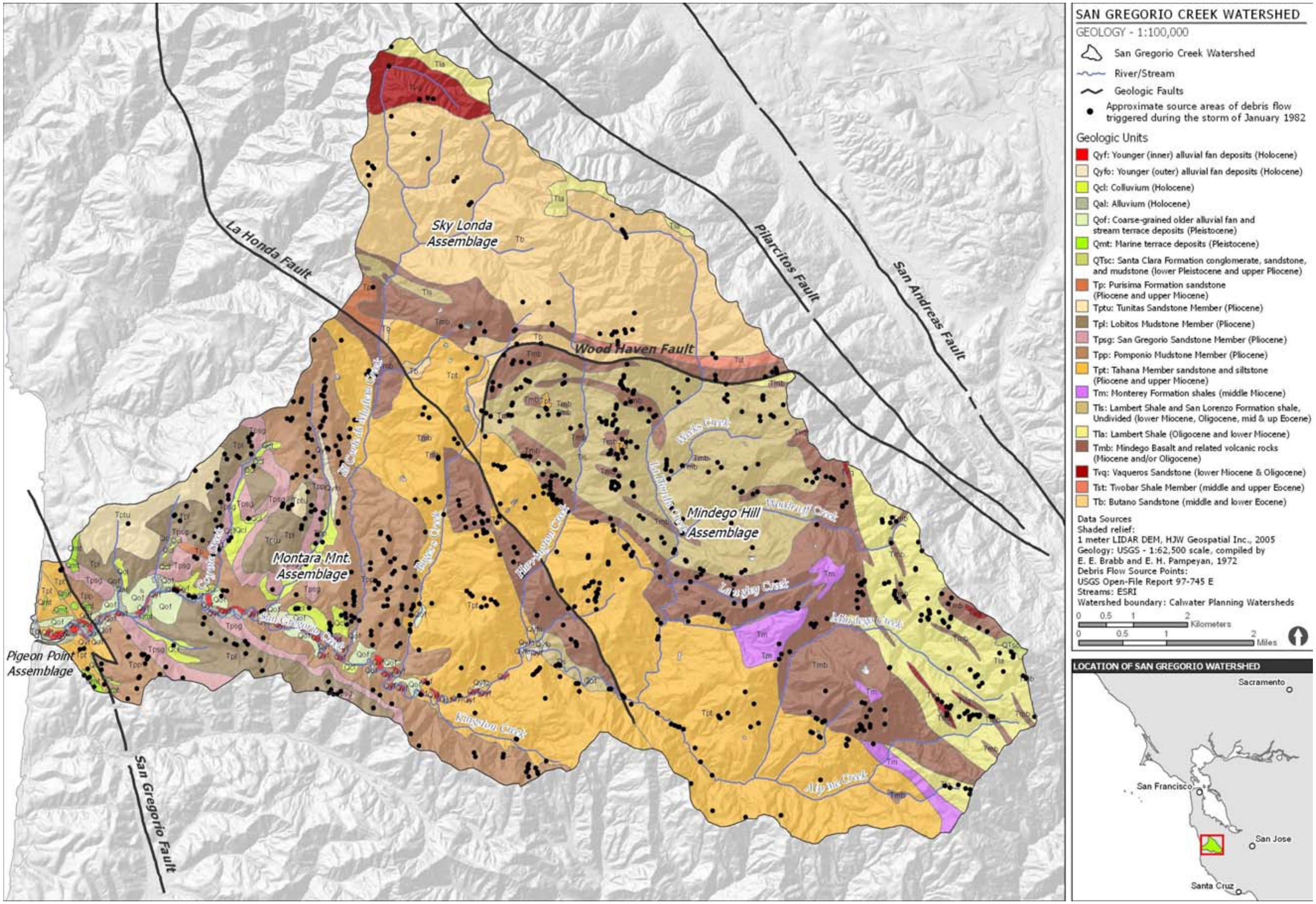

Figure 2-7. Rock units, faults, and debris flows in the San Gregorio Creek watershed.

Table 2-7. Geologic units in the San Gregorio Creek watershed.

Geologic unit		Area			Total (%)
Abbr.	**Description**	**km^2**	**mi^2**	**ac**	
Qal	Alluvium (Holocene)	0.4	0.2	105	0.3
Qcl	Colluvium (Holocene)	2	1	446	1.3
Qmt	Marine terrace deposits (Pleistocene)	0.3	0.1	69	0.2
Qof	Coarse-grained older alluvial fan and stream terrace deposits (Pleistocene)	2	1	381	1.1
QTsc	Santa Clara Formation (lower Pleistocene and upper Pliocene)	0.1	0.0	27	0.1
Qyf	Younger (inner) alluvial fan deposits (Holocene)	0.6	0.2	139	0.4
Qyfo	Younger (outer) alluvial fan deposits (Holocene)	0.3	0.1	80	0.2
Tb	Butano Sandstone (middle and lower Eocene)	20	8	4,914	14.7
Tla	Lambert Shale (Oligocene and lower Miocene)	9	4	2,249	6.7
Tls	Lambert Shale and San Lorenzo Formation, Undivided (lower Miocene, Oligocene, and middle and upper Eocene)	15	6	3,799	11.4
Tm	Monterey Formation (middle Miocene)	2	1	442	1.3
Tmb	Mindego Basalt and related volcanic rocks (Miocene and/or Oligocene)	21	8	5,194	15.6
Tp	Purisima Formation (Pliocene and upper iocene)	0.5	0.2	124	0.4
Tpl	Lobitos Mudstone Member (Pliocene)	6	2	1,365	4.1
Tpp	Pomponio Mudstone Member (Pliocene)	13	5	3,228	9.7
Tpsg	San Gregorio Sandstone Member (Pliocene)	4	2	1,005	3.0
Tpt	Tahana Member (Pliocene and upper Miocene)	35	13	8,601	25.8
Tptu	Tunitas Sandstone Member (Pliocene)	2	1	488	1.5
Tst	Twobar Shale Member (middle and upper Eocene)	0.6	0.2	143	0.4
Tvq	Vaqueros Sandstone (lower Miocene and Oligocene)	2	1	455	1.4
H_2O	Water	0.2	0.1	50	0.1

The decomposition of these rock units into their constituent materials (e.g., sand, silt, or clay and rock fragments) over time involves a combination of chemical weathering, biogenic processes (e.g., tree throw and gopher burrowing), landslides, and direct erosion of bedrock exposed in stream channels. These first two processes contribute directly to the production of soil in the watershed, which mantles hillslopes and accumulates as colluvium within hollows at channel headwaters until released episodically as landslides (Figure 2-7). Deep-seated landslides (another mechanism by which bedrock is converted into soil) also occur in the watershed.

Toward the lower watershed along the mainstem San Gregorio Creek in the Montara Mountains and Pigeon Point assemblages, the underlying geology is composed of Quaternary stream-terrace and alluvial deposits and some upper Tertiary siltstones and fine-grained sandstones (Figure 2-7). These geologically young units are generally poorly lithified (i.e., characterized by sediments having relatively low strength and cohesiveness) and are typical of sediment deposited along actively migrating or incising channels in lowland floodplain valleys. The presence of stream terraces in this watershed expresses the long-term episodic tectonic uplift in the region, whereby the terrace surfaces correspond to ancestral and now-stranded floodplain elevations in the watershed.

2.5.2 Sediment sources

This section describes the primary sediment source areas in the San Gregorio Creek watershed determined through analysis of existing maps and modeling of potential shallow landslides. Two existing digital databases of landslides and earth flows compiled by the USGS (Ellen et al. 1997, Wentworth et al. 1997) that include the San Gregorio Creek watershed were used to characterize historical landsliding in the basin. Historical instability is relevant because future movement of landslides is most likely to occur within and around the places where they have previously occurred. Results are compared to geology and land use in the watershed to identify spatial trends in sediment source areas.

In addition to landsliding, erosion from roads, trails, and streambanks, as well as run-off from adjacent residential and agricultural lands, also supply sediment—primarily sand and silt, but some gravel as well—to the watershed. While a large proportion of the watershed has been inventoried for road- and trail-related sediment sources, few of these inventories characterize the volume or rate of sediment supplied to the channel by these sources. Studies in El Corte de Madera OSP and along La Honda Creek are the exceptions. A multi-year study of sedimentation in El Corte de Madera Creek estimated that approximately 20% of sediment delivery to the creek may come directly from actively-used roads and trails, whereas the remaining 80% or so likely originates from more “natural” sources of sediment such as landslides, bank failures, and debris flows (Balance Hydrologics 2006a). Brady et al. (2004) assessed erosion and fine sediment supply from Highway 84 to a portion of La Honda Creek. The study found that runoff from Highway 84 did not appreciably increase turbidity (i.e., suspended sediment) in La Honda Creek, and that the main source of sediment supplied to the creek is from landsliding. That said, local residents frequently observe silt-laden runoff from roads, including Highway 84, Alpine Road, and other County-maintained roads, as well as privately-maintained roads, during rain events.

Bank erosion in the upper watershed is driven by re-directed flow around landslide deposits towards banks and by bank oversteepening and destabilization due to channel incision (i.e., bed lowering). Bank erosion rates measured by Brady et al. (2004) along La Honda Creek were found to vary from a few inches per year up to 7 in/yr, and they concluded that modifications made to accommodate Highway 84 and to protect private property have significantly modified the lower reaches of the channel, causing accelerated bank erosion and the release of sediment into the channel. Lower in the watershed, revetment of County-maintained roads such as Highway 84, Alpine Road, and others, which is designed to protect the base of the road from streambank erosion, has been frequently observed to increase bank erosion on the opposite downstream streambank.

2.5.2.1 Shallow landslides

Weathering of exposed and subsurface bedrock produces soil that, by means of soil creep and biogenic disturbances (e.g., tree throw and gopher burrowing), accumulates as colluvium in regularly spaced un-channeled hollows near the ridgecrests (Reneau et al. 1984). These colluvial deposits are the focus of gullying and episodic landslides, which typically occur during large storm events, but their downslope movement also can be triggered by earthquakes (Wieczorek and Keefer 1984). During large storms, landslides occur when increased pore water pressures and saturation overland flow, resulting from groundwater concentrating in the hollows, destabilize the colluvial deposits along the soil−bedrock interface (Wilson et al. 1989). For example, El Niño storms in January 1982 triggered over 850 debris flows[8] in the San Gregorio

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[8] Shallow landslides typically only involve the soil mantle and commonly occur at or near the soil-bedrock boundary. These landslides may mobilize and travel a short distance downslope before coming to rest either still on the hillside or

Creek watershed (Ellen et al. 1997) (Figure 2-7). Mapping of the debris flows following the 1982 storm (Ellen et al. 1988, 1997) provide an example of the abundance of landslides that might be expected during a major rainstorm, and where they are likely to occur (Figure 2-7). Overall, debris flows are the dominant source of sediment to the upper tributaries of the San Gregorio watershed (Balance Hydrologics 2006b).

The relative potential for shallow landsliding was estimated using a digital elevation model (DEM) based on 33 ft topographic data and Shalstab, a model that predicts the relative potential for shallow landsliding by identifying areas where groundwater flow is concentrated during storms, thereby increasing the probability of a shallow landslide (Figure 2-8) (Dietrich et al. 2001). Assessing the relative potential for shallow landsliding can help identify where future instability is likely to occur, and provide comparisons to geology, land use, and existing maps of debris flows in the region (e.g., Ellen et al. 1997). Shalstab is based on the physical processes of subsurface runoff and slope instability, with high hazard potential predicted where little subsurface runoff is needed to generate a landslide, and low potential where much is needed. Shalstab's primary input (as used in this analysis) is topographic data and it does not explicitly include geology or land use data; although, different geology and land uses may produce different topographic signatures that are reflected in the DEM. It does not estimate the rainfall intensity needed to trigger debris slides, but it does tend to identify areas where shallow landsliding is most likely to occur. It also does not account for the local effects of road construction or other land use activities~~.~~

Based on comparisons with landslide occurrence elsewhere (Dietrich et al. 2001), Shalstab data were classified into five hazard classes: stable areas, low instability areas, moderate instability areas, high instability areas, and chronic instability areas. Areas classified as "stable" are locations where the landscape is not sufficiently steep to expect shallow landslides to occur. Deep-seated landslides involving the underlying bedrock may occur in such areas but are not included in the model. The shallow landslide hazard modeling showed that most of the San Gregorio Creek watershed (67.9%) is stable, 9.4 % is predicted as moderately unstable, and that only about 4.4% is predicted as chronic or high instability (Table 2-8, Figure 2-8). The areas of highest instability tend to occur in the headwater regions of the El Corte de Madera, La Honda, and Mindego Creek sub-basins (Figure 2-8). Shalstab results are a theoretical prediction of where shallow landslides are most likely, and can be used to help stratify appropriate locations for restoration or enhancement projects in the watershed. For example, repairing or decommissioning roads in areas predicted as chronically or highly unstable could reduce the likelihood of roads exacerbating instability in those areas. In contrast, some types of in-stream habitat enhancement projects (e.g., gravel placement) may not be appropriate in these same areas since the benefit of enhancement projects could be undermined by localized high sediment inputs from shallow landslides[9].

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in a nearby channel. Other landslides may mobilize into a debris flow and enter a channel at sufficiently high momentum and on a sufficiently steep slope that they travel a great distance down the channel network, commonly scouring the channel to bedrock and depositing a massive amount of sediment downstream (e.g., Dietrich and Dunne 1978, Pierson 1977, Benda and Dunne 1997).

[9] Other types of habitat enhancements (such as the placement of LWD to promote localized channel bed scour) may be appropriate.

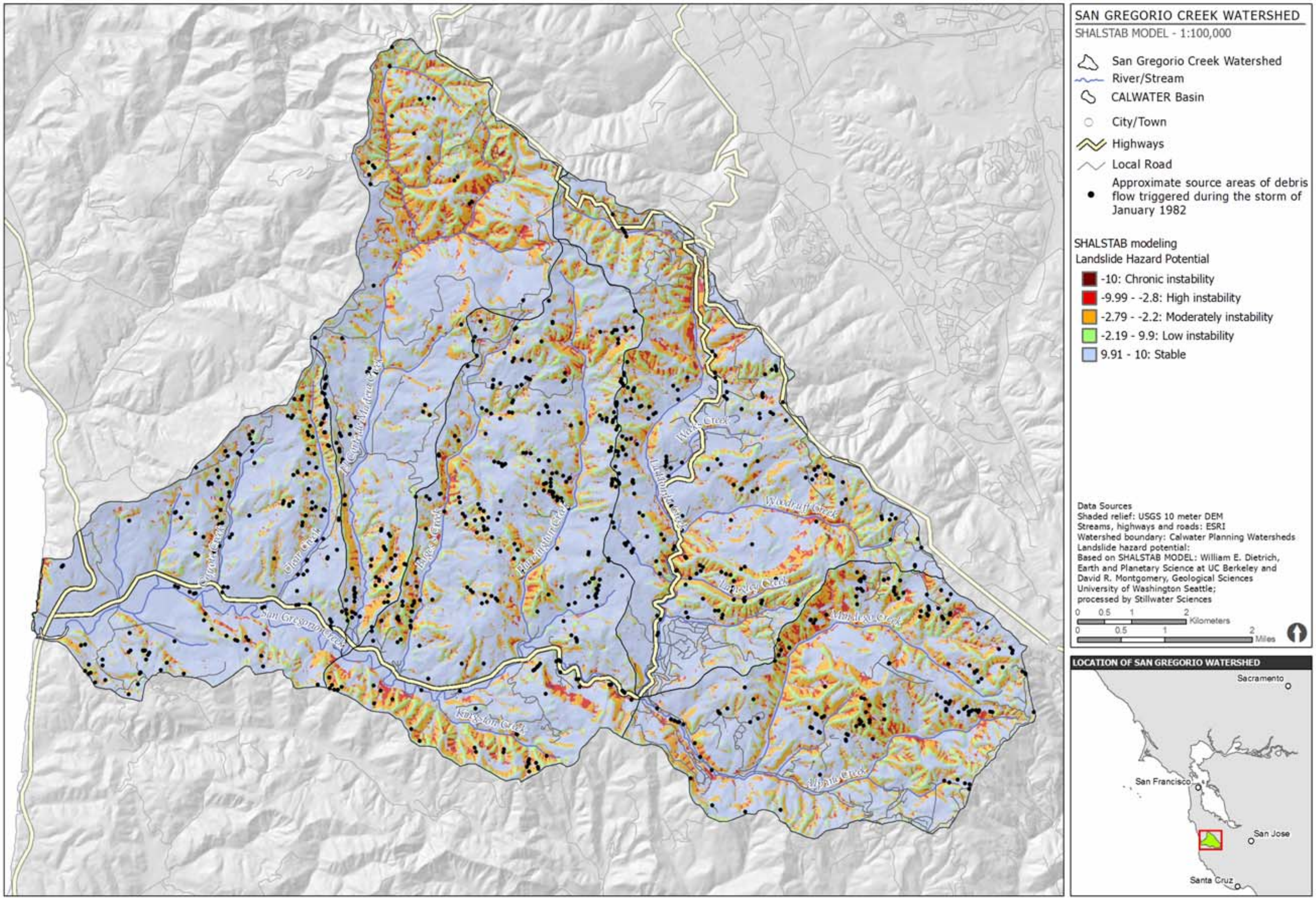

Figure 2-8. Landslide hazard areas in the San Gregorio Creek watershed, as predicted by Shalstab.

Table 2-8. Landslide hazard areas in the San Gregorio Creek watershed, as predicted by Shalstab.

Hazard class	Area (ac)	% of total area
Chronic instability	49	0.1
High instability	1,433	4.3
Moderate instability	3,114	9.4
Low instability	6,054	18.3
Stable	22,487	67.9

The location and frequency of mapped debris flows are somewhat correlated with geology (Figure 2-7, Table 2-9). The highest densities of debris flows triggered during the 1982 storm occurred in geologic units that weather easily and deeply, such as Pomponio Mudstone, Lambert Shale, San Lorenzo Formation, and Lobitos Mudstone. These erodible geologic units are likely made more unstable due to the watershed's tectonic activity and rainfall patterns that are punctuated by orographic effects of storm clouds being forced over the Santa Cruz Mountains.

Table 2-9. Occurrence and density of 1982 debris flows by geologic unit, and the percent of each geologic unit predicted to be unstable by Shalstab.

Geologic unit	Area (km^2)	% of area predicted as highly unstable[1]	No. of 1982 debris flows[2]	Density of debris flows (#/km^2)	% of debris flows in highly unstable area[3]
Tpt: Tahana Member (Pliocene and upper Miocene)	35	3	175	5	2
Tmb: Mindego Basalt and related volcanic rocks (Miocene and/or Oligocene)	21	7	164	8	7
Tpp: Pomponio Mudstone Member (Pliocene)	13	4	157	12	4
Tls: Lambert Shale and San Lorenzo Formation, Undivided (lower Miocene, Oligocene, and middle and upper Eocene)	15	3	131	9	3
Tla: Lambert Shale (Oligocene and lower Miocene)	9	5	74	8	8
Tpl: Lobitos Mudstone Member (Pliocene)	6	2	48	9	2
Tb: Butano Sandstone (middle and lower Eocene)	20	7	36	2	11

[1] Percent of area predicted as chronic or highly unstable by Shalstab
[2] Ellen et al. 1997
[3] Percent of 1982 debris slides occurring within an area predicted as chronic or highly unstable by Shalstab

The geologic units with the highest percentage of unstable areas predicted by Shalstab (i.e., Butano Sandstone and Mindego Basalt) tended not to be the units with the highest density of mapped debris flows in 1982 (Table 2-10). This suggests that aspects of geologic unit erodibility are not reflected in the topography that drives the Shalstab predictions. Of particular interest are the Butano Sandstone that appears to have a lower frequency of debris flows than predicted by

Shalstab, and the Pomponio and Lobitos mudstones that appear to have a higher frequency of debris flows than predicted.

In addition to topography and geologic unit, land use also appears to influence the frequency of debris flows. Shalstab, which is based on topography, predicted more than three times as much chronically and highly unstable area within forest lands as compared to rangeland (Table 2-10). But this was not the case in 1982; the density of debris flows in rangeland was more than double that of forest lands (Table 2-10).

Table 2-10. Occurrence and density of 1982 debris slides by land use, and the percent of each land use area predicted to be a debris slide source area by Shalstab.

Land use	km^2	% of area predicted as highly unstable[1]	# of debris slides[2]	Density (#/km^2)	% of slides predicted as source area[3]
Agricultural land	0	0	0	0	0
Barren land	0.1	5	0	0	0
Forest land	66	7	271	4	9
Rangeland	66	2	568	9	3
Urban or built-up land	0.4	1	4	11	0
Wetland	2	3	13	6	0

[1] Percent of area predicted as chronic or highly unstable by Shalstab
[2] Ellen et al. 1997
[3] Percent of 1982 debris slides occurring within an area predicted as chronic or highly unstable by Shalstab

Some of the discrepancy between Shalstab predictions and 1982 debris flows based on land use may be explained by the coupling of geology with land uses. For example, the Butano Sandstone (which is the geologic unit with the lowest density of 1982 debris flows; Table 2-8) supports almost entirely forested areas (see Figure 2-15) (Wentworth et al. 1997). Similarly, the majority of the apparently more erosive Pomponio and Lobitos Mudstones occur in the lower portions of the watershed where rangeland is the more prevalent land use. Without additional analysis is not possible to differentiate whether geology or land use is the predominate variable controlling the different densities of 1982 debris flows. These results do, however, suggest that land use influences debris flow occurrence and potential sediment delivery, and that a simple model that ignores this factor will not fully describe the factors important to sediment delivery in the watershed.

2.5.2.2 Deep-seated landslides

Wentworth et al. (1997) compiled a digital database distribution of landslide and earth flow events in the San Francisco Bay Area region (including San Mateo County), the majority of which are slumps, translational slides, and earth flows. Original identification and mapping of these landslides was conducted by Nilsen and Wright (1979) through detailed analysis of topography and aerial photographs. Using the Wentworth et al. (1997) database, approximately 60% of hillslope surfaces in the San Gregorio Creek watershed have been mapped as landslide deposits (Figure 2-9). Deep-seated landslides generally take the form of either earthflows or translational-rotational (block) failures (Cruden and Varnes 1996). Deep-seated landslides can underlie large slopes and, if active, can constitute the major source of sediment inputs to stream channels in a watershed (Kelsey 1988, Miller 1995). Because late Holocene (including

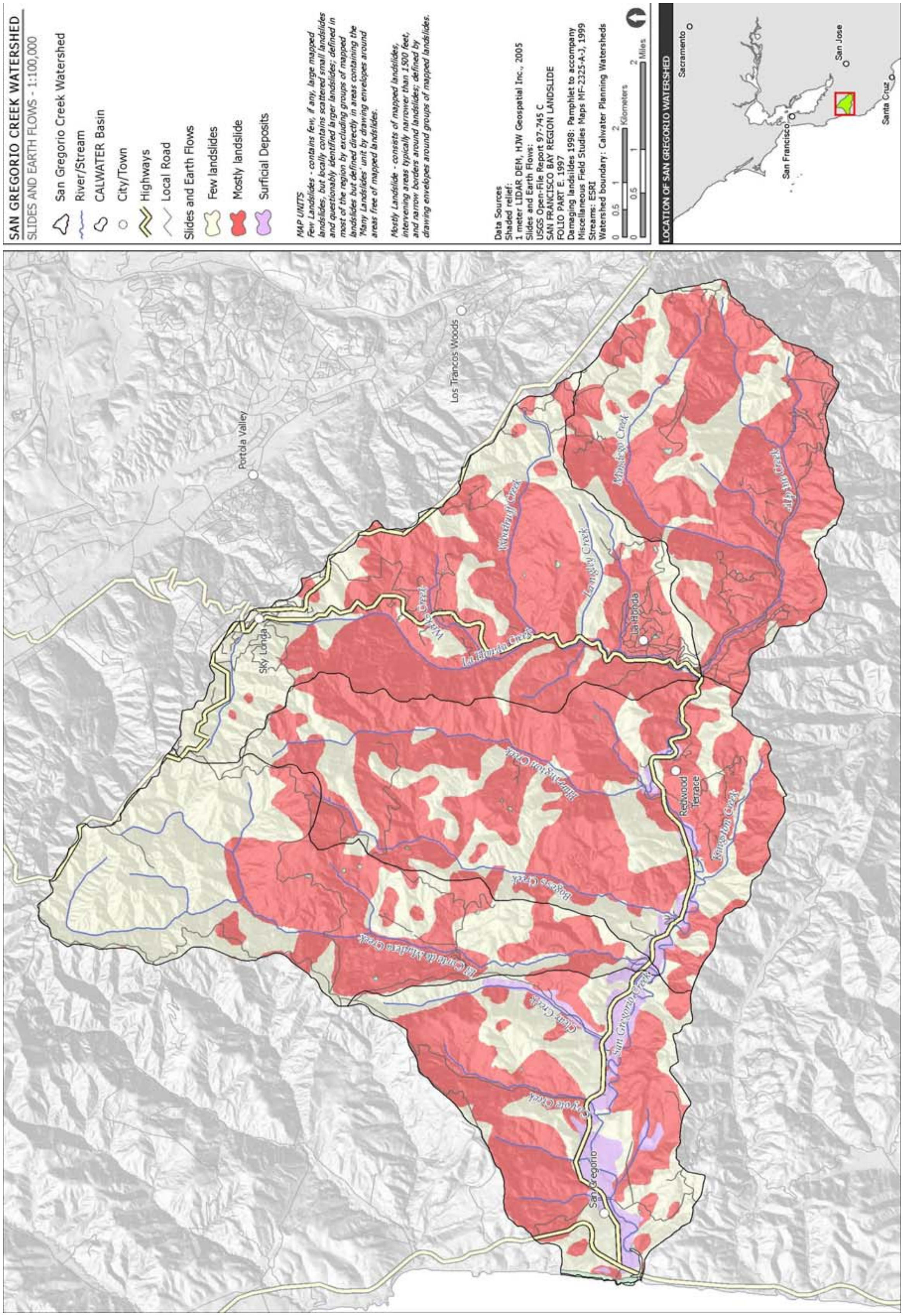

Figure 2-9. Mapped landslides in the San Gregorio Creek watershed (Source: Wentworth et al. 1997).

present-day) climatic conditions are dry compared to the wetter Pleistocene climate under which the landscape has evolved during most of the Quaternary, deep-seated landslides are likely presently less active than they have been during the past 125,000 years. Despite this reduced activity level, not all deep-seated features are dormant; deep-seated landslides in the watershed are known to move occasionally, typically in very wet years, or after many years of above-average rainfall (Ellen et al. 1997). Movement of these features may range from only a few centimeters up to many meters, with most of the displaced mass typically remaining on the hillslope while the toe enters the channel, or while portions of the toe peel off as shallow slides or deepening gullies. Evidence of recent activity of deep-seated landslide complexes within the watershed include the re-activation in January 1998 of a large (1.0 to 1.25 km^2) ancient landslide complex on Scenic Drive near the town of La Honda (Jayko et al. 1998). This ancient slide moved as fast as 20 cm/day in late February 1998 and more recurrent motion was observed in the winters of 2005 and 2006 (Jayko et al. 1998, Wells et al. 2005, Wells et al. 2006). Sediment delivery from deep-seated features to the channel network is typically accomplished by secondary landsliding (e.g., slumping, shallow translational sliding, gullying) where the channel impinges on the toe of the deep-seated feature (Best 2007).

2.5.3 Geomorphology

Generally, the hillslopes and stream channels in the San Gregorio Creek watershed are morphologically similar to those found throughout the majority of central California coastal watersheds. The upper reaches are characterized by narrow, steep-walled canyons, with perennial and intermittent streams, that are covered by relatively thin soils and dense conifer and hardwood stands. At mid-elevations, the steep canyons transition into gently rounded, convex upland ridges mantled by thick colluvium and shrub and oak woodland vegetation. Both terrains drain into a moderately wide, low-gradient floodplain valley where San Gregorio Creek meanders as a single-thread, entrenched channel towards the ocean.

The alluvial reach of lower San Gregorio Creek runs approximately 12 mi downstream through a moderately wide (0.3 km), low-gradient valley bottom to its mouth at the ocean. A narrow but dense riparian corridor borders the creek, providing bank strength and the potential for local recruitment of LWD (primarily of small and short-lived alder). Channel incision in lower San Gregorio Creek has lowered the channel bed approximately 13–20 ft (as estimated at USGS gauge #11162570) below the valley floor, effectively disconnecting the channel from its historical floodplain. Channel incision is likely predominantly due to historical anthropogenic land use associated with land conversion and logging in the late 19th and early 20th centuries, although active channel degradation has been observed recently in La Honda Creek (Brady et al. 2004). Peak flows in winter now rarely inundate the floodplain according to the San Gregorio Creek at Stage Road stream gauge (USGS gauge #11162570). Although flows potentially great enough to drive morphologic change still occur, reach-scale bank erosion is generally too infrequent and spatially discrete to promote active channel migration through the valley bottom. As a result, the primary source of sediment transported through this reach is from upland sources rather than from locally eroded banks. The seasonality of discharge and sediment flux downstream (i.e., predominantly during winter storms) facilitate onshore sediment transport and deposition from wave action resulting in the formation of a sandbar across the mouth of the estuary, which becomes closed during late spring, summer, and fall (U.S. Fish and Wildlife Service [USFWS] 2006).

2.5.3.1 Channel morphology

River channels show distinct bed morphologies in response to their capacity to transport sediment, the supply of available sediment, links to hillslope processes, and external forcing by valley confinement (Montgomery and Buffington 1997). In low-order (e.g., headwater) streams, relatively steep gradients (3–10%) and narrow valleys result in channels where sediment transport capacity exceeds the sediment supply, leaving bedrock cascades and large clasts that form a step-pool channel morphology (Montgomery and Buffington 1997). Fine sediment is transported from cascade reaches but is stored in step pools, along the channel margins, or near boulders and LWD. Plane-bedded channels typically occur in relatively steep gradients (1–3%) where rivers are unable to form pools and riffles because of relatively low width-to-depth ratios and coarse bed substrates that diminish lateral flow (Montgomery and Buffington 1997). "Forced" pool-riffle bed morphologies can form in plane-bedded environments in the presence of flow obstructions, such as LWD (Montgomery et al. 1995). Channel gradients less than 1% support plane-bedded and pool-riffle channel morphologies, with or without flow obstructions. The presence of pool-riffle channels is influenced by the grain size, with smaller sediment favoring the formation of pool-riffle sections, and by the presence of LWD, which would be a major factor of pool formation in channels of intermediate gradient. Channel gradient is used below as an indicator of channel morphology, to predict characteristic grain size, and by inference, locations of suitable aquatic habitat.

Channel gradient in the watershed was calculated within a GIS by overlaying the channel network on 10 m USGS topographic data (Figure 2-10). These data tend to predict slopes that are greater (more steep) than the actual channel slope, particularly near tributary junctions, due to interpolation errors between the relatively flat mainstem valley floor and steeper tributary canyons, but provide a general picture of channel gradient and associated morphology found within the watershed. Most of the stream length in the watershed possesses gradients greater than 0.1 (Table 2-11), which occur in first and second-order channels that are tributary to major sub-basins (e.g., Bogess, Harrington, El Corte de Madera, La Honda, and Mindego creeks) and are likely ephemeral, hydrologically connected and contributing sediment and organic material to the channel network during storms. Despite being ephemeral, the seasonal contribution of water and sediment from high-gradient tributaries is critical in shaping the steep, incised upland tributary reaches with alternating step-pool, plane-bedded, and pool-riffle sequences, that flow into lowland plane-bedded and pool-riffle tributary mouths and mainstem reaches (Figure 2-10). Primary sub-basin streams are generally third-order channels, with gradients typically ranging from 3 to 10% in the upper reaches and 1 to 3% in the lower reaches as they grade towards their confluence with San Gregorio Creek. Based on gradient, the lower, flatter reaches of the primary sub-basin streams are expected to be dominated by plane-bed and pool-riffle morphologies. The mainstem San Gregorio Creek is a fourth-order stream (i.e., downstream of the confluence of Alpine and La Honda creeks) with a gradient <1%, and it is the reach most likely to exhibit pool-riffle morphology within the watershed. While field data were not systematically collected to evaluate these predictions, CDFG stream surveys from 1996–1997 and 2006–2007, and studies conducted in 2008 as part of developing this Watershed Management Plan (Stillwater Sciences 2008, unpubl. data), generally agree with these predictions.

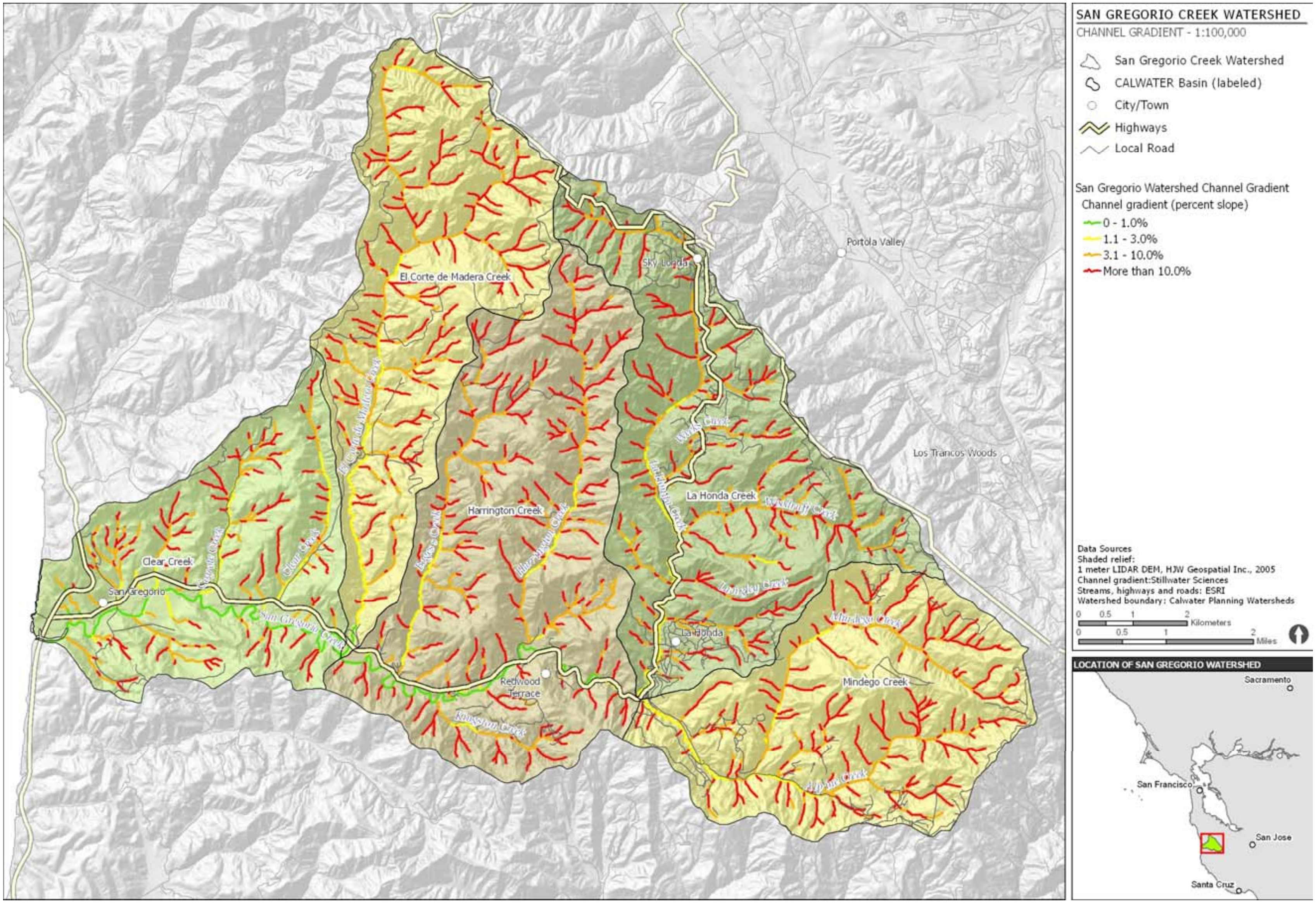

Figure 2-10. Channel gradients in the San Gregorio Creek watershed.

Table 2-11. The extent of channel gradients in the San Gregorio Creek watershed.

Channel gradient	Length	
	km	mi
>0.10	226	140
0.03–0.10	114	71
0.01–0.03	33	20
0.001–0.01	19	12

2.5.3.2 Sediment characterization

Sediment (both coarse and fine) is predominantly delivered to the channel by landslides on steep hillslopes, streambank erosion in the upper watershed, and sediment transported from upstream reaches. Coarse and fine sediment may also be supplied from erosion of the stream-bed, as active channel degradation has recently been observed in La Honda Creek (Brady et al. 2004), but the extensive volume of sediment generated by historical channel incision in lower San Gregorio Creek appears to have transported out of the system. Road- and trail-related erosion also delivers fine sediment to the channel. The beds of channels in the San Gregorio Creek watershed are composed of a full size distribution of sediment, ranging from fines to boulders, in addition to bedrock exposures. All sediment sizes are subject to erosion in the stream channel during subsequent transport downstream; however, shear stresses even during floods are seldom sufficient to transport boulders and coarse cobbles. These coarse particles are therefore often eroded in place rather than abraded during transport.

The median channel-bed grain size was predicted based on the local slope and an estimated bankfull depth (calculated using regional hydrologic relationships with drainage area) (Figure 2-11). These values were incorporated into a “threshold channel”-based formula that uses the dimensionless critical shear stress (the Shields number) and the boundary shear stress at bankfull flow (Buffington 1995, Dietrich et al. 1989, Montgomery and Buffington 1993) to infer a median grain size across the entire channel network that correlates with the size of incipiently transported sediment at bankfull discharge. This predicted grain size tends to systematically over-predict the observed grain size on the channel bed because of major simplifications in the model assumptions. In particular, the additional resistance due to bars, bank irregularities, and LWD that represents a loss in available shear stress to transport sediment is not accounted for in the calculations. We therefore used very broad grain-size categories that are much wider than the likely range of error/uncertainty, and which correspond to biologically-relevant habitat characteristics (e.g., gravel vs. cobble vs. sand) (Table 2-12). Cobble and boulder/bedrock streambeds are expected to have limited salmonid spawning gravel area, whereas we would expect gravel reaches to have abundant spawning gravels. The gravel-sand transition on San Gregorio Creek is likely farther upstream than predicted because of the additional in-channel form resistance not accounted for in the model and limitations of slope estimations in low-gradient areas.

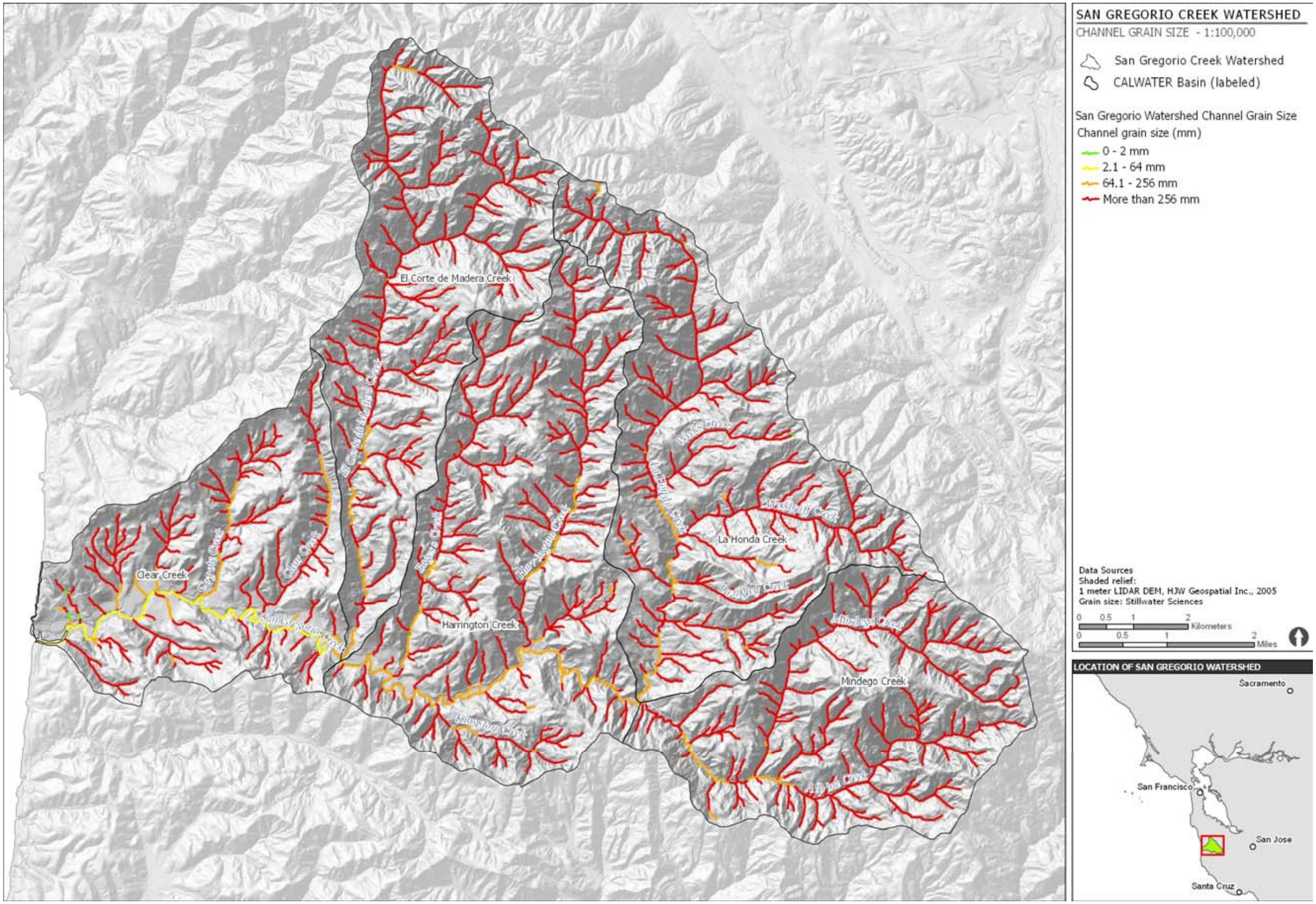

Figure 2-11. Estimated median channel grain sizes in the San Gregorio Creek watershed.

Table 2-12. Predicted median grain size categories distributed by channel gradient within the San Gregorio Creek watershed.

Channel gradient	Grain size category		Length	
	Size (mm)	Description	km	mi
>0.10	>256	Boulder or Bedrock	226	140
	64–256	Cobble	0.003	0.002
0.03–0.10	>256	Boulder or Bedrock	110	68
	64–256	Cobble	4	2
0.01–0.03	>256	Boulder or Bedrock	11	7
	64–256	Cobble	22	14
0.001–0.01	64–256	Cobble	10	6
	2–64	Gravel	8	5
	0–2	Sand/silt/clay	0.4	0.3

A simple pattern emerges from the grain-size calculations and the slope determinations (Figure 2-11). Each of the major tributaries (e.g., Bogess, Harrington, El Corte de Madera, La Honda, and Mindego creeks) is predicted to be mainly boulder bedded, with stretches of cobble. Overall, these channels would tend to have relatively shallow pools and spawning gravels near LWD, bed irregularities, and channel bends, and in shallow pools and at some pool tails. In contrast, much of the length of the mainstem San Gregorio Creek is predicted to have a gravel or cobble bed. Field data were not systematically collected to evaluate these predictions, but observations regarding grain size and channel type contained in CDFG stream surveys from 1996–1997 and 2006–2007, and studies conducted in 2008 as part of developing this Watershed Management Plan (Stillwater Sciences 2008, unpubl. data), generally agree with these predictions.

Due to its geology, rainfall patterns, steep gradients, and tectonic activity, the San Gregorio Creek watershed has the potential for a very high fine sediment yield. This was likely exacerbated by historical logging activities, which often lead to very high rates of fine sediment delivery to stream channels, to the detriment and occasion destruction of instream habitat. Currently, the San Gregorio Creek watershed is listed as impaired for sediment (State Water Resources Control Board [SWRCB] 2006). Locations of potential sources of fine sediment, including bank erosion, landslides, and road-related erosion, are identified in the more contemporary stream surveys and inventories conducted in Alpine, Bogess, and La Honda creeks (Baglivio and Kahles 2006a, 2006b; CDFG 1997a, 1997b; Renger and Dunn 1996). In addition, road-related erosion has been evaluated in detail along El Corte de Madera Creek (Balance Hydrologics 2006a, 2006b, 2007; Best 2002), La Honda Creek (Brady et al. 2004), and in Sam McDonald County Park (Pacific Watershed Associates [PWA] 2003).

Many of the stream surveys and inventories in the watershed indicate some level of substrate embeddedness by fine sediment that may be limiting salmonid spawning quality, although several note that some of the fines would be expected to wash out during the first winter high flow (since the surveys were conducted during summer low-flow periods) (Baglivio and Kahles 2006a, 2006b; CDFG 1985a, 1985b, 1997a, 1997b). Pearce et al. (2007) and Brady et al. (2004) (as cited in Pearce et al. 2007) report high levels of spawning substrate embeddedness in portions of La Honda Creek that may limit spawning success, but attribute most of the embeddedness to in-situ breakdown of mudstone clasts rather than hydraulic deposition of fine sediment. Balance Hydrologics (2006a, 2006b, 2007) documented pool-filling by fine sediment in the El Corte de Madera Creek subwatershed, and Titus et al. (2006) reported pool filling from upslope sediment sources in the watershed in general, and note that this has been reducing available habitat throughout the watershed since the 1970s. In 1985 a massive debris flow in La Honda Creek was observed to result in pool filling and a localized fish kill (L. Ulmer, CDFG, unpublished file letter, 13 October 1987, as cited in Titus et al. 2006).

2.6 Water Quality

Water quality data in the watershed are collected by a range of organizations (Table 2-13). From 2001 to 2003, SFBRWQCB collected water quality data under the surface water ambient water monitoring program (SWAMP). More recently, water quality data is currently being collected by the San Gregorio Environmental Resource Center (SGERC) (beginning in 2003) as well as CDFG (beginning in 2005). Additional information on the designated beneficial uses and water quality criteria for San Gregorio Creek watershed is provided in Appendix B.

The goal of the SWAMP is to monitor and assess watersheds based upon physical, chemical and biological water quality (SFBRWQCB 2007a) in order to:

1. Identify specific problems preventing the SWRCB, Regional Water Quality Control Boards (RWQCBs), and the public from realizing beneficial uses (Appendix B) in targeted watersheds.
2. Create an ambient monitoring program that addresses all hydrologic units of the State using consistent and objective monitoring, sampling and analysis methods; consistent data quality assurance protocols; and centralized data management.
3. Document ambient water quality conditions in potentially clean and polluted areas.
4. Provide the data to evaluate the effectiveness of water quality regulatory programs in protecting beneficial uses of waters of the State.

Data collected under SWAMP included rapid bioassessment of benthic macroinvertebrates (BMI), water quality parameters measured continuously (temperature, dissolved oxygen, pH, sediment concentration (turbidity) and discretely (nutrients, chlorophyll, organic carbon), water contaminants and toxicity, and pathogens (coliform bacteria) at sites in San Gregorio, El Corte de Madera, La Honda, and Alpine creeks (Table 2-13, Figure 2-12) (SFBRWQCB 2007a).

Water quality monitoring by SGERC was initiated to improve overall ecosystem function and water quality in the San Gregorio Watershed for multiple benefits, including native species protection and restoration. In 2003, SGERC began collecting discrete water temperature, dissolved oxygen, turbidity, pH, and conductivity data on a weekly to monthly basis, and initiated collecting continuous temperature and physical water quality data (temperature, DO, conductivity, pH) at some sites in 2008 (Table 2-13).

Since 2005, CDFG has been collecting discrete water temperature, dissolved oxygen, and salinity data at varying depths in the lagoon on an approximately weekly basis (K. Atkinson, pers. comm., 2009). Unfortunately, CDFG water quality data for the lagoon are not yet available and, as such, are not discussed further here. The SGERC data collected through 2008, as well as the SWAMP data, are summarized in the sections below in the context of designated beneficial uses for the watershed (Appendix B).

Table 2-13. Water quality monitoring sites, parameters, and collection dates.

Site	Location[1]	Parameters sampled[2]	Dates collected (Entity)
SGR-002	San Gregorio Lagoon	• Discrete (WT, salinity, DO) • Discrete (WT, CO, DO, pH, TU) • Continuous (WT)	• 2005–current (CDFG) • 2007–current (SGERC) • 2008–current (SGERC)
SGR-010	San Gregorio Creek near Stage Road	• BMI, Continuous (WT, DO, pH, TU), CWQ, WMT, SCT, TMO	• 2002–2003 (SWAMP)
		• Discrete (WT, CO, DO, pH, TU)	• 2003–current (SGERC)
SGR-020	El Corte de Madera Creek above San Gregorio Creek	• Continuous (WT, DO, pH, TU)	• 2002–2003 (SWAMP)
SGR-030	El Corte de Madera Creek near Star Hill Road	• BMI	• 2002–2003 (SWAMP)
SGR-040	San Gregorio Creek near Boysville	• BMI, Continuous (WT, DO, pH, TU),CWQ, BAC	• 2002–2003 (SWAMP)
		• BAC (sampled once) • Discrete (WT, CO, DO, pH, TU)	• 2008–current (SWAMP)
SGR-060	Harrington Creek above San Gregorio Creek	• BMI	• 2002–2003 (SWAMP)
SGR-075	San Gregorio Creek between La Honda Creek and Harrington Creek	• BMI	• 2002–2003 (SWAMP)
SGR-079	San Gregorio Creek below La Honda Creek and Alpine Creek confluence	• BAC	• 2002–2003 (SWAMP)
SGR-080	La Honda Creek above San Gregorio Creek	• BMI, CWQ, WMT	• 2002–2003 (SWAMP)
SGR-090	Alpine Creek above San Gregorio Creek	• BMI, Continuous (WT, DO, pH, TU), CWQ	• 2002–2003 (SWAMP)
SGR-100	La Honda Creek near Playbowl	• BAC, Continuous (WT, DO, pH, TU)	• 2002–2003 (SWAMP)
		• Discrete (WT, CO, DO, pH, TU) • Continuous (WT)	• 2004–current (SGERC) • 2008–current (SGERC)
SGR-102	San Gregorio Creek Near Entrada Br.	• BAC (sampled once)	• 2008–current (SGERC)
SGR-104	Woodhams Creek above La Honda Creek	• Discrete (WT, CO, DO, pH, TU) • Continuous (WT)	• 2007–current (SGERC) • 2008–current (SGERC)
SGR-110	La Honda Creek near Spanish Ranch	• BMI	• 2002–2003 (SWAMP)
		• Discrete (WT, CO, DO, pH, TU)	• 2007–current (SGERC)
SGR-120	La Honda Creek near Sky Londa	• BMI • Continuous (WT, DO, pH, TU),	• 2002–2003 (SWAMP)
SGR-130	Mindego Creek above Alpine Creek	• BMI	• 2002–2003 (SWAMP)
SGR-150	Alpine Creek near Heritage Grove	• BMI	• 2002–2003 (SWAMP)
		• Discrete (WT, CO, DO, pH, TU)	• 2007–current (SGERC)

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[1] See Figure 2-12 for site locations.

[2] BAC = coliform bacteria, BMI = benthic macroinvertebrates and physical habitat, WT = water temperature, CO = conductivity (often used as a measure of salinity), DO = dissolved oxygen, TU = turbidity, CWQ = conventional water quality (includes nutrients, chlorophyll, organic carbon), WMT = water metals and toxicity, SCT =sediment chemistry and toxicity (includes metals and organics), TMO = tissue metals and organics (bioaccumulation).

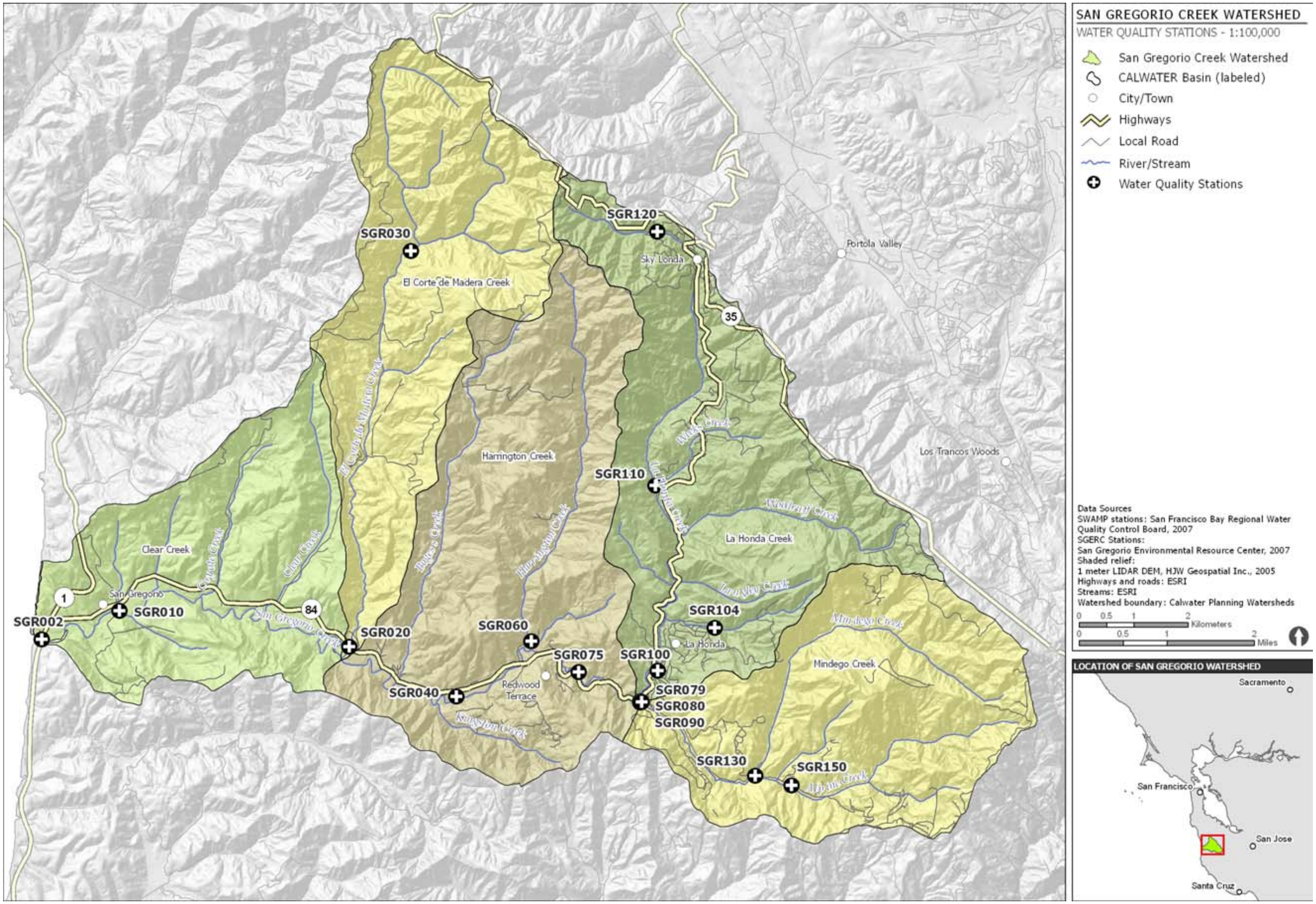

Figure 2-12. Water quality monitoring sites in the San Gregorio Creek watershed.

2.6.1 Aquatic bioassessment

The composition, distribution, and relative abundance of the BMI assemblage in a stream channel, which can range from highly sensitive to highly tolerant of poor water quality conditions, are indicators of water quality and ecosystem health (Barbour et al. 1999). In general, SFBRWQCB (2007a) found that San Gregorio Creek had among the highest water quality and most intact BMI communities among nine Bay Area watersheds sampled[10]. Macroinvertebrates were sampled using the California Stream Bioassessment Procedure, as adapted from the U.S. Environmental Protection Agency (EPA), to measure the BMI community and physical habitat characteristics. SFBRWQCB (2007a) noted three distinct assemblages in the mainstem, tributaries, and in the most downstream site in San Gregorio Creek. Along the mainstem of San Gregorio and La Honda creeks (sites SGR-040, -075, -080; Figure 2-12), BMI tolerance values were the lowest (indicating relatively high water quality) found in the San Francisco Bay Area (SFBRWQCB 2007a). In tributaries to San Gregorio and La Honda creeks (sites SGR-030, -060, -090, -110, -120, -130, -150; Figure 2-12), high taxa richness and low tolerance values suggested high biological integrity and excellent water quality (SFBRWQCB 2007a). The San Gregorio Creek near Stage Road site (SGR-010) provided "a rare glimpse of a minimally disturbed benthic assemblage from a large perennial stream in the Bay Area (SFBRWQCB 2007a)."

2.6.2 Bacteria

The 2007 San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan) (SFBRWQCB 2007b) is the master water quality policy document for the San Francisco Bay Region, including the San Gregorio Creek watershed, and includes water quality objectives for total coliform bacteria, fecal coliform bacteria, *E. coli,* and *Enterococci* in waters designated for contact recreation (which San Gregorio Creek is; see Appendix B).

Based upon data collected by the San Mateo County EHD and local Surfrider Foundation chapter beginning in 1998, San Gregorio Creek was listed under Clean Water Act Section 303 (d) provisions as impaired by coliform bacteria in 2002. During sampling conducted under SWAMP in 2002, Basin Plan objectives were slightly exceeded for *E. coli*, fecal coliforms, and total coliforms in San Gregorio Creek below the La Honda Creek and Alpine Creek confluence (SGR-079) and for *E. coli* and total coliforms in La Honda Creek near Playbowl (SGR-100) (Figure 2-12) (SFBRWQCB 2007a). Measurements within the watershed by SGERC in October 2008 showed high concentrations of total coliform (up to 198,630 MPN/100 mL), *E. coli* (up to 2,909 MPN/100 mL) and *Enterococci* (up to 24,810 MPN/100 mL). It should be noted, however, that the data were collected after the first rain following the dry season, or the "first flush", which may contain a higher pollutant load than later storms of greater magnitude or duration, and should be interpreted within this context.

While the SGERC sampling did not follow the Basin Plan's specific sampling regime for total coliform (a minimum of five consecutive samples equally spaced over a 30-day period), the results are consistent with the elevated bacterial levels documented by SWAMP monitoring downstream of the town of La Honda (SFBRWQCB 2007a). These results indicate that bacterial contamination may be a water quality concern in some portions of the watershed during the rainy season and SFBRWQCB (2007a) recommends that they be further investigated. Elevated bacteria levels in rural surface waters can be the result of wild or domestic animals or livestock in

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[10] The other watersheds sampled were: Walker Creek (Marin County), Lagunitas Creek (Marin County), San Leandro Creek (Alameda County), Wildcat/San Pablo Creeks (Contra Costa County), Suisun Creek (Solano County), Arroyo Las Positas (Alameda County), Pescadero/Butano Creeks (San Mateo County), and Stevens/Permanente Creek (Santa Clara County).

stream channels, leaky septic systems (a concern of SFBRWQCB [2007a]), and/or poorly managed horse and livestock facilities that are subsequently mobilized by rainfall. In estuaries, total bacterial levels may be elevated as a result of large congregations of birds.

Despite episodic increases, the SWAMP report noted that the results of their survey did not indicate any specific sites of concern for nutrients (SFBRWQCB 2007a). Based on a recent review of long-term beach monitoring data from the San Mateo County EHD, the watershed is likely to be considered for delisting as impaired by coliform bacteria (J. Marshall, pers. comm., 2009).

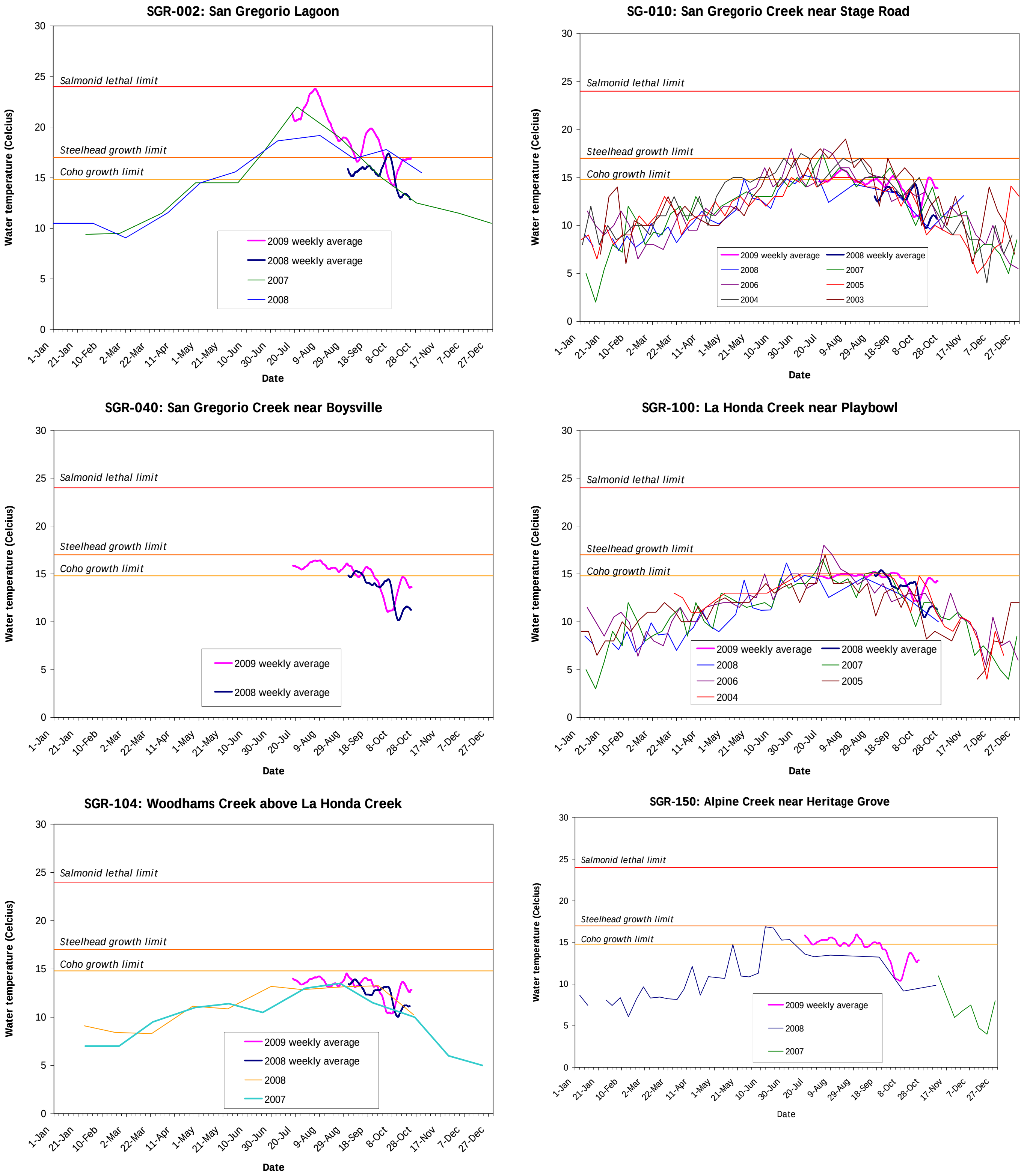
2.6.3 Temperature

In streams with designated beneficial uses such as cold freshwater habitat or rare threatened or endangered species, such as San Gregorio Creek (see Appendix B), Basin Plan objectives for water temperature are based, in part, on species-specific temperature tolerances (SFBRWQCB 2007b, SWRCB Resolution No. 68-16). Moyle (2002) reports optimal water temperatures for juvenile coho salmon ranging from 12 to 14°C (54 to 57°F), depending on food availability. SFBRWQCB (2007b) considers the maximum weekly average temperature (MWAT) of 14.8°C (59°F) as the upper limits for optimal coho salmon growth, based in part by literature reviews by Sullivan et al. (2000). Water temperatures in excess of these levels for extended periods of time are associated with reduced growth rates (up to 10%), based upon increased metabolic needs and lower fitness. It should be noted, however, that the NMFS (1997) specifies an MWAT of 16.8°C (62°F) for late summer juvenile rearing coho salmon and determined that when maximum weekly temperatures exeed 18°C coho salmon are absent from otherwise suitable rearing habitat.

Steelhead are somewhat less sensitive to high water temperatures, with preferred temperatures ranging from 15 to 18°C (59 to 64°F) depending on food availability, and lethal temperatures ranging from 24 to 27°C (75 to 80°F) (Hokanson et al. 1977, Bell 1991, Bjornn and Reiser 1991, Myrick and Cech 2001, Moyle 2002). The SFBRWQCB (2007b) considers an MWAT of 17.0°C (63°F) as the upper limits for optimal steelhead growth.

Data for the watershed indicate that water temperature occasionally exceeds limits for optimal coho salmon and steelhead growth (Figure 2-13). SFBRWQCB (2007a) continuously measured temperature at six sites for several weeks in summer 2002 and concluded that temperatures were supportive of salmonids at all sites, with the exception of San Gregorio Creek near Stage Road (SGR-010), which had an MWAT of 15.3°C (60°F) during the dry season and Sky Londa (SGR-120) in the fall. Instantaneous water temperatures collected in the upper freshwater layer of the lagoon (SGR-002) regularly exceeded 17°C (63°F), and were as high as 22°C (72°F) in July 2007,- still below critical temperature thresholds identified above, however. Temperatures in the bottom saltwater layer of the lagoon reached 29°C (84°F) in 2005 and 35°C (95°F) in 2008 (K. Atkinson, pers. comm., 2010).

Continuous water temperature data was collected by SGERC in September and October 2008 and did not include the part of the year when water temperatures were highest (June–August) as shown in the discrete water quality sampling data. Therefore, the calculated weekly average temperatures are likely not the maximum that occurred in 2008. Nevertheless, from September and October 2008, weekly average water temperatures exceeded the 14.8°C (59°F) threshold for optimal coho salmon growth in the four mainstem San Gregorio/La Honda Creek sites (SGR-002, -010, -040, and -100) and exceeded the 17°C (63°F) threshold for optimal steelhead growth at the San Gregorio lagoon (SGR-002) site (Figure 2-13). Weekly average temperatures in Woodhams Creek (SGR-104) did not exceed 14.8°C (59°F) over this time period (Figure 2-13).



SGR-002: San Gregorio Lagoon

SG-010: San Gregorio Creek near Stage Road

SGR-040: San Gregorio Creek near Boysville

SGR-100: La Honda Creek near Playbowl

SGR-104: Woodhams Creek above La Honda Creek

SGR-150: Alpine Creek near Heritage Grove

Figure 2-13. Water temperatures (ºC) at six San Gregorio Creek monitoring sites from 2003 to 2009, with SFRWQCB (2007b) temperature criteria for steelhead and coho salmon.

In 2009, weekly average water temperatures consistently exceeded the 14.8°C (59°F) threshold for optimal coho growth at all San Gregorio/La Honda Creek sites (SGR-010, -040, -100, and -150) (Figure 2-13). Further downstream at the San Gregorio lagoon site (SGR-002), maximum instantaneous surface water temperatures were found in excess of 25°C (77°F) on 6 and 7 August 2009 (temperatures in the bottom portions of the lagoon were likely much higher) and weekly average temperatures (MWAT of 24°C [75°F] on 6 August 2009) exceeded the coho salmon growth threshold for the entire recording period except for five days in early October, when the weekly average fell to approximately 14.2°C (58°F). For the San Gregorio/La Honda Creek sites (SGR-010, -040, -100, and -150), weekly average temperatures were in excess of 14.8°C (59°F) from 30 days (MWAT of 15.9°C [60.6°F] at SGR-010 on 5 August 2009) to as many as 71 days (MWAT of 16.4°C [61.6°F] at SGR-040 on 9 August 2009) out of the 104 day recording period. None of the San Gregorio/La Honda Creek sites (SGR-010, -040, and -100) exceeded the 17.0°C (63°F) threshold for optimal steelhead growth. As in 2008, the Woodhams Creek site (SGR-104) (MWAT of 14.3°C [57.7°F] on 8 August 2009) did not exceed the 14.8°C (59°F) threshold for coho salmon (Figure 2-13).

2.6.4 Turbidity

The Basin Plan requires that waters be free of changes in turbidity that cause nuisance or adversely affect beneficial uses (SFBRWQCB 2007b). Turbidity is an optical property (light scattering), typically measured in Nephelometric Turbidity Units (NTUs), due to fine (colloidal) suspended matter such as clay, silt, and organic matter (although plankton and other microscopic organisms can cause turbidity in lentic, lake-like systems). High turbidity can interfere with feeding habits of aquatic organisms and avian predators, photosynthesis, and is associated with total metals loadings and sorption of contaminants from the water column (e.g., polar organics and cationic metal forms). For salmonids specifically, chronically elevated turbidity can potentially limit production by affecting intra-gravel oxygen levels during egg incubation periods as well as sight-feeding effectiveness (Henley et al. 2000). Basin Plan criteria for turbidity applies to receiving water measurements taken downstream of specific discharges or turbidity generating activities (e.g., agricultural and urban stormwater runoff), with criteria based upon background turbidity levels in the receiving water body. Where natural turbidity is greater than 50 NTU, increases shall not exceed 10% (SFBRWQCB 2007b). It should be noted that this criterion is not applied to the turbidity measurements taken in the San Gregorio Creek watershed, since these were taken at representative tributary junctions to provide an assessment of background conditions rather than identifying turbidity contributions from particular locations or land use.

SGERC collected discrete, monthly or weekly turbidity measurements at five sites from 2003 to 2008 (a sixth site on Alpine Creek was added in late 2007), and continuous measurements at two sites during September and October 2008 (Table 2-13)[11]. This data shows turbidity levels at SGERC sites were highest in the winter months (coincident with high flows) and lowest in the late spring through the fall (Figure 2-14). Mainstem San Gregorio Creek and La Honda Creek (sites SGR-010 and -100) showed high spring (50 JTU/NTU or greater) and high winter (up to 205 JTU/NTU) turbidities from 2005 to 2008 (Figure 2-14). Similarly, elevated turbidity levels were measured at Woodhams Creek (SGR-104), La Honda Creek near Spanish Ranch (SGR-110), and Alpine Creek (SGR-150) in winter 2008 (Figure 2-14). These turbidity ranges and patterns measured by SGERC indicate primarily storm-related spikes in turbidity that would not be detrimental to aquatic species. A four-month period of elevated turbidity (i.e., >25 JTU) from

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[11] Prior to 2008, SGERC measured turbidity in Jackson Turbidity Units (JTUs). JTUs and NTUs are considered to be roughly equivalent (USGS, variously dated)

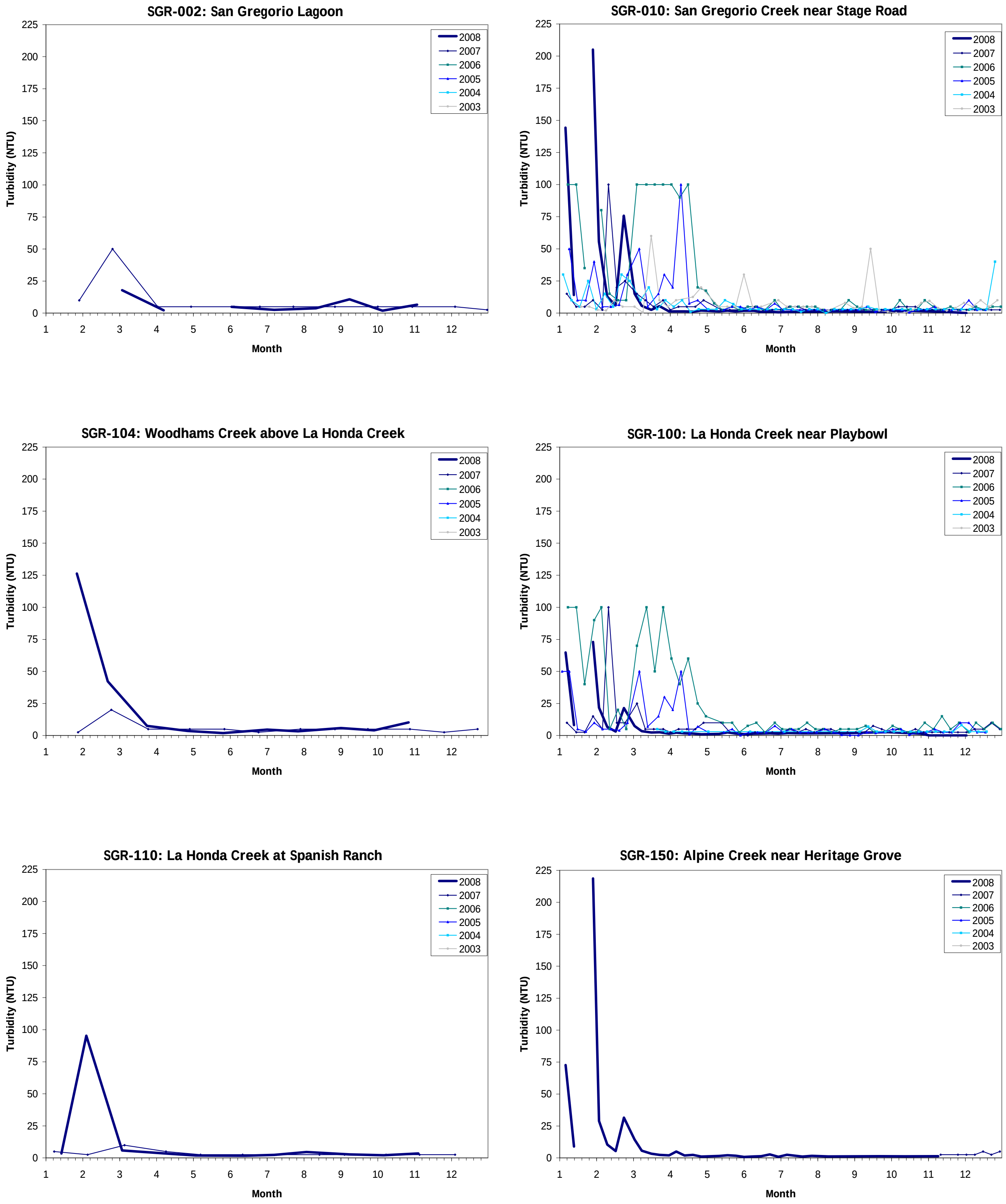

Figure 2-14. Turbidity (JTU/NTU) at six San Gregorio Creek monitoring sites from 2003 to 2008.

January to April 2006 at the downstream ends of both San Gregorio and La Honda creeks (SGR-010 and SGR-100) (Figure 2-14) is believed to be the result of frequent winter and spring rains (2006 was a relatively wet water-year). Turbidity during late winter through April could potentially reduce feeding efficiency and thus growth for coho salmon and steelhead smolts. From 2003 to 2008, turbidity ranged from 0 to10 JTU/NTUs in the summer at all sites (Figure 2-14). Continuous turbidity monitoring in the mainstem San Gregorio Creek at two sites (SGR-010 and SGR-040) in August and September 2008 showed turbidity levels rarely exceeding 5 NTU, and usually below 2 NTU (Figure 2-14).

2.6.5 Beneficial use attainment

The Basin Plan (SFBRWQCB 2007b) identifies nine beneficial uses in the surface waters of the San Gregorio Creek watershed: agricultural supply, cold and warm freshwater habitat, fish migration and spawning, preservation of rare and endangered species, water contact and non-contact recreation, and wildlife habitat (see Appendix B). In addition to these uses, San Gregorio Creek serves as a source of drinking water for residents. With the exception of episodic increases in stream temperatures, turbidity and bacteria at particular times of year, existing beneficial uses are supported as shown by water quality data collected to date (e.g., BMI indices, biostimulatory substances, chemical constituents, dissolved oxygen, toxicity, and pH). However, San Gregorio Creek is currently listed under Clean Water Act Section 303 (d) provisions as impaired by sediment (listed in 1998), with specific reference to impairment to steelhead habitat, and coliform bacteria (listed in 2002) (SFBRWQCB 2006).

Section 303(d) of the federal Clean Water Act requires that every two years each state submit to the EPA a list of rivers, lakes and reservoirs in the state for which pollution control or requirements have failed to provide for water quality. For the upcoming 2012 303(d) list, the State solicits public submission of any new data that may affect inclusion or removal from the list. Under a weight of evidence approach and allowable exceedance frequencies, the SWRCB (2004) 303(d) listing policy guidelines allow the review of new data demonstrating either continued impairment or attainment of designated beneficial uses. Water bodies that consistently do not meet water quality objectives for a beneficial use require a total maximum daily load (TMDL) for the pollutant causing the water quality impairment (SWRCB 2004). A TMDL determines the pollutant load necessary to comply with the applicable water quality standard and includes numeric targets, source and linkage analyses, waste load and load allocations, and implementation and monitoring plans. Currently there are no TMDL studies or actions planned for the watershed related to its listing as impaired by sediment (J. Marshall, pers. comm., 2009). Based on a recent review of available data, the watershed is likely to be considered for delisting as impaired by coliform bacteria (J. Marshall, pers. comm., 2009).

2.7 Vegetation

Vegetation in the San Gregorio Creek watershed influences terrestrial habitat availability, aquatic habitat quality, and sediment delivery rates. It also includes special-status species that are protected under the Federal and/or state Endangered Species Acts (ESA) or identified as rare by the California Native Plant Society (CNPS), and provide a basis for identifying priority conservation areas in the watershed. In addition, a number of non-native invasive plant species have been documented in the watershed, several of which are aggressive invaders that should be considered for treatment/control.

2.7.1 Vegetation types

Twenty-nine different vegetation series, classified according to the California Manual of Vegetation (Sawyer and Keeler-Wolf 1995), have been mapped in the San Gregorio Creek watershed (Aerial Information Systems 2001, 2006) (see Appendix C). There is also detailed vegetation information available for the La Honda Creek OSP (DCE 2007, RCHR and EcoLogic 2005).

Detailed vegetation series are described by Aerial Information Systems (2001). For this assessment, these detailed vegetation series have been compiled into broader vegetation types, based on the dominant plant species, to provide a simplified description of vegetation patterns in the watershed (see Appendix C for details). These vegetation types are depicted in Figure 2-15 and listed in Table 2-14.

Vegetation types are distributed within the watershed based primarily on slope position and proximity to the coast (Figure 2-15). Douglas-fir, redwood and Monterey pine occur in the northern reaches of El Corte de Madera, Harrington, and La Honda Creeks, and cover the lower two-thirds of the slopes along Alpine and Mindego Creeks in the eastern portion of the watershed. Most of these forests are second- and third-growth, after having been logged historically.

Table 2-14. Major vegetation types in the San Gregorio Creek watershed.

Vegetation type	Acres	Hectares	Percent of watershed
Grassland	9,142	3,699	27.47%
Douglas-fir	5,876	2,378	17.66%
Coyote brush	5,205	2,107	15.64%
Redwood	4,828	1,954	14.51%
Coast live oak	2,376	962	7.14%
California bay - tanoak	1,779	720	5.35%
Developed	1,149	465	3.45%
Mixed willow	445	180	1.34%
Unvegetated	434	176	1.31%
California buckeye woodland	408	165	1.23%
Red alder	393	159	1.18%
Agriculture	332	134	1.00%
Manzanita - blue blossom	254	103	0.76%
Poison oak	171	69	0.51%
Monterey pine	168	68	0.51%
Eucalyptus	128	52	0.38%
Pond	53	21	0.16%
Hazelnut - dogwood	53	21	0.16%
Landslide - outcropping	18	7	0.06%
Wetland	18	7	0.05%
Broom	16	7	0.05%
Water	12	5	0.04%
Box elder	11	4	0.03%
Blue blossom	9	4	0.03%
Reservoir	2	1	0.01%
Total	**33,281**	**13,469**	**100%**

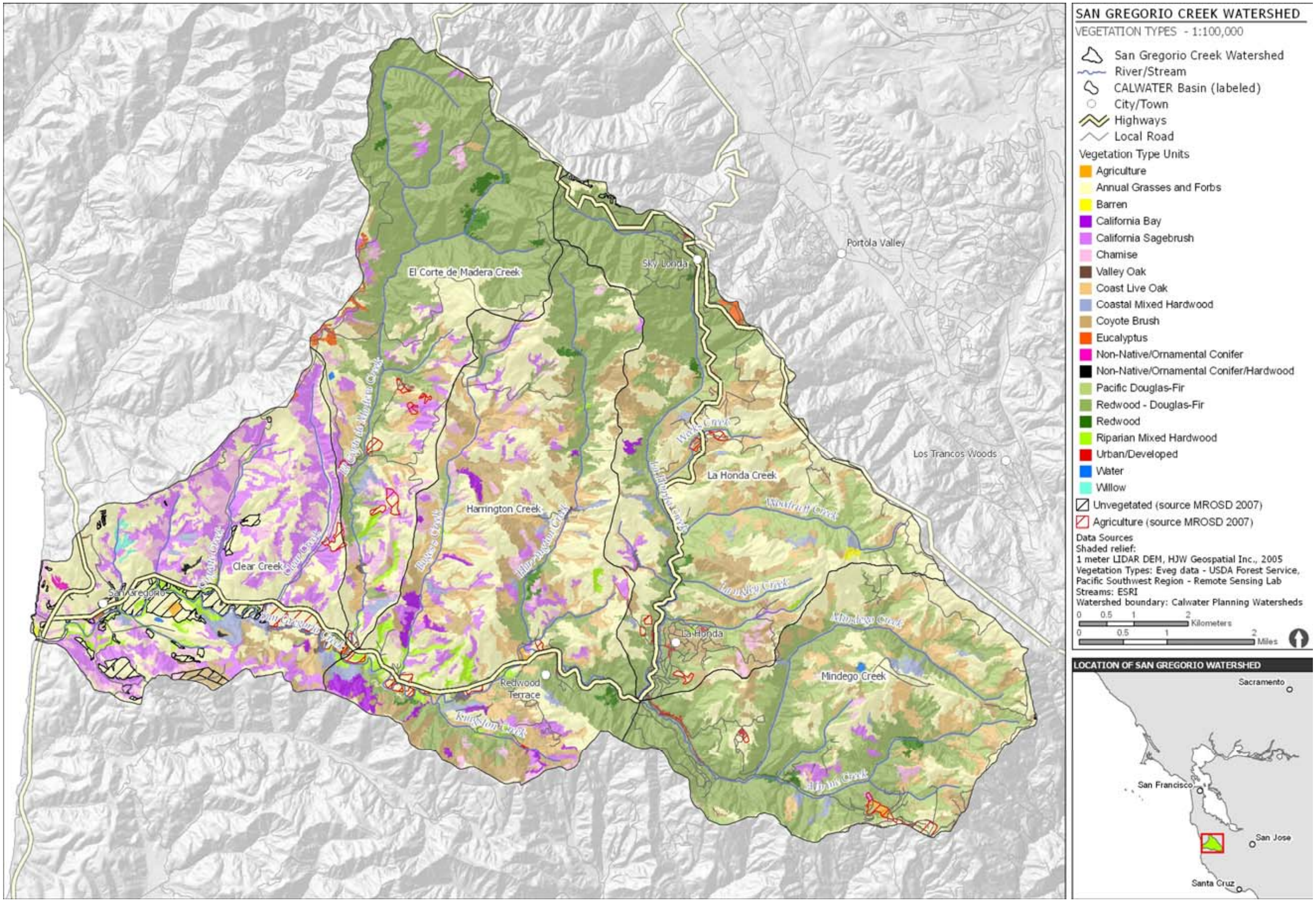

Figure 2-15. Vegetation types in the San Gregorio Creek watershed.

Grassland is the dominant vegetation series in the watershed, particularly on the tops and south-faces of hillslopes. The vast majority of this is annual grassland that is dominated by non-native species that are now considered naturalized, such as wild oat (*Avena fatua*), soft chess (*Bromus hordeacous*), and rip-gut brome (*B. diandrus*). Other mapped grasslands are also dominated by at least one non-native grass or forb, including Harding grass (*Phalaris aquatica*), velvet grass (*Holcus lanatus*), and yellow star-thistle (*Centaurea solstitialis*) (Appendix C). Only one patch of native grassland, dominated by meadow barley (*Hordeum brachyantherum*), was mapped in the Russian Ridge OSP (Appendix C). Despite being dominated by non-native species, grasslands in the La Honda Creek OSP have been documented to contain several native grasses and forbs that are indicative of native coastal prairie (Ford and Hayes 2006, DCE 2007), and patches of native California oatgrass (*Danthonia californica*) have been observed in the Clear Creek sub-basin (J. Rigney, pers. comm., 2009). Coastal prairie vegetation, which occurs in fog-influenced areas from the Oregon border to northern Santa Barbara County, is increasingly rare and endangered (Ford and Hayes 2006). Even though coastal prairie also tends to be dominated by non-native grasses, it supports a high diversity of native perennial grasses and forbs, many of which are endangered, threatened, or rare species, particularly when exposed to appropriate magnitudes and durations of grazing and burning (Hayes and Holl 2003). Given the magnitude of coastal fog influence and cattle grazing in the watershed, it is quite likely that coastal prairie vegetation is supported in at least some areas mapped as annual grassland. In response to the regional loss of coastal prairie vegetation and the number of protected plant and animal species associated with the vegetation type, there is increasing interest and effort to preserve and maintain coastal prairie through land acquisition, and grazing and fire management. In fact, MROSD conducted a prescribed burn on 120 ac of the Russian Ridge OSP in 2007 as part of a grassland management program to increase the abundance of native species, reduce the dominance of invasive, introduced species, and reduce the amount of flammable vegetation along the open ridge top.

In the western and central portions of the watershed, scrub and chaparral vegetation dominated by coyotebrush, manzanita, and sagebrush covers the mid and lower slopes (Figure 2-15). Like coastal prairie, these coastal scrub vegetation types are increasingly rare and endangered (Ford and Hayes 2006). As such, many coastal scrub and coastal prairie vegetation alliances are afforded protection by the State of California, either as CDFG-recognized Natural Communities of concern or as the host of state-protected plant and animal species (Hillyard 2009).

Coast live oak, California bay, and wetland and riparian vegetation types occur at the bottom and in the hollows of most hillslopes (Figure 2-15). Stream surveys on mainstem San Gregorio Creek note an abundant canopy of riparian vegetation, consisting primarily of alder, willow, and box elder in the lower reaches, with increasing amounts of maple, California bay, redwood, Douglas fir, and tanoak in the upper reaches (CDFG 1980, 1985a, 1985b). This high-quality riparian habitat, in addition to an abundant redwood canopy along tributaries in the upper watershed and the fact that cattle are largely excluded from stream channels (although breaches do occur), suggests that the riparian corridor is providing critical ecosystem services for the watershed, such as filtering runoff, moderating stream temperatures, and providing a long-term source of LWD for instream habitat (Gregory et al. 1991, Naiman and Descamps 1997).

2.7.2 Special-status plant species

Western leatherwood (*Dirca occidentalis*), Santa Cruz manzanita (*Arctostaphylos andersonii*), and King's Mountain manzanita (*A. regismontana*), which are all included in the CNPS's inventory of rare and endangered plants on list 1B.2 (rare, threatened, or endangered in California and elsewhere), have been documented in the La Honda Creek OSP (Kan 2002, as cited in DCE

2007). Other special-status plant species with the potential to occur in the watershed were identified through searches of the California Natural Diversity Database (CNDDB) (RareFind software, version 3.1.0), the U.S. Fish and Wildlife Service (Sacramento Office) official endangered species list (USFWS 2009), and the CNPS online rare plant inventory (CNPS 2009). Each database was queried for the four USGS 7.5-minute quadrangles overlapping the San Gregorio Creek watershed: Mindego Hill, Woodside, La Honda, and San Gregorio.

While nearly 30 special-status species were identified by the database searches (see Appendix D), many of these are found in specialized habitats that do not occur in the San Gregorio Creek watershed, such as serpentine-derived soils. Of the special-status species with the potential to occur in the watershed, three are protected under the federal and/or state ESA. San Mateo woolly sunflower *(Eriophyllum latilobum*) and white-rayed pentachaeta (*Pentachaeta bellidiflora)* are listed as Federal and state endangered species, and Dudley's lousewort (*Pedicularis dudleyi)* is listed as a state rare species. San Mateo woolly sunflower occurs in cismontane woodlands, while white-rayed pentachaeta occurs in valley and foothill grasslands, but both prefer open, dry environments and can occur on serpentine soils. Dudley’s lousewort grows in shady areas in chaparral, conifer forests, and grasslands. Fourteen other plant species are identified as rare, threatened, or endangered by CNPS (Appendix D). Most of these species are found along the coast, in chaparral/coastal scrub, or in upland forests (Appendix D).

2.7.3 Non-native invasive plant species

Non-native invasive plant species are often a watershed management concern, since they can aggressively invade the habitats where they are introduced and displace native plant species and associated animal species. Although no comprehensive surveys for invasive plants have been conducted of the San Gregorio Creek watershed as a whole, infestations have been documented at several locations in the watershed including the La Honda Creek OSP (RCHR and EcoLogic 2005; Shelterbelt Builders 2004, as cited in DCE 2007), and along the riparian zone in La Honda Creek (Brady et al. 2004). In addition, the San Mateo County Weed Management Area has identified several weeds of particular concern in the watershed (SMCWMA, pers. comm., 2009). These occurrences are summarized in Table 2-15, and organized according to their rating by the California Invasive Plant Council (Cal-IPC 2006). Species rated as “high” have severe ecological impacts on physical processes, plant and animal communities, and vegetation structure. Their reproductive biology and other attributes are conducive to moderate to high rates of dispersal and establishment. Most are widely distributed ecologically. “Moderate” species have substantial and apparent—but generally not severe—ecological impacts. They also have moderate to high rates of dispersal, though establishment is generally dependent upon ecological disturbance. Their distribution may range from limited to widespread. “Limited” species are invasive but their ecological impacts are minor on a statewide level or there was not enough information to justify a higher score. They have low to moderate rates of invasiveness, and are generally limited in distribution, although they may be locally persistent and problematic. It should be noted that there are very likely additional non-native invasive plant species in the watershed that have not been formally documented.

Table 2-15. Non-native invasive plant species documented in the San Gregorio watershed.

Common name	Scientific name	Source
High		
Yellow star thistle	*Centaurea solstitialis*	• RCHR and EcoLogic (2005) • Aerial Information Systems (2006)
Pampas grass/Jubata grass	*Cortaderia* spp.	• N. Panton, pers. comm., 2009 • SMCWMA, pers. comm., 2009
Sweet fennel	*Foeniculum vulgare*	• RCHR and EcoLogic (2005)
French broom	*Genista monspessulana*	• DCE (2007) • RCHR and EcoLogic (2005)
English ivy	*Hedera helix*	• Brady et al. (2004) • CDFG stream survey data, as cited in Brady et al. (2004)
Purple loosestrife	*Lythrum salicaria*	• SMCWMA, pers. comm., 2009
German (=Cape) ivy	*Senecio mikaniodies* (=*Delairea odorata*)	• Brady et al. (2004) • CDFG stream survey data, as cited in Brady et al. (2004) • SMCWMA, pers. comm., 2009
Medusahead	*Taeniatherum caput-medusae*	• SMCWMA, pers. comm., 2009
Broom[1]	Various	• Brady et al. (2004) • Aerial Information Systems (2006)
Moderate		
Wild oat	*Avena barbata*	• RCHR and EcoLogic (2005)
False brome	*Brachypodium distachyon*	• RCHR and EcoLogic (2005)
Black mustard	*Brassica nigra*	• RCHR and EcoLogic (2005)
Ripgut brome	*Bromus diandrus*	• RCHR and EcoLogic (2005)
Italian thistle	*Carduus pycnocephalus*	• DCE (2007) • RCHR and EcoLogic (2005)
Distaff thistle	*Carthamnus lanatus*	• DCE (2007) • SMCWMA, pers. comm., 2009
Purple (=spiny) starthistle	*Centaurea calictrapa*	• DCE (2007) • RCHR and EcoLogic (2005) • SMCWMA, pers. comm., 2009
Crown daisy	*Chrysanthemum coronarium*	• RCHR and EcoLogic (2005)
Bull thistle	*Cirsium vulgare*	• DCE (2007) • RCHR and EcoLogic (2005)
Poison hemlock	*Conium maculatum*	• DCE (2007) • RCHR and EcoLogic (2005)
Annual ryegrass	*Lolium multiflorum*	• RCHR and EcoLogic (2005)
Grass poly loosestrife	*Lythrum hysoppifolium*	• RCHR and EcoLogic (2005)
Pennyroyal	*Mentha pulegium*	• RCHR and EcoLogic (2005)
Harding grass	*Phalaris aquatic*	• DCE (2007) • RCHR and EcoLogic (2005) • Aerial Information Systems (2006) • SMCWMA, pers. comm., 2009
Rose clover	*Trifolium hirtum*	• RCHR and EcoLogic (2005)
Periwinkle	*Vinca major*	• Brady et al. (2004) • CDFG stream survey data, as cited in Brady et al. (2004)
Acacia[1]	*Acacia* sp.	• CDFG stream survey data, as cited in Brady et al. (2004)

Common name	Scientific name	Source
Eucalyptus[1]	*Eucalyptus* sp.	• CDFG stream survey data, as cited in Brady et al. (2004) • Aerial Information Systems (2006) • SMCWMA, pers. comm., 2009
Limited		
Soft chess	*Bromus hordeaceus*	• RCHR and EcoLogic (2005)
Forget-me-not	*Myosotis crystallinum*	• DCE (2007)
Bristly ox-tongue	*Picris echioides*	• DCE (2007)
Rabbitsfoot grass	*Polypogon monspeliensis*	• RCHR and EcoLogic (2005)
Curly dock	*Rumex crispus*	• RCHR and EcoLogic (2005)
Milk (=blessed) thistle	*Silybum marianum*	• DCE (2007) • RCHR and EcoLogic (2005) • SMCWMA, pers. comm., 2009
Evaluated but not listed		
Silver hairgrass	*Aira caryophyllea*	• RCHR and EcoLogic (2005)
Mayweed	*Anthemis cotula*	• RCHR and EcoLogic (2005)
Cancerwort	*Kickxia elatine/spuria*	• SMCWMA, pers. comm., 2009
Bird's foot trefoil	*Lotus corniculatus*	• RCHR and EcoLogic (2005)

[1] No species name indicated. Cal-IPC Inventory Ratings are provided for each species with a known California distribution.

2.8 Fish and Wildlife

The diversity of vegetation types, as well as aquatic environments, in the San Gregorio Creek watershed support a wide variety of habitats for a number of fish and wildlife species. This section summarizes the special-status species that occur in the watershed, along with their designated critical habitat, as well as documented non-native invasive species. Four special-status species—California red-legged frog (*Rana draytonii*), coho salmon (*Oncorhynchus kisutch*), steelhead (*O. mykiss irideus*), and tidewater goby (*Eucyclogobius newberryi*)—are the focal species of this Watershed Management Plan and are described in detail in Section 4: Limiting Factors Analysis.

2.8.1 Special-status species

California red-legged frog, coho salmon, steelhead, and tidewater goby, the focal species of this Watershed Management Plan are all special-status species that have been documented in the watershed. Detailed descriptions of their distribution and abundance are provided in Section 4. San Francisco garter snake (*Thamnophis sirtalis tetrataenia*), a federal and state-listed endangered species, has also been documented in the watershed (CDFG 2009), as have western pond turtle (*Actinemys marmorata*), pallid bat (*Antrozous pallidus*), and Townsend's big-eared bat (*Corynorhinus townsendii),* which are all state species of special concern (CHC 2002; Heady and Frick 2000, Seymour et al. 2006, as cited in DCE 2007).

Other special-status species with the potential to occur in the watershed were identified through searches of the CNDDB (RareFind software, version 3.1.0) and the U.S. Fish and Wildlife Service (Sacramento Office) official endangered species list (USFWS 2009). Each database was queried for the four USGS 7.5-minute quadrangles overlapping the San Gregorio Creek watershed: Mindego Hill, Woodside, La Honda, and San Gregorio. In addition, due to the dispersal capabilities of some wildlife species, the nine quadrangles surrounding the original four were also searched (i.e., Montara Mountain, San Mateo, Redwood Point, Mountain View, Palo

Alto, Half Moon Bay, Cupertino, Castle Rock Ridge, Big Basin, Franklin Point, and Pigeon Point). The search included:

- species listed as endangered or threatened, or candidates for listing, under the Federal and/or state ESAs;
- CDFG species of special concern and fully protected and/or rare species; and
- California Department of Forestry and Fire Protection (CDF) sensitive species.

Twenty-five special status invertebrate, fish, bird, and mammal species were identified during the database searches, although several of these are unlikely to occur in the San Gregorio Creek watershed due to their restricted distributions and/or specialized habitat requirements (see Appendix D). Ten of the species that have the potential to occur in the watershed are protected under the Federal and/or state ESA. These include the four focal species of this Watershed Management Plan —California red-legged frog, coho salmon, steelhead, and tidewater goby—as well as California tiger salamander (*Ambystoma californiense),* San Francisco garter snake, marbled murrelet (*Brachyramphus marmoratus*), western snowy plover (*Charadrius alexandrinus nivosus*), American peregrine falcon (*Falco peregrinus anatum),*and California brown pelican (*Pelecanus occidnetalis californicus)* (Appendix D).

Critical habitat can be designated for Federally-listed species by USFWS or NMFS under the Federal ESA, and are areas considered essential to a species' conservation. Once proposed for designation, critical habitats are offered the same level of protection under the ESA as the listed species' themselves. Designating critical habitat is an important tool for species recovery. Taylor et al. (2005) found that species with critical habitat for two or more years were more than twice as likely to have increased in population as species without. Critical habitat has been designated in the San Gregorio Creek watershed for four species. All accessible stream reaches (including estuarine areas and tributaries) in the watershed are designated as critical habitat for the Central California Coast (CCC) coho salmon Evolutionarily Significant Unit (ESU) and CCC steelhead Distinct Population Segment (64 FR 24049, 70 FR 52488). The estuary is designated critical habitat for tidewater goby (73 FR 5920), and dense, old growth redwood forests in the watershed have been designated as critical habitat for marbled murrelet (61 FR 26255). In addition, proposed revisions to critical habitat for California red-legged frog would include the majority of the San Gregorio Creek watershed (70 FR 53492).

2.8.2 Non-native invasive species

While most non-native species are not particularly invasive or detrimental, some have no natural controls in their new environment and are able to spread unchecked, causing significant and sometimes irreparable damage to native habitats and species. For example, non-native invasive species can prey on or transmit exotic diseases to native species, outcompete native species for food and other resources, and/or degrade habitat for native species. As with plants, to date there have been no comprehensive surveys for non-native invasive fish and wildlife species in the San Gregorio Creek watershed. However, surveys conducted in neighboring watersheds and elsewhere in San Mateo County, coupled with incidental observations provide an indication of the non-native invasive species that may occur in the watershed.

During a 2002 tour of the San Mateo County coast by amphibian and reptile expert Dr. Dan Holland, several non-native predatory species were observed in the San Gregorio Creek watershed that could threaten native species such as California red-legged frogs and San Francisco garter snakes (CHC 2002). These included:

- Green sunfish (*Lepomis cyanellus*)

- Mosquito fish (*Gambusia affinis*)
- Largemouth bass (*Micropterus salmoides*)
- Black bullhead (*Ameiurus melas*)
- Carp (*Cyprinus carpio*)
- Introduced crayfish (*Procambarus clarkia, Pacifiasticus* spp., and *Orconectes* spp.)
- Bullfrog (*Rana catesbiana*)

Seymour et al. (2007), who conducted amphibian surveys of MROSD land holdings, also confirmed the presence of bullfrogs, bass, sunfish, and mosquito fish in lakes and ponds in the watershed. In addition, CDFG has documented striped bass (*Morone saxatilis*), which can prey on juvenile salmonids and other native fish, in the seasonal lagoon (K. Atkinson, pers. comm., 2009).

Brown-headed cowbirds are widespread brood-parasites of many native bird species (i.e., they lay their eggs in the nests of native birds, who then raise the cowbird chicks often to the detriment of their own offspring) in riparian areas throughout California, especially those near agricultural lands. While brown-headed cowbirds are native to North America, their range expanded to include California only recently by the aid of human-induced factors (Muehter 1997). There have been no documented reports of brown-headed cowbirds in the San Gregorio Creek watershed specifically, but during surveys for saltmarsh yellowthroats, Foster (1977) noted that “cowbirds are not uncommon in the study areas”, which included San Gregorio Creek. Brown-headed cowbirds are “fairly common” for most of the year and are considered regular breeders in San Mateo County (Metropulos 2006). Eurasian collared dove (*Streptopelia decaocto*) has been observed along the coast (T. Frahm, pers. comm., 2009).

Wild swine (*Sus scrofa*) are known to occur in the watershed (Rigney, pers. comm., 2010). California’s feral swine population likely started with escaped domestic swine brought over by Spanish settlers, who commonly released swine to forage in woodlands (Groves and Di Castri 1991). Swine have the greatest reproductive capacity of all free-ranging, large mammals in the United States (Wood and Barrett 1979) and population expansion can occur rapidly. Feral swine degrade ecosystems through predation and competitive impacts on native fauna, grazing on native plants, and physically altering habitats by rooting. Rooting creates large, disturbed areas that can lead to extensive erosion, displace native species, and facilitate invasion by non-native, invasive plant species (Barrett 1977).

While there have been no documented reports of established non-native invasive invertebrate species in the San Gregorio Creek watershed, Asian clam (*Corbicula fluminea*) and New Zealand mudsnail (*Potamopyrgus antipodarum*), both highly invasive aquatic invertebrates, have been documented in nearby drainages to the south. Asian clam was documented at Waddell Beach (Count 1991), New Zealand mudsnail was documented in the San Lorenzo River (Post 2008), and both species have been documented in the San Lorenzo-Soquel drainage (Santa Cruz County, California) by the USGS Nonindigenous Aquatic Species program.

2.9 Watershed Characterization Synthesis

In many respects, the San Gregorio Creek watershed is in relatively good health: second- and third-growth forests are establishing in many of the areas that were historically logged, a significant portion of the watershed is protected from future development and habitat loss, it has a relatively healthy riparian zone and high water quality, and it supports a diversity of native vegetation types and plant and animal species. These characteristics make the watershed uniquely suitable for the conservation and restoration of native habitats and the preservation and reintroduction of native species populations. There are, however, several issues that may be impairing ecological conditions in the watershed and make obvious focal points for restoration and management planning. These issues are summarized below and include water quantity; fine sediment sources and effects on the riparian ecosystem; stream temperature, turbidity, and bacteria levels; and non-native invasive species. Recommendations to address these issues are made in Section 5.

2.9.1 Water quantity

During the late summer and fall in some dry years there can be very little to no running water in the San Gregorio Creek channel in some locations. While the watershed, due to its climate and setting, likely experienced very low and intermittent flows in the late summer and fall on occasion under historical conditions, riparian water diversions and perhaps groundwater pumping (the extent of which is currently unknown) are likely removing water that would otherwise be available to the stream channel. Although the precise effects of water diversion and groundwater pumping on the volume of instream flow at any given point in the stream are not currently known, hydrologic modeling provides insight into the relationship between water diversions and streamflow (see Section 3) and there is a general understanding of the potential effects of low instream flows on the Watershed Management Plan focal species (see Section 4).

2.9.2 Fine sediment

Due to its geology, steep gradients, and tectonic activity, the San Gregorio Creek watershed has the potential for a relatively high fine sediment yield. This was likely exacerbated by historical logging activities, which often lead to very high rates of fine sediment delivery to stream channels to the detriment and occasional destruction of instream habitat. The San Gregorio Creek watershed has been listed as impaired for sediment since 1998 (SWRCB 2006). Fine sediment is delivered to the channel in the watershed through landsliding, bank erosion, road-related erosion, and from upstream reaches. Bank-erosion and road-related sources of fine sediment have been identified or inventoried in a relatively large proportion of the watershed, including MROSD land holdings (Best 2002, 2007), Sam McDonald County Park (PWA 2003), the portion of Highway 84 in La Honda Creek (Brady et al. 2004), and along several other tributary channels (Baglivio and Kahles 2006a, 2006b, 2006c). But these reports do not necessarily evaluate the sediment contribution from these sources relative to more “natural” sources such as landslides (with the exception of Balance Hydrologics [2006a] in El Corte de Madera Creek). Many of the stream surveys and inventories in the watershed indicate some level of substrate embeddedness and pool filling by fine sediment that may be limiting salmonid spawning and rearing habitat quality (as discussed in detail in Section 4.3.2 and 4.3.3). However, the magnitude of sediment impacts on salmonid populations in the watershed is still not well understood.

2.9.3 Water temperature and bacteria levels

Ongoing monitoring by SWAMP and SGERC and analysis in the Basin Plan (SFBRWQCB 2007b) indicate that stream temperature and bacterial levels can be problematic in some areas of the watershed at certain times (Section 2.6). Water temperature increases that exceed Basin Plan criteria during the later summer and fall are likely a result of low instream flows, since the riparian corridor is generally intact and temperatures in the watershed are moderated by coastal fog. Follow-up sampling conducted by SGERC suggests continued episodes of exceeded bacterial levels within the watershed. Anecdotal reports of leaking septic systems are hypothesized as potential sources of spikes in fecal indicator bacteria levels after rainfall events (SFBRWQCB 2007a), although targeted follow-up sampling or bacterial source identification has not been conducted to date.

2.9.4 Non-native invasive species

Stream surveys and other resource inventories have documented a variety of non-native invasive plant and animal species in the watershed. With the exception of bullfrogs, which may be limiting the population of California red-legged frog in the watershed (see Section 4), there are few reports of large infestations or impairment of ecological processes as a result of non-native invasive species. However, for some of the non-native invasive species documented in the watershed (e.g., yellow star thistle, purple loosestrife, French broom, and English ivy) this can quickly change since they are known to spread rapidly and can be difficult or problematic to control. Once established, non-native invasive species can spread rapidly; invasive plants can displace native habitats and associated native species, and invasive animal species can prey upon and outcompete native species. For many non-native invasive species, early detection is critical so that control measures can be undertaken before an infestation worsens and control becomes unfeasible.

3 HYDROLOGIC ASSESSMENT

A hydrologic assessment of the San Gregorio Creek watershed was conducted by Stockholm Environment Institute to characterize streamflow patterns and identify the implications of water diversions on downstream water supply. Because the watershed lacks comprehensive long-term hydrologic datasets for the watershed[12], a watershed simulation model was used to estimate streamflows and the impact of river diversions. The modeling tool chosen (described in detail below) is the Water Evaluation and Planning, or WEAP, system which integrates historical and contemporary rainfall records with sub-basin drainage size and other watershed attributes such as geology and land cover to predict the unimpaired or "natural" instream flow in different parts of the watershed. By understanding the amount of stream flow in the system and the approximate amount of water diverted, the model can assess (to the degree possible based on available input data) the effect of diversions on instream flows[13]. In addition to developing an understanding of flow relationships in the watershed, the WEAP model was used to assess the potential for instream flow water management scenarios to achieve hypothetical dry season flow targets.

3.1 Background and Approach

Although a number of research, environmental interest, and governmental organizations have conducted isolated stream monitoring and data collection efforts in the San Gregorio Creek

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[12] USGS stream gage #11162570 at Stage Road near the town of San Gregorio is the only long-term gauge in the watershed. However, due to funding constraints, it has an intermittent period of record.

[13] A more technical review of the model is provided by Yates et al. (2009) as follows: The WEAP model attempts to address the gap between water management and watershed hydrology by integrating physical hydrological processes with the management of demands and installed infrastructure in a seamless and coherent manner (Yates et al. 2005a, b). Within the water resources systems logic is embedded a watershed hydrology module, which allows for the direct assessment of hydrologic changes on managed water systems. These integrations combine information on the biophysical characteristics of a catchment with climate forcing data to simulate streamflow and other terrestrial components of the hydrologic cycle. This makes WEAP unique as a planning study model, since both supply and demand side interactions can be addressed simultaneously, allowing for analysis of alternative and/or future climate scenarios that are unbounded by a reliance on historical hydrologic patterns. Analysis in the WEAP model flows directly from the climate scenarios and not from a perturbation of the historic hydrology as is necessary in other models to the question of potential impacts of climate variation and change on the water sector.

watershed over the past few decades, with few exceptions they have been conducted over a limited time-frame and have not produced a dataset that reveals long-term trends. Stream flow measurement for the watershed has been, and still is, dependent on flow measurements taken at the USGS stream gauge near the town of San Gregorio (#11162570). However, this USGS gauge is not consistently funded and thus even this data set is incomplete.

Given these limitations, it was determined that the existing historical stream flow records were insufficient to use as supporting data to assess streamflow patterns throughout the basin and address the implications of river diversions on downstream water users, including in-stream uses. Therefore, we selected an alternative approach for assessing the hydrologic regime of San Gregorio Creek that relies on the Water Evaluation and Planning (WEAP) system. WEAP is an integrated water resources planning tool developed by the Stockholm Environment Institute that is widely used to support collaborative water resource planning. The WEAP system integrates watershed hydrology (i.e., rainfall-runoff) with a simulation of the operation of the main control features in the basin (i.e., diversions), such that we can use historic climatic data to generate stream flows for each of the major control points within the basin and then evaluate the impacts of water usage throughout the basin.

Before we get to the details of the model, it is important that we address the utility of the tool and acknowledge its limitations. As with any model of a complex system, there are limitations to the extent to which we can represent the detail of many of the processes occurring within the watershed. One aspect of water management that the model will not be able to address is the impact of each individual diversion within the watershed. This owes to the fact that because the distribution of stream flow records within the basin is sparse, the spatial resolution of the model and the characterization of hydrologic processes must remain rather coarse as compared with the actual distribution of points of diversion within the basin. There are 258 known points of diversion in the San Gregorio Creek watershed, but at best only four stations for calibrating the model.

The relatively coarse resolution of the model suggests that the hydrologic response predicted by a rainfall-runoff model will be fairly homogeneous across the basin. Thus, stream flows on tributaries will likely be influenced mostly by their spatial extent (i.e., sub-basin area). This implies too that the rainfall-runoff model may also over- or under-predict stream flows on tributaries where there is no reliable observation data to confirm model performance. Thus, it may not be possible to state with certainty the absolute impact on stream flows due to diversions from tributaries. The model will, however, be able to show the relative changes in stream flow due to changes in water management.

Despite these limitations, there are important water management considerations that this model can address. One question that the model may be used to evaluate is the impact of diversions on in-stream flow requirements established at the town of San Gregorio (at Stage Road, USGS #11162570). Because most of the basin's diversions are upstream of the point where minimum bypass flows have been established, the model can be used to evaluate the impacts of different management alternatives on flows at San Gregorio. The model may also be used to evaluate how water management throughout the basin impacts the overall hydrologic regime. In this application of the model, various management alternatives could be evaluated relative to a baseline, which represents current water management practices. Lastly, where simulated stream flows do not agree with the locally observed experience the model will be useful in identifying important data gaps and areas where monitoring and data collection can be focused, which can be used, in turn, to further refine the model. In this way, potential streamflow management alternatives can be conceptualized, assessed, refined, and reevaluated at both watershed and local scales.

3.2 The Water Evaluation and Modeling (WEAP) System

The WEAP system is a comprehensive, fully integrated water basin analysis tool. It is a simulation model that includes a robust and flexible representation of water demands from all sectors and flexible, programmable operating rules for infrastructure elements such as reservoirs, canals, and hydropower projects. Additionally, it has watershed rainfall-runoff modeling capabilities that allow all portions of the water infrastructure and demand to be dynamically nested within the underlying hydrological processes. In effect, it allows the modeler to analyze how specific configurations of infrastructure, operating rules, and priorities will affect water uses as diverse as in-stream flows, agricultural irrigation, and municipal water supply under the umbrella of input weather data and physical watershed conditions.

The WEAP system allows the user to set priorities among different users, such as urban users and agriculture, to define the preference of a particular user for a particular source, such as surface water or groundwater, and to constrain the transmission of water between sources and users based on physical and or regulatory constraints. In formulating a WEAP application, the user describes the multi-objective nature of most engineered water systems.

3.2.1 Modeling approach

The development of WEAP applications follows a common approach (see Figure 3-1). The first step in this approach is the study definition, wherein the spatial extent and system components of the area of interest are defined and the time horizon of the analysis is set. Following this initial assessment, the ‘current accounts’ are defined, which is a baseline representation of the system – including the existing operating rules for both supplies and demands. The current accounts serves as the point of departure for developing scenarios, which characterize alternative sets of future assumptions pertaining to policies, costs, and factors that affect demands, pollution loads, and supplies. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets and sensitivity to uncertainty in key variables.

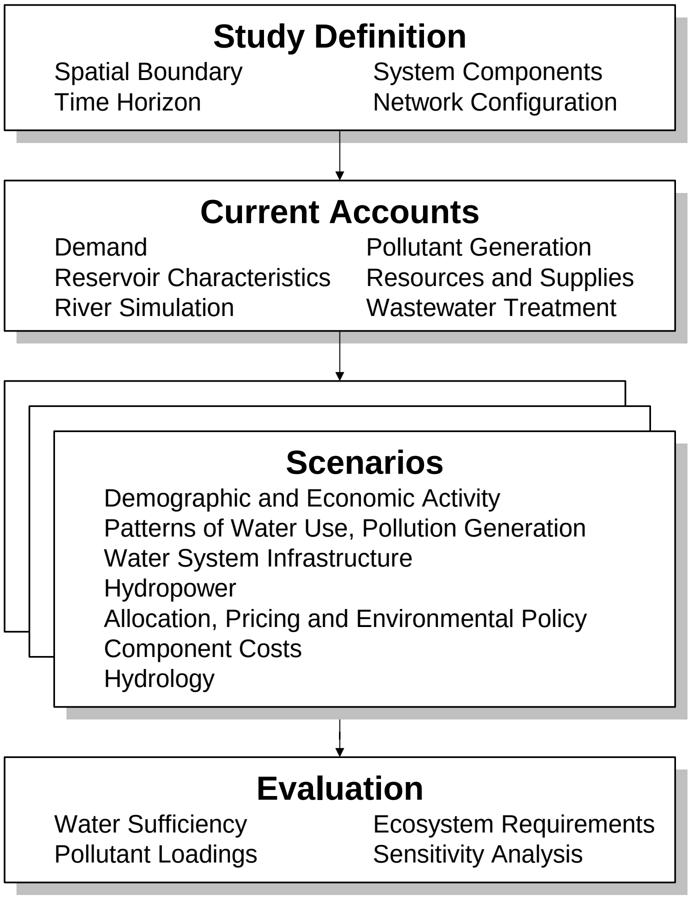

Figure 3-1. Developing a WEAP application.

The steps in the analytical sequence are described in greater detail below.

3.2.1.1 Study definition

Evaluating the implications of managing diversions and impoundments along a river requires the consideration of the entire land area that contributes to the flow within the river; namely, the watershed or “river basin”. Within WEAP it is necessary to set the spatial scope of the analysis by defining the boundaries of the river basin. Within these boundaries there are smaller rivers and streams (or tributaries) that flow into the main river of interest. Because these tributaries determine the distribution of water throughout the entire basin, it is also necessary to divide the study area into sub-basins such that we can characterize this spatial variability of river flows.

3.2.1.2 Current accounts

The current accounts represent the basic definition of the water system as it currently exists. Establishing current accounts requires the user to "calibrate" the system data and assumptions to a point that accurately reflects the observed operation of the system. The current accounts include the specification of supply and demand data (including definitions of reservoirs, diversions, pipelines, treatment plants, pollution generation, etc.). This calibration process also includes setting the parameters for WEAP’s rainfall-runoff module such that WEAP can use climatic data (i.e., temperature and precipitation) to estimate water supply (i.e., river flows, aquifer recharge) and demand (i.e., evaporative water demand) in the delineated basins.

3.2.1.3 Scenarios

At the heart of WEAP is the concept of scenario analysis. Scenarios are self-consistent story-lines of how a future system might evolve over time. The scenarios can address a broad range of "what if" questions. This allows us to evaluate the implications of potential changes in the system and then how these changes may be managed through policy and/or technical interventions. For example, WEAP may be used to evaluate the water supply and demand impacts of a range of future changes in demography, land use, and climate. The result of these analyses will be used to guide the development of response packages, which are combinations of management and/or infrastructural changes that enhance the productivity of the system.

3.2.1.4 Evaluation

Once the performance of a set of response packages has been simulated within the context of future scenarios, the packages can be compared relative to key metrics. Often these relate to water supply reliability, water allocation equity, ecosystem sustainability, and cost, but any number of performance metrics and be defined and quantified within WEAP.

This same approach was used to develop a WEAP application for the San Gregorio Creek watershed. The following sections outline the model development and use of the model in evaluating water management strategies within the basin.

3.2.2 Measured precipitation and streamflow

A review of all available hydrologic and climactic monitoring datasets within the San Gregorio watershed revealed that appropriate long-term hydrologic and climatic data has been collected at only two locations within the watershed: 1) The USGS has been collecting daily streamflow data at San Gregorio since 1969 (with data gaps from 1995-2001 and 2006-2007); 2) The California Department of Forestry and Fire Protection (CDF) has been collecting hourly precipitation data at La Honda since 1989. Figure 3-2 summarizes the total annual (Oct-Sep) values for these data, where the streamflow data is expressed as the cumulative discharge volume over the 52 square miles of the watershed. Average annual values for precipitation and discharge were 23.7 inches and 9.2 inches, respectively.

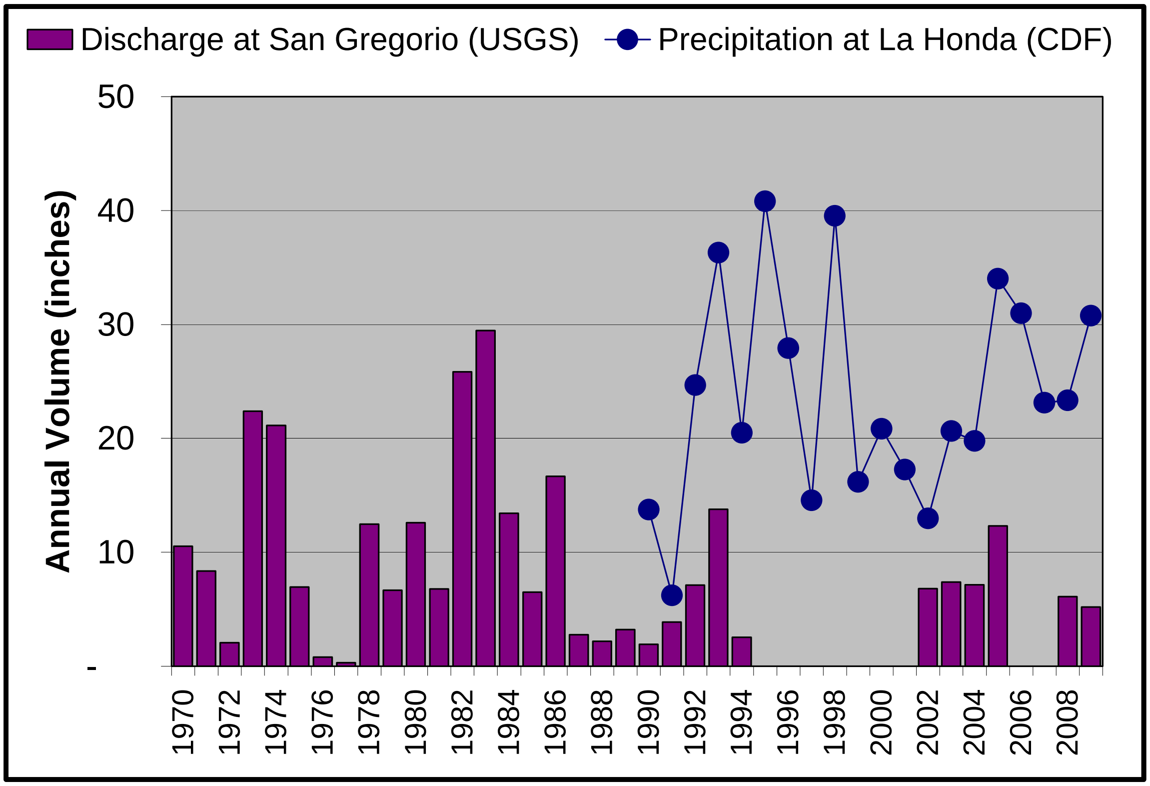

Figure 3-2. Annual (October-September) streamflow and precipitation in the San Gregorio Creek watershed.

A review of these data suggests that there is considerable variability in both precipitation and total annual discharge, with the standard deviation being 9.4 inches for precipitation and 7.4 inches for discharge. It naturally follows that, since streamflow is generated by precipitation, the two parameters are positively correlated (correlation coefficient = 0.73) such that fluctuations in annual discharge reflect changes in precipitation. This data suggests that, on average, 35 percent of the precipitation at La Honda showed up as streamflow at San Gregorio. However, precipitation/streamflow fraction varied from 12 percent in 1994 to 62 percent in 1991.

There are three main factors that may contribute to the year-to-year variability in the percentage of rainfall appearing as streamflow. First, the base hydrologic conditions are dependent upon the previous year's rainfall. That is, high rainfall infiltration during a wet year will increase the soil water storage that is carried over into the following year, such that base flows may be elevated following wet years. This could increase the fraction of rainfall that appears to show up as discharge from the basin. Conversely, base flows may be lower following dry years, which would reduce this fraction.

An evaluation of the USGS measured streamflow for three selected years (1983, 1987, and 1993) suggests that the previous year's rainfall does indeed have an effect on total discharge in subsequent years (Figure 3-3). Baseflow appeared to be sustained at higher levels in the fall of 1987, following a wet year. On the other hand, baseflows were somewhat lower going into the 1993 water year following several dry years, but streamflow quickly rebounded after a couple of early winter storms. In each of the years, total annual discharge was dominated by peak flows generated by winter storm events.

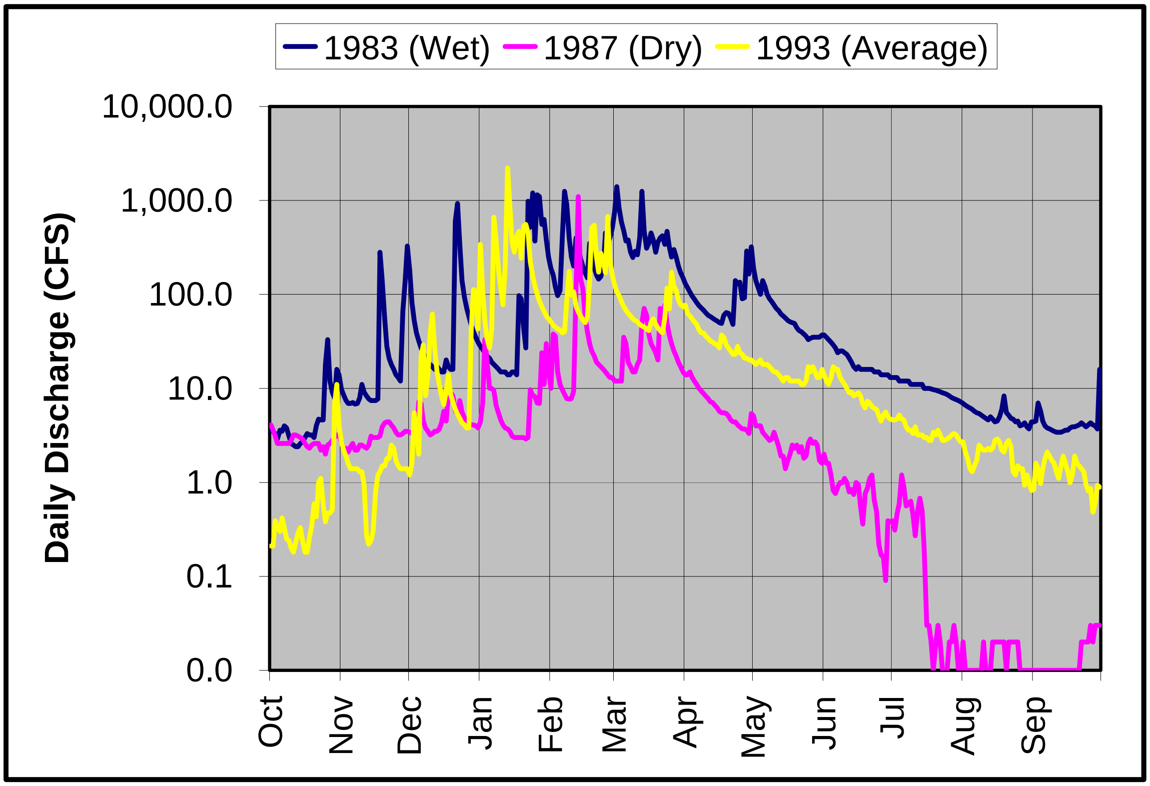

Figure 3-3. Daily streamflow at USGS San Gregorio gauge for three selected years.

The second factor that could change the fraction of rainfall that arrives as streamflow at San Gregorio is total surface water diversions. The adjudication document outlines that approximately 1,416 million gallons (or 1.6 inches of water averaged over the 52 square mile watershed) can be diverted from San Gregorio Creek each year[14]. This represents about 25 percent of the annual precipitation at La Honda in the driest year (1991) and 4 percent in the wettest year (1995). If we assume for a moment that total diversions are fixed at the adjudicated levels, then it follows that a higher percentage of the available water would go to diversions in dry years, which should, in turn, result in a lower fraction of the rainfall arriving at San Gregorio. The data in Figure 3-2, however, do not support this thesis. In fact, no such pattern exists even if we account for increases in diversions (of up to 100 percent of adjudication levels) in dry years.

The third factor that could change the fraction of rainfall that translates to streamflow at San Gregorio is the precipitation data itself. In our discussion so far, we have assumed that the precipitation measured at La Honda is representative of the average rainfall over the whole San Gregorio Creek watershed. There is reason to believe, however, that there is considerable variability in precipitation across the basin. Recent data collected by the Midpeninsula Regional Open Space District in the upper portion of the El Corte de Madera sub-basin recorded annual precipitation of 34.5, 50.0, and 63.6 inches for water years 2004, 2005, and 2006. Measured precipitation at the CDF station in La Honda was significantly less at 19.8, 34.0, and 31.0 inches for the same years.

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[14] Diversion allowances under the adjudication decree should be reviewed and corrected as necessary for future model runs to ensure consistency with total diversion days and stock pond certificates.

Also, previous studies have found that mean annual precipitation is dependent on elevation and ranges from 32 to 40 inches within the watershed (Rantz 1971; Saah and Nahn 1989). While there are no long-term precipitation data to compare within the basin, we evaluated climate station data[15] from the Santa Cruz Creek watershed to confirm this pattern. Climate stations located at Santa Cruz and Ben Lomond are separated by about 10 miles and 320 feet in elevation. Despite their proximity, however, there is a very strong signal of increasing precipitation with elevation (Figure 3-4).

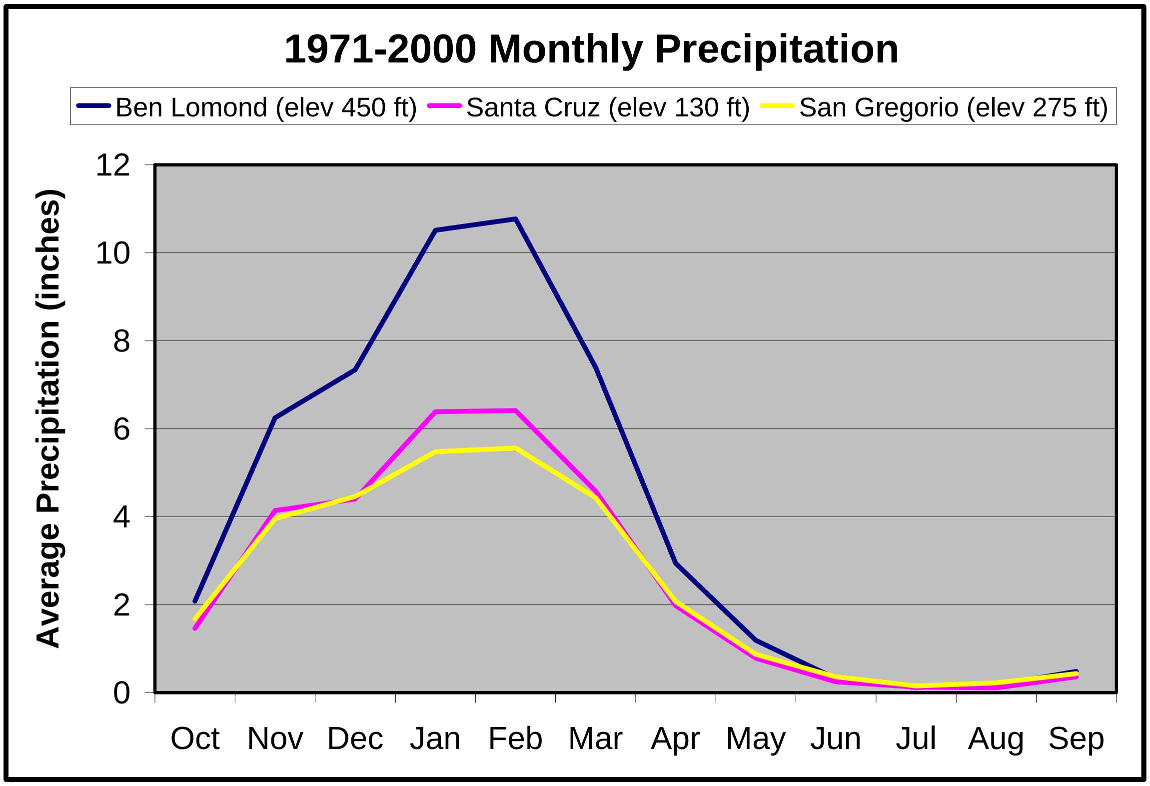

Figure 3-4. Average monthly precipitation for three climate stations in the Santa Cruz mountains.

Our assessment of the long-term climatic and streamflow data shows that we can make only general observations about the hydrology of the basin (i.e., how rainfall translates to streamflow) and the effect of water management (i.e., diversions) on streamflow in San Gregorio creek. To fully understand these interactions would require substantially more data than is presently available. It is possible, however, to use models to estimate and evaluate some of the interactions that influence water flows throughout the basin that the data do not presently capture.

We can use the information we have available regarding physical characteristics of the watershed, and the distribution of water demands within it, to build hydrologic and water management models of the San Gregorio basin. Since these models will be calibrated using the limited historical measurements previously discussed, these models will by necessity be imperfect representations of the watershed, and their spatial refinement will reflect the aggregate nature of

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[15] Data obtained from the Western Regional Climate Center http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca0674

these limited data. That said, all models are by definition imperfect representations of reality and the modeling tools developed to date for the San Gregorio watershed can provide significant value as first-order screening tools to explore the ‘large-scale’ implications of proposed management alternatives. This process will, in turn, highlight data needs and guide future data collection efforts within the basin. The development and application of such a tool is presented in the following sections.

3.2.3 Hydrography

San Gregorio Creek is a fourth order perennial stream with an average annual discharge of approximately 26,300 acre-feet (36.4 cfs), as recorded by the USGS gauge at Stage Road (#11162570) near the town of San Gregorio. It is fed by eight named major tributaries and a number of smaller unnamed tributaries that flow into the trunk from the north and west. The eight named tributaries (listed in descending order of approximate size) are:

1. El Corte de Madera Creek
2. La Honda Creek (Woodruff Creek, tributary to La Honda Creek)
3. Harrington Creek
4. Bogess Creek
5. Mindego Creek
6. Clear Creek
7. Alpine Creek
8. Coyote Creek

Within the WEAP model we defined sub-basins of the watershed for which we estimated rainfall-runoff and river diversions and their combined effect on daily streamflow. To this end, we used the eight tributaries as the basis for delineating sub-basins. The main stem of San Gregorio Creek was divided into four sub-basins that represent areas between tributary inflows. Also, El Corte de Madera Creek was split into two sub-basins due to the presence of a stream gage at the Virginia Mill Trail, which was used to help calibrate the model. This resulted in twelve sub-basins (Figure 3-5).

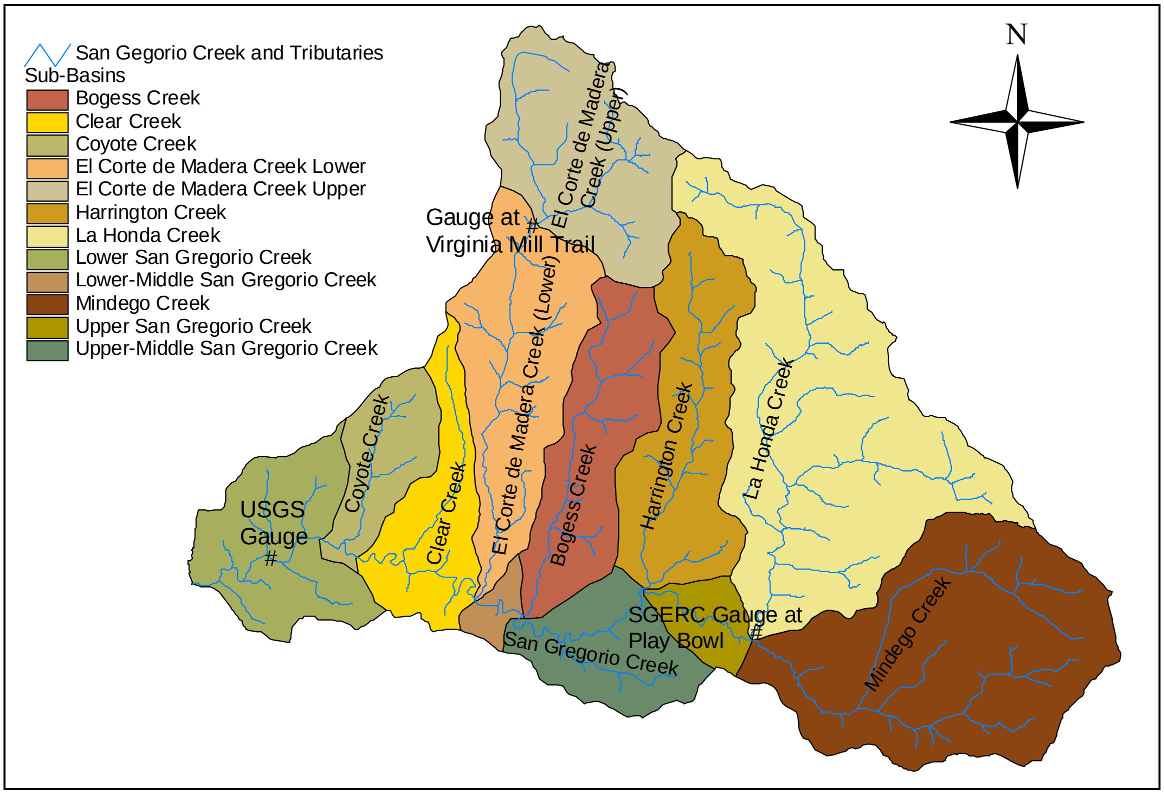

Figure 3-5. Sub-basins of San Gregorio Creek watershed used in the WEAP model.

3.2.4 Hydrology

In the WEAP model, the twelve sub-basins define the contributing areas for runoff within the watershed. Using the climate data (precipitation, temperature, and relative humidity) as model drivers, we used WEAP's soil-water balance routine to generate for each of the sub-basins the hydrologic response. That is, we represented in WEAP the partitioning of precipitation between: 1) rainfall-runoff that discharges surface water directly into local streams, 2) evapotranspiration that returns water back to the atmosphere, and 3) infiltration that is either stored within the soil, discharged back to local streams through interflow, or percolated to the groundwater (see Figure 3-6).

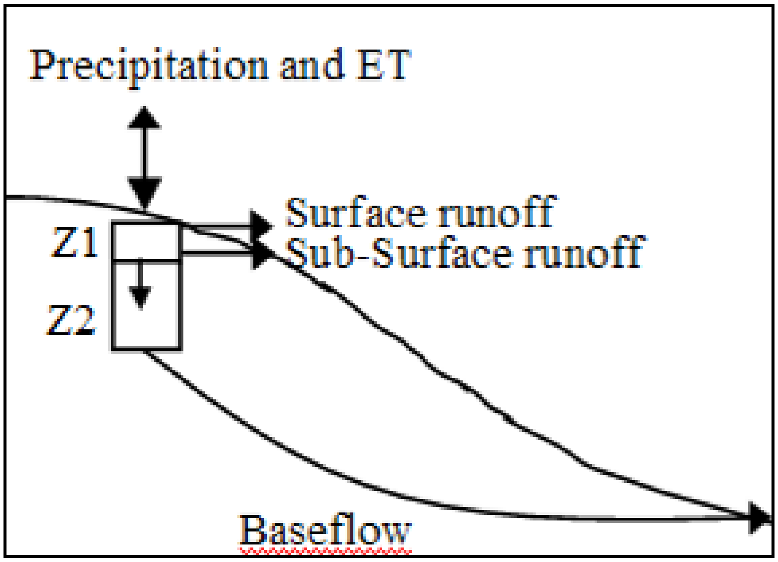

Figure 3-6. Conceptual hydrologic model.

WEAP uses a lumped-parameter hydrology module to approximate the critical hydrologic processes making use of a few key parameters given for each fractional area. These include a plant/crop coefficient (K_c) that in combination with an estimate of potential evapotranspiration determines evaporative losses; a conceptual runoff resistance factor, with higher values reducing rapid surface runoff; and water holding capacity and hydraulic conductivity parameters that determine the slower, interflow response and its seasonal fluctuation. A partitioning fraction (preferred flow direction) determines whether water moves horizontally or vertically.

The hydrologic response of each sub-basin is uniquely defined by its topographical, geologic, and land use characteristics. These characteristics inform WEAP's hydrology module, which determines rainfall-runoff responses for the various sub-basins. We made a first-order approximation at describing these characteristics by dividing each sub-basin into unique fractional areas according to land use descriptions obtained from the USEPA's National Land Cover Data (Figure 3-7) and geologic information from Jennings (1977) geologic map of California (Figure 3-8). These data are summarized for each sub-basin in Table 3-1. While more detailed data sources were available, these were selected as appropriate data sources to reflect the level of input and observation data available for model development and calibration. The goal was to maintain a consistent data resolution level to avoid developing an unnecessarily (or worse, misleadingly) over-parameterized model.

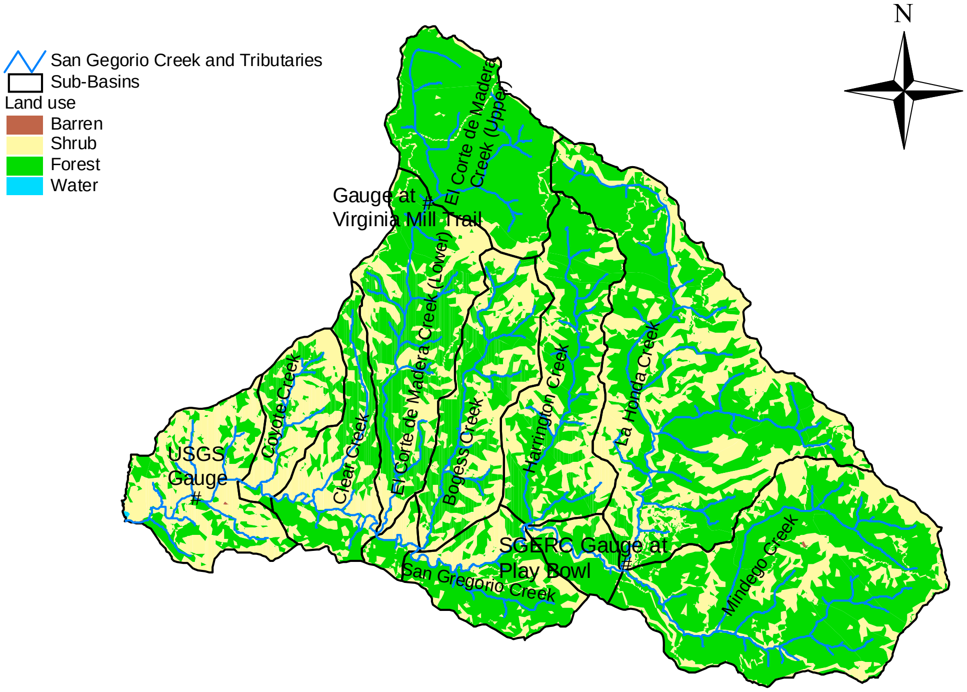

Figure 3-7. Land use within San Gregorio Creek watershed used in the WEAP model.

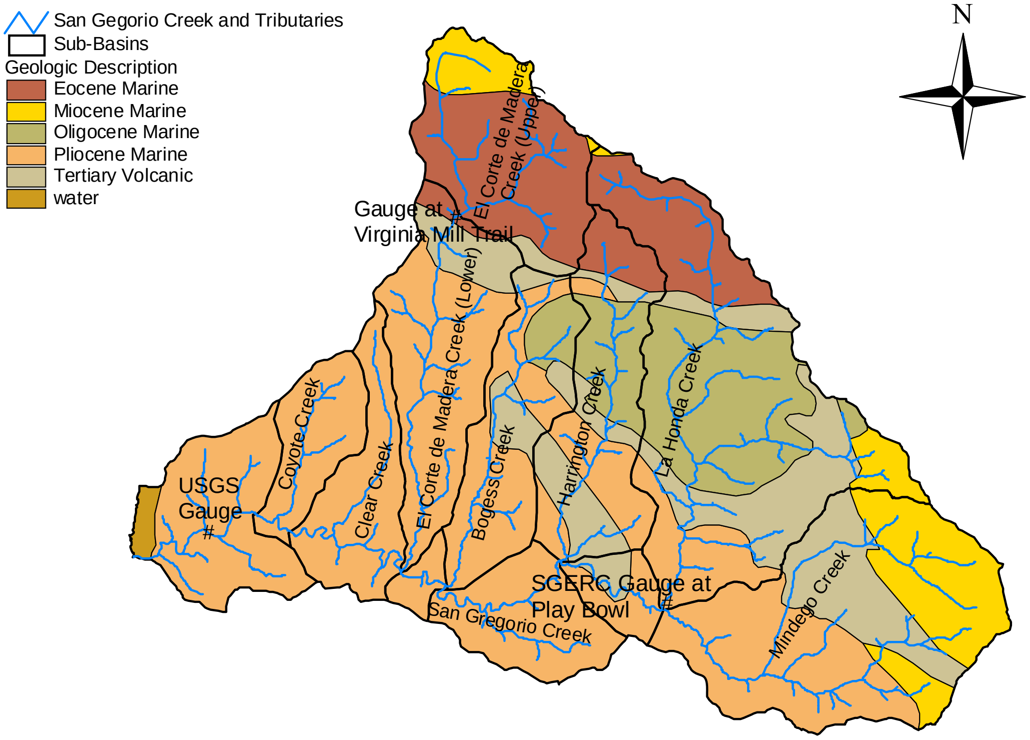

Figure 3-8. Geology of San Gregorio Creek watershed used in the WEAP model.

Table 3-1. San Gregorio Creek watershed land uses and geology used in the WEAP model.

Sub-basin	Area (mi^2)	Forest		Shrub	
		Non-volcanic	Volcanic	Non-volcanic	Volcanic
La Honda Creek	11.28	48	14	28	10
Mindego Creek	9.20	57	17	19	7
San Gregorio Creek (between La Honda Creek and Harrington Creek)	1.00	55	16	16	13
Harrington Creek	4.75	46	20	26	9
San Gregorio Creek (between Harrington Creek and Bogess Creek)	2.61	65	0	35	0
Bogess Creek	3.93	47	10	34	9
San Gregorio Creek (between Bogess Creek and El Corte de Madera Creek)	0.45	47	0	53	0
El Corte de Madera Creek (Lower)	5.01	54	10	30	6
El Corte de Madera Creek (Upper)	4.74	91	2	5	2
Clear Creek	2.77	52	0	48	0
Coyote Creek	1.96	35	0	65	0
San Gregorio Creek (Lower)	3.56	30	0	70	0

The NLCD vegetation data included 29 land cover classes that were aggregated into four land cover classes for the San Gregorio watershed: barren land, forest, shrub, and water. These aggregations were based on the similarities in hydrological properties, such as transpiration rates and leaf area index. This characterization of land uses within the watershed resulted in a further aggregation of land cover classes to just two main land classes – Forest and Shrub – because the total watershed area coverage associated with open water and barren lands is not significant for the purposes of this model.

With respect to geology, anecdotal evidence suggests that volcanic and non-volcanic areas influence rainfall-runoff differently. While it may be difficult to detect this with the limited streamflow data available for the basin, evidence of this may appear at two gages: Virginia Mill trail and Play Bowl (see Figure 2-6). As such, we have included in the model a distinction between these two general geologic types.

3.2.5 Climate

Due to the large variation in temperature and precipitation over the study area caused by orographic effects, and the relatively limited available weather data, we opted to use interpolated weather data as input to the model. The DAYMET[16] data set (Thornton et al. 1997) is a model that generates daily temperature, precipitation, and relative humidity over large areas of complex terrain. The DAYMET method interpolates climate station data using a spatial convolution of a truncated Gaussian weighting filter. Sensitivity to the typical heterogeneous distribution of stations in complex terrain is accomplished with an iterative station density algorithm. This method also adjusts for temperature and precipitation changes with elevation by applying spatially and temporally explicit empirical analyses of these relationships. For each of the twelve sub-basins, we obtained from DAYMET a single time-series record of daily temperature and precipitation for the calendar years 1980-2003.

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[16] Made available by the Numerical Terradynamic Simulation Group (NTSG) at the University of Montana at http://www.daymet.org/

3.2.6 Water use

We used the adjudication document for the San Gregorio Creek basin (Superior Court of San Mateo, Decree #355792) to define the system demands for the water planning model. As discussed above, for each water right the adjudication defines the type of water usage, the priority for delivery, the volume of annual allowable diversions, the time period during which diversion are permitted, and the associated point of diversion.

We began by grouping all of the points of diversion that fell within each sub-basin. Figure 3-9 shows the 258 known points of diversion within the watershed and their distribution among the twelve sub-basins. Table 3-2 tabulates these points of diversion by their associated sub-basin.

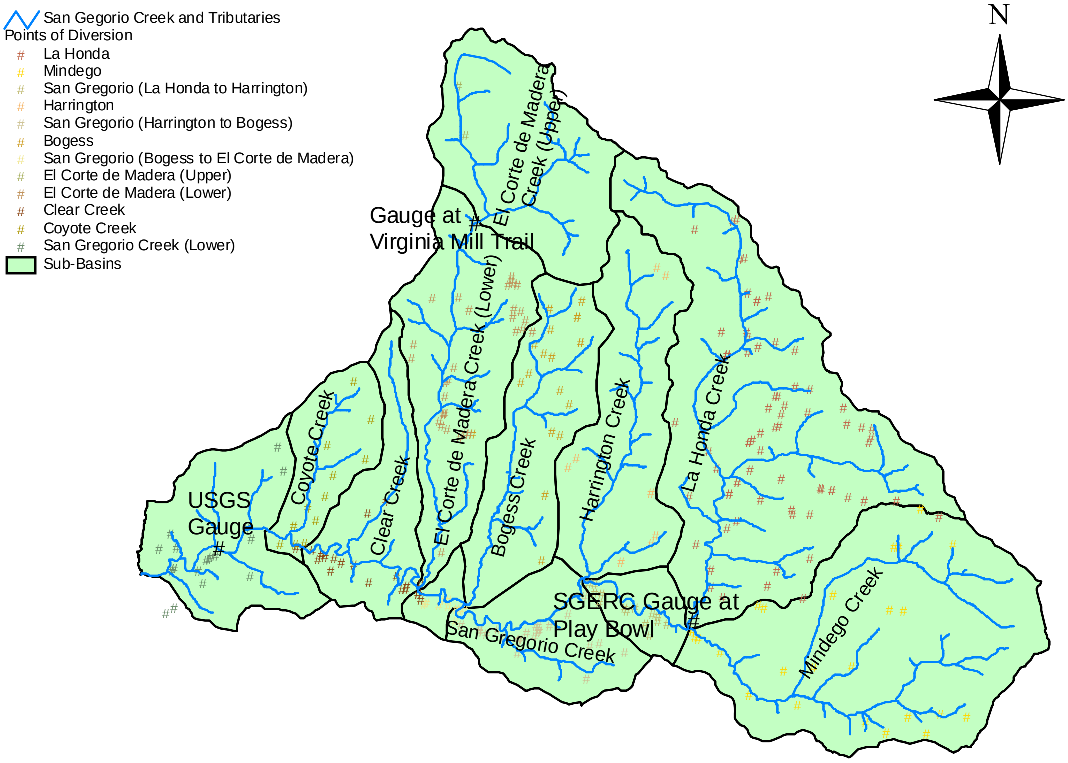

Figure 3-9. Points of diversion within the San Gregorio Creek watershed.

Table 3-2. Points of diversion within San Gregorio Creek watershed sub-basins.

Sub-basin	Diversions
La Honda Creek	1–75b
Mindego Creek	76–99
San Gregorio Creek (between La Honda Creek and Harrington Creek)	100–106; 115–199
Harrington Creek	107–114
San Gregorio Creek (between Harrington Creek and Bogess Creek)	120–138a
Bogess Creek	139–160

Sub-basin	Diversions
San Gregorio Creek (between Bogess Creek and El Corte de Madera Creek)	161–168
El Corte de Madera Creek (Upper)	169–169a
El Corte de Madera Creek (Lower)	170–196
Clear Creek	197–215a
Coyote Creek	216–221
San Gregorio Creek (Lower)	222–241

In addition to distributing demands among the sub-basins, we grouped the various demands based on the five water use types and three levels of priority established in the adjudication. Table 3-3 shows the overall distribution of these demands across the entire basin. This table shows that: (1) the first priority demands for water are almost exclusively domestic (96%), and (2) the second priority demands are by far the largest class of demand (94%) with irrigators representing the bulk (93%) of all water demands within the basin.

Table 3-3. Watershed demands (in million gallons per year) by priority and water use type.

Priority	Water use type					
	Domestic	Fish culture	Industrial	Irrigation	Stock watering	Total
1st	78.6	--	--	4.4	--	**82.2**
2nd	3.8	0.4	1.5	1,309.4	18.3	**1,333.3**
3rd	--	--	0.5	--	--	**0.5**
Total	**81.6**	**0.4**	**1.9**	**1,313.8**	**18.3**	**1,416.0**

Within each sub-basin we grouped water demands according to these same water use types and priorities. Figure 3-10 shows how these demands are distributed across the sub-basins. The graph shows that: (1) almost all of the domestic demand is in the eastern part of the basin; (2) irrigation demands are highest in the western (downstream) part of the basin; and (3) the third priority demands are negligible.

The above demands are used to characterize the demands within the WEAP model. Given the uncertainty in the historical diversions, we have assumed for the purposes of this analysis that these demands are sufficient to describe the baseline situation within the San Gregorio Creek basin. Actual diversions authorized by the Decree fluctuate from year to year and are not used in full in most years. This may be offset, however, by other unauthorized diversions, which are difficult to quantify, but are suspected of significantly influencing the total amount withdrawn from the creek.

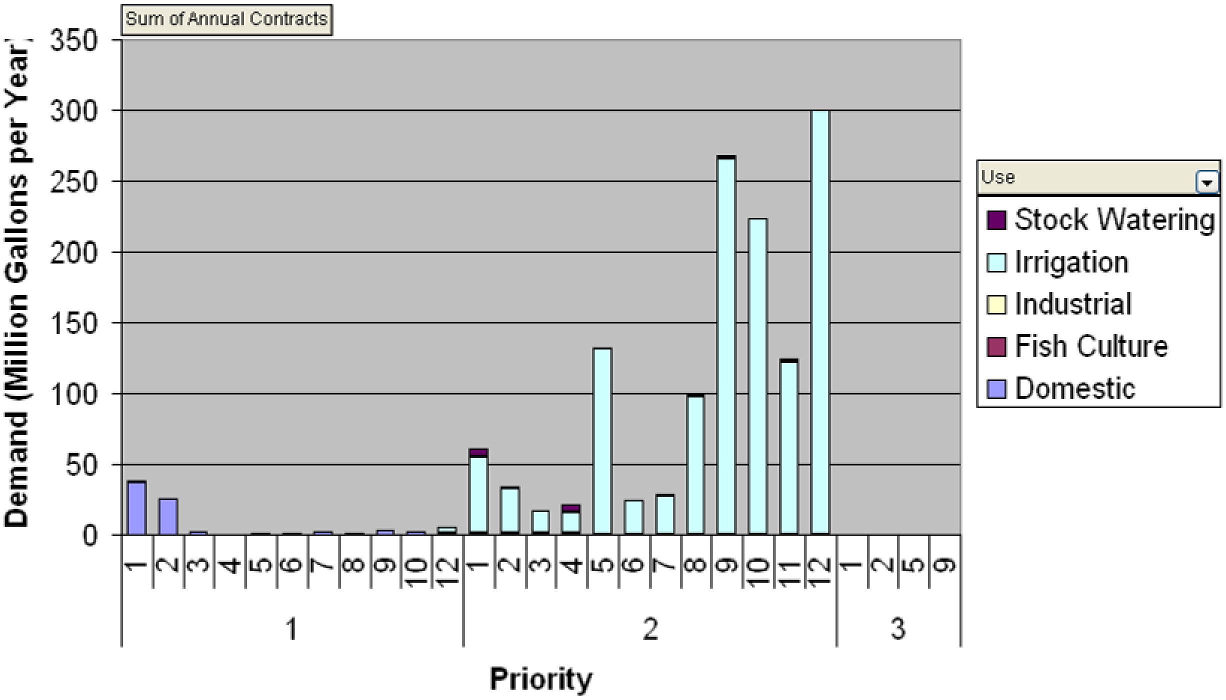

Figure 3-10. Water demands within the 12 San Gregorio Creek watershed sub-basins[17].

3.2.7 Model schematic

The features of the San Gregorio Creek watershed discussed in the previous sections are represented in WEAP using the model's link-node architecture. In this configuration, water moves through the basin via "links" that represent river reaches, diversion canals, drainage ditches, etc. These links are used to connect water sources (reservoirs, groundwater, catchments, etc.) with demand sites, which are represented in WEAP as model "nodes."

The model schematic for San Gregorio Creek is shown in Figure 3-11. This schematic shows that for each sub-basin there is a single "catchment" (green circle) that is used to evaluate the hydrologic response. This rainfall-runoff signal is transmitted to associated tributaries and river reaches (solid blue lines) through "runoff/infiltration" links (dashed blue lines). Water is then diverted from the creeks to "demand sites" (red dots), which are grouped according to priorities, through "transmission links" (solid green lines). Some fraction of these diversions may return to creeks as "return flows" (solid red lines). A minimum bypass flow requirement (purple bull's eye) represents another water demand near the outlet of the watershed. When water supplies become limited this flow requirement competes with other consumptive demands in the basin and receives water according to an assigned priority.

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[17] The sub-basins are 1) La Honda Creek, 2) Mindego Creek, 3) San Gregorio Creek (between La Honda Creek and Harrington Creek), 4) Harrington Creek, 5) San Gregorio Creek (between Harrington Creek and Bogess Creek, 6) Bogess Creek, 7) San Gregorio Creek (between Bogess Creek and El Corte de Madera Creek), 8) El Corte de Madera Creek (Upper), 9) El Corte de Madera Creek (Lower), 10) Clear Creek, 11) Coyote Creek, and 12) San Gregorio Creek (Lower)

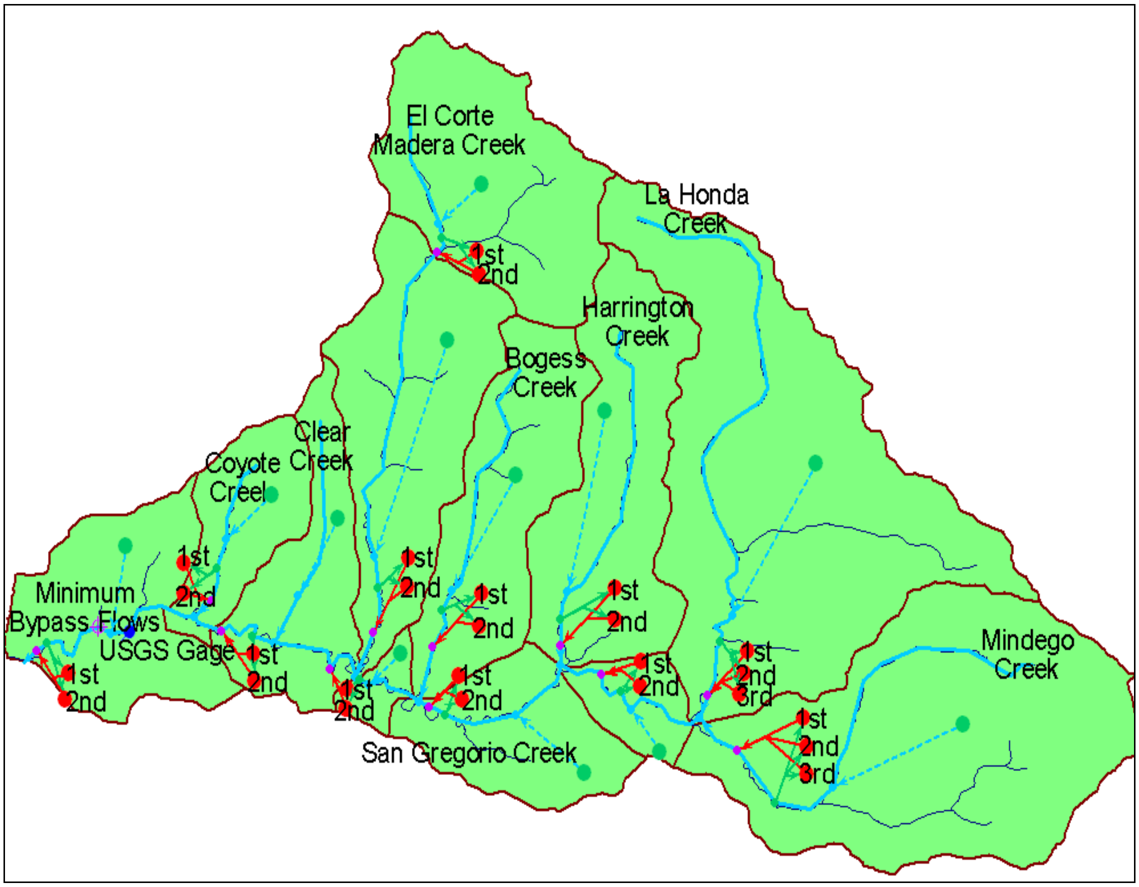

Figure 3-11. WEAP model schematic.

3.3 Model Calibration and Results

The goal of the calibration was to find a set of model parameters that would reproduce the key features of the flow hydrograph throughout the study area. Due to the relative dearth of stream gages within the watershed, it was not possible to calibrate individual sub-watersheds. It is anticipated that spatial resolution will be improved through future data collection efforts and continued model refinement. As such, the current calibration focused on matching the overall annual water balance for the entire basin as measured by the USGS streamflow gage at San Gregorio.

The model calibration focused on the historical period for which concurrent streamflow (USGS) and climatic (Daymet) data exists: water years 1981-1994 and 2002-2003. We were fortunate to capture a range of water year types within this record, including an extended drought from 1987-1992. This allowed us to test the response of the WEAP model under a range of hydrologic conditions. To test the accuracy of model outputs, we looked at changes in daily streamflow as well as cumulative annual discharge at San Gregorio.

The calibration parameters focused on the physical characteristics for which we had limited data. These included the water holding capacity and hydraulic conductivity of soils, the preferred flow direction of infiltrated rainfall (i.e., towards groundwater recharge or interflow to local streams), and a runoff resistance factor that accounts for the attenuation of rainfall runoff due to physical factors such as slope and the density of vegetative ground cover.

The results of the calibration are shown for three "representative" water years in Figure 3-12 selected to represent the range of runoff conditions from very wet (e.g., 1983 was the wettest year of record for the San Gregorio gage) to dry. These graphs show that the WEAP model captures both the changes in daily streamflow and the total annual discharge under the range of observed hydrologic variability. In all years, the WEAP model accurately simulated winter storm events and maintained base seasonal flows at levels comparable to those observed at San Gregorio. The simulations, however, did not consistently track the falling limb of the seasonal hydrograph (i.e., decreasing flows in late spring and summer) for all years and tended to underestimate these flows in average and wet years. It is important to note these limitations in the model calibration, and to consider this trend when evaluating streamflow management scenarios in the following section.

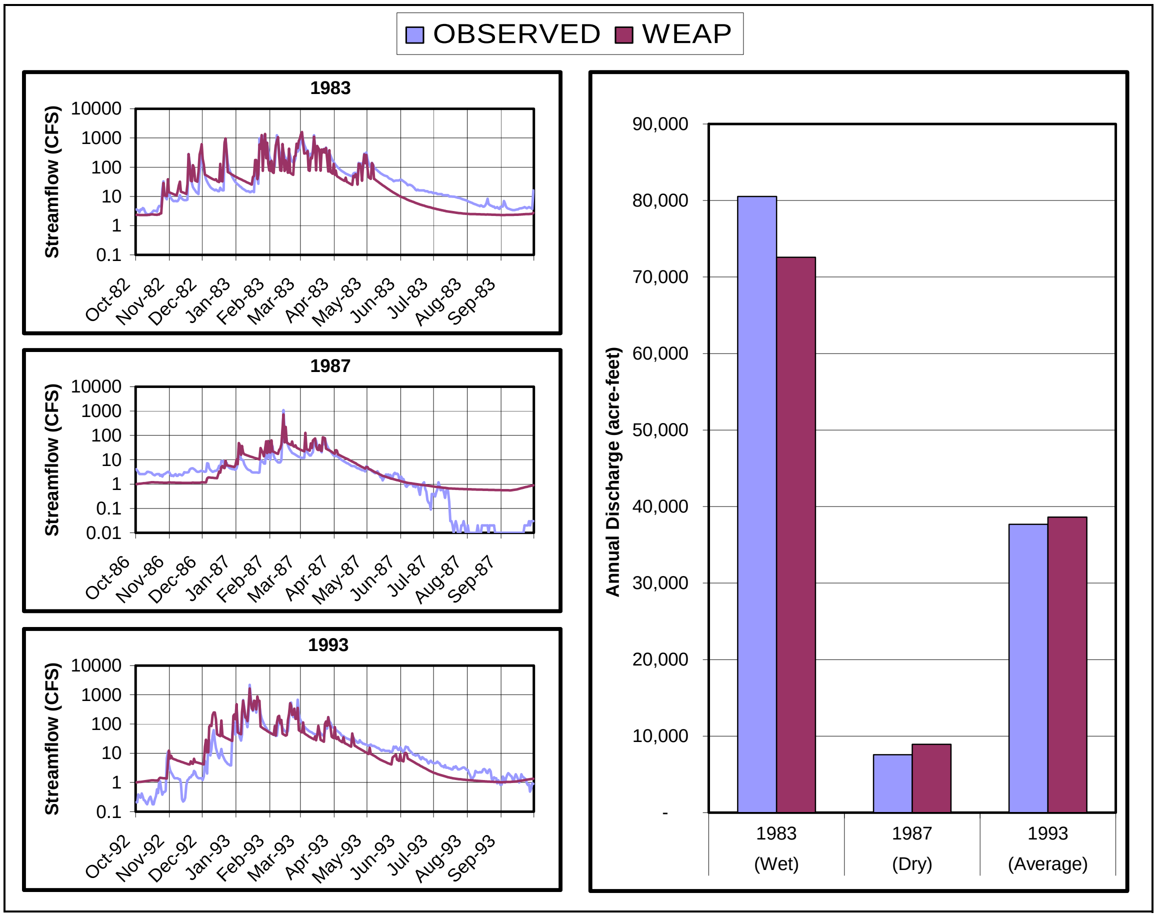

Figure 3-12. Observed and simulated streamflow at USGS San Gregorio gauge.

3.4 Evaluation of Management Strategies

The WEAP model provides us with a tool to account for the movement of water throughout the San Gregorio Creek watershed. This tool allows us to assess the interactions between surface water diversions and streamflow reliability at different locations throughout the basin. Within this context, we used the tool to consider different management strategies and to evaluate the impact of these strategies on supply reliability. For this evaluation, water supply reliability was assessed with regard to the systems ability to satisfy minimum ecological flow requirements and meet the adjudicated water demands of diverters throughout the basin. The management strategies that we considered included establishing a minimum bypass flow target at San Gregorio, and constructing off-stream storage facilities to enhance water supplies during the irrigation season. Because inter-annual climatic variability will greatly influence the effectiveness of each management strategy, impacts were evaluated for water years that represent a range of dry, average, and wet conditions years (i.e., 1983, 1987, and 1993).

3.4.1 Minimum bypass flows

The San Gregorio Creek adjudication established a minimum bypass flow requirement of 2 cfs during most of the summer and fall for all new, post-adjudication water diversions (or activation of unexercised riparian rights) in the watershed[18]. Although this requirement does not apply to existing, adjudicated water diversions, it does provide a baseline for evaluation of potential water supply management scenarios[19].

Discharge from the San Gregorio Creek basin is often less than the 2 cfs minimum flow standard established (with the above described limitations) in the adjudication. Figure 3-13 shows that over the past 40 years (1970-2009) flow at San Gregorio has exceeded 2 cfs only 45.5 percent of summer-fall days (June-November). By way of comparison, daily flows at San Gregorio, in the winter and spring (December-May) exceeded 2 cfs 93 percent of the time.

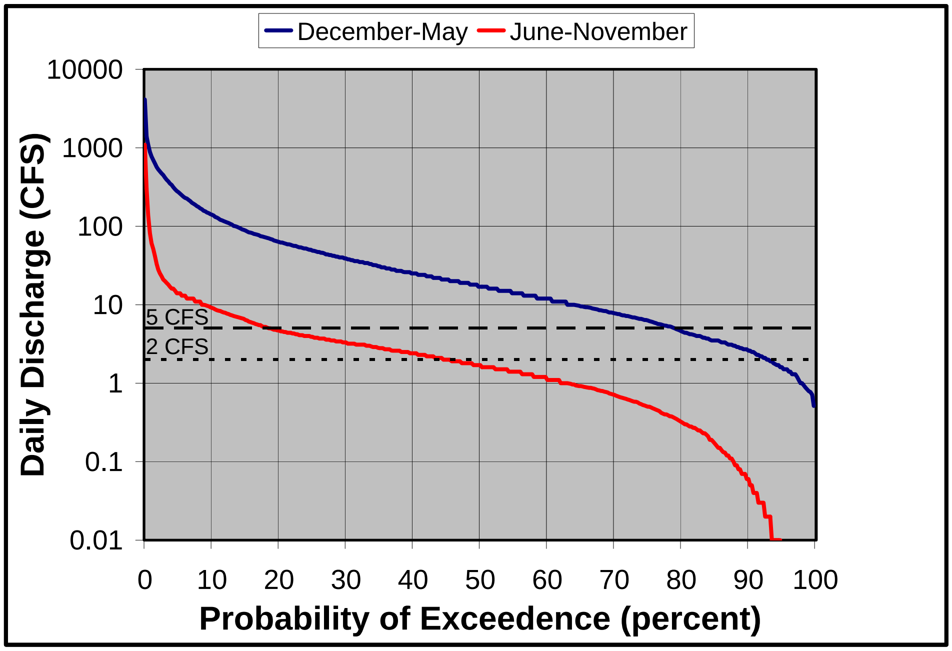

Figure 3-13. Observed summer-fall (June-November) and winter-spring (December-May) streamflow at USGS San Gregorio gauge, 1970-2009.

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[18] 2 cfs from May 1 to 15 June when the sand bar is closed; and 2 cfs or the entire streamflow, which ever is less, from 16 June to 30 November.

[19] It should be noted that the 2 cfs minimum instream flow baseline may underestimate flows necessary to support the full range of desired fisheries. The recovery strategy for California coho salmon (CDFG, 2004) states that the prescribed bypass flow is too low to assure viable coho salmon populations. In addition, CDFG (1995) identifies critically low flows in the draught years of the late 1970s as being at least partially responsible for the extirpation of coho salmon from the watershed.

We used WEAP to evaluate the streamflow and diversion implications of achieving a 2 cfs bypass flow target at the San Gregorio gage. In this scenario, the bypass flow target was given a priority for water allocation equal to that of diverters with 1st priority adjudicated water rights. Figures 3-14 and 3-15 compare the results of this scenario to a reference case in which no target was fixed. These simulations suggest that in wet years the 2 cfs target can be met throughout the year without any change in management. In dry and average years however, maintaining bypass flows requires some reduction in diversion by water users with 'junior' water rights (i.e., 2nd and 3rd priority adjudicated rights). For the simulation years selected, this translated into delivery/diversion reductions of 90 million gallons for the dry water year (1987) and 45 million gallons for the average water year (1993). Further, the diversion reductions were sufficient only to sustain the 2 cfs bypass flows for the duration of the average year, but not in the dry year. In the dry year, streamflow began to taper off after July 1st and gradually declined to 1.57 cfs by the end of September.

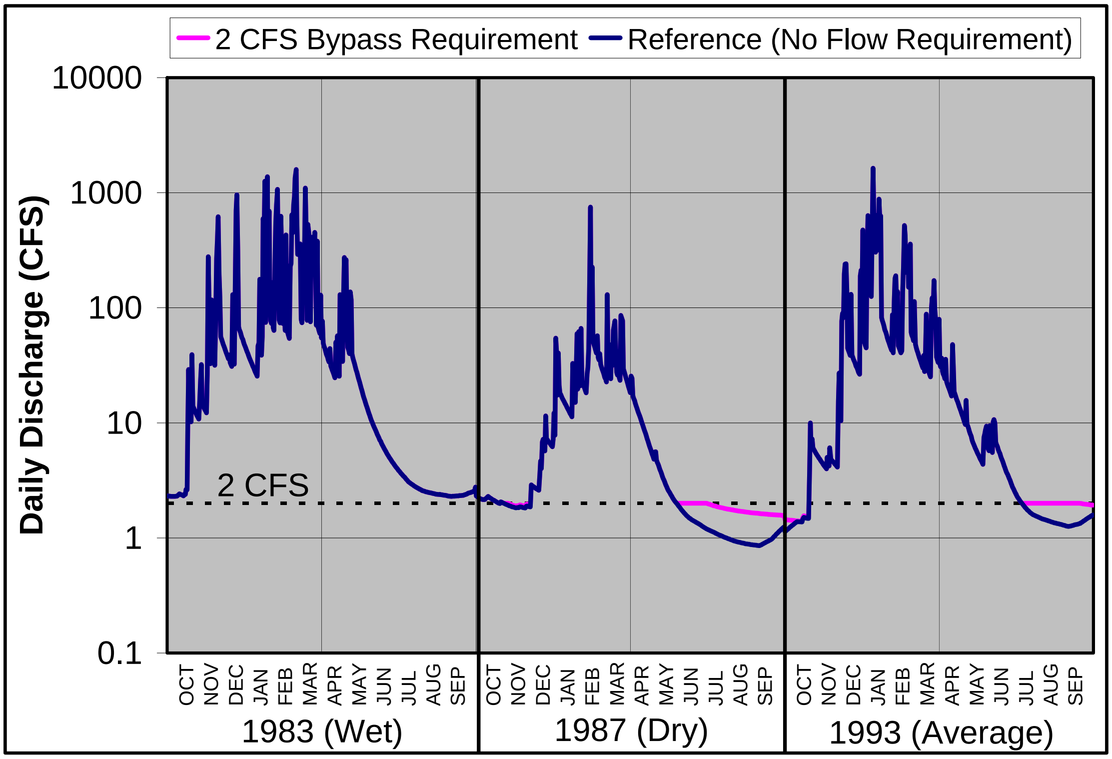

Figure 3-14. Effect of bypass flow target on average daily flow at USGS San Gregorio gauge.

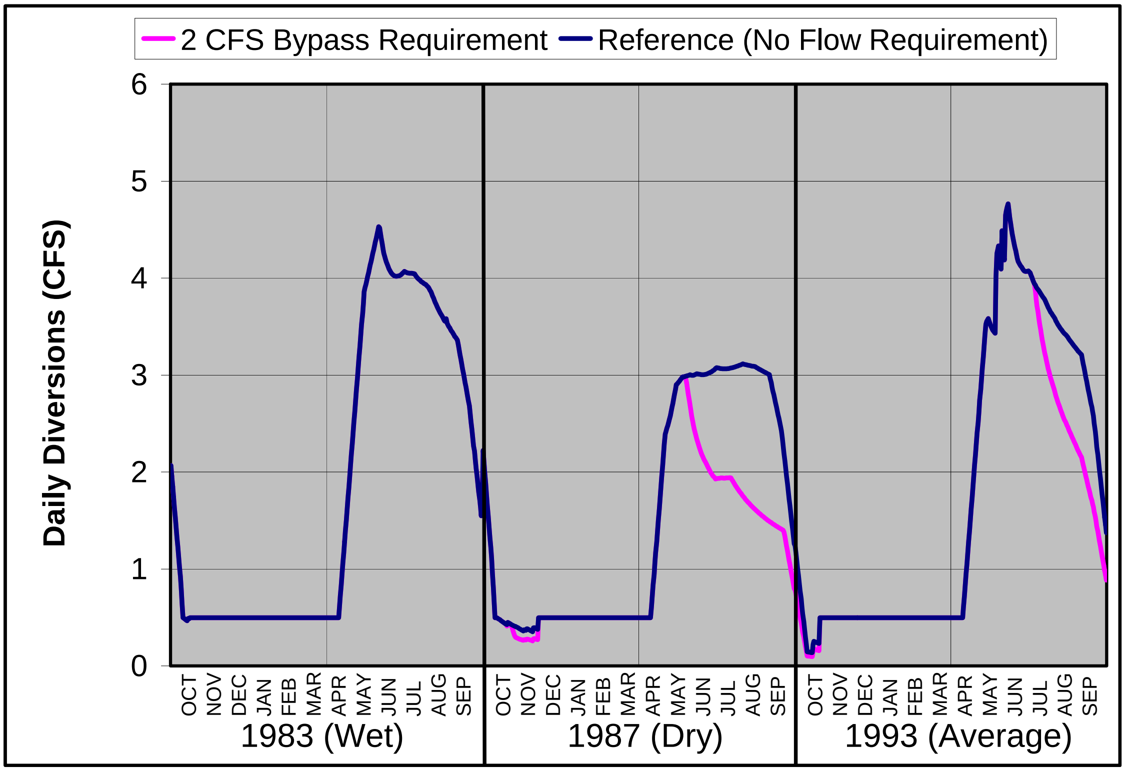

Figure 3-15. Effect of bypass flow target on total daily diversions.

3.4.2 Off-stream storage

The previous simulation results suggest that maintaining bypass flows of 2 cfs will require a reduction in diversions from San Gregorio Creek in most years. However, it may be possible to offset some, if not all, of these reductions by augmenting water storage within the basin through the construction of off-stream water storage facilities.

Off-stream storage (OSS) systems may be a means of ensuring a reliable source of water for irrigators and other diverters throughout the summer months, while minimizing the impacts of stream diversion on the environment. These storage facilities can be operated to capture and store water during the wet winter months, and subsequently, deliver stored water to farmers during the dry summer and fall months. This stored water supply augmentation for the farmers may, in turn, allow additional water to remain instream to support aquatic habitat during the dry season.

Several potential OSS sites have already been identified throughout the San Gregorio Creek basin. The potential storage at these sites varies in size from approximately 3.3 to 16.3 million gallons (10 to 50 acre-feet). For this analysis, we assumed that eight of these sites could be developed to provide 16.3 million gallons each (50 acre-feet) for a total of 130 million gallons (400 acre-feet) of surface water storage. These sites were distributed throughout the watershed in each of the major sub-basins.

This analysis also assumed that the off-stream storage systems were managed in conjunction with minimum summer bypass flow targets at the outlet of the watershed, and within the constraints of the 10 cfs winter minimum bypass flow (discussed above in Section 2.4.2). The off-stream storage systems, however, were not operated to provide water to meet dry season flow target. Rather, all of the water diverted to these storage sites was available only to satisfy local demands and no water was returned directly to San Gregorio Creek to meet downstream demands. With regard to the filling of OSS ponds, the analysis indicates that the quantity of storage considered could be filled without violating the 10 cfs winter by-pass specified in the adjudication decree.

Off-stream storage systems were evaluated within the WEAP model to assess their effectiveness in supporting irrigation demands and aquatic habitat in summer months. Because of the current uncertainty regarding the establishment of an appropriate minimum flow target (e.g., the existing 2cfs minimum flow requirement does not apply to adjudicated diversions, and the Department of Fish and Game (CDFG 2004) has questioned whether even the 2 cfs requirement is sufficient to assure viable habitat for coho salmon) we evaluated the effectiveness of OSS in supporting a range of bypass flow targets: 1, 2, and 5 cfs. The 1 cfs and 5 cfs targets were arbitrarily selected as modeling examples only, and do not necessarily represent desired management goals. The results of these WEAP simulations are presented in Figures 3-16 and 3-17.

The model suggests that with OSS systems in place, there would be little problem in meeting a 1 cfs bypass flow target in most years. In fact, it would require only occasional active management to achieve this target, allowing the off-stream storage systems to be managed solely as a means to increase the efficiency of irrigators' normal surface water deliveries. When bypass flow targets were increased to 2 cfs, off-stream storage systems again enabled enough water to remain instream to maintain the flow target throughout even the driest year. Under this 2 cfs scenario, total surface water diversions were only marginally less than they would have been under a reference case with no flow target and no surface water storage. However, modeling showed that a bypass flow target as high as 5 cfs was difficult to maintain through the summer in even the wettest year. The analysis indicates that a flow target as high as 5 cfs is likely not sustainable, as it came at great cost to irrigators attempting manage their diversions to meet an instream flow level that simply could not be maintained with available streamflows.

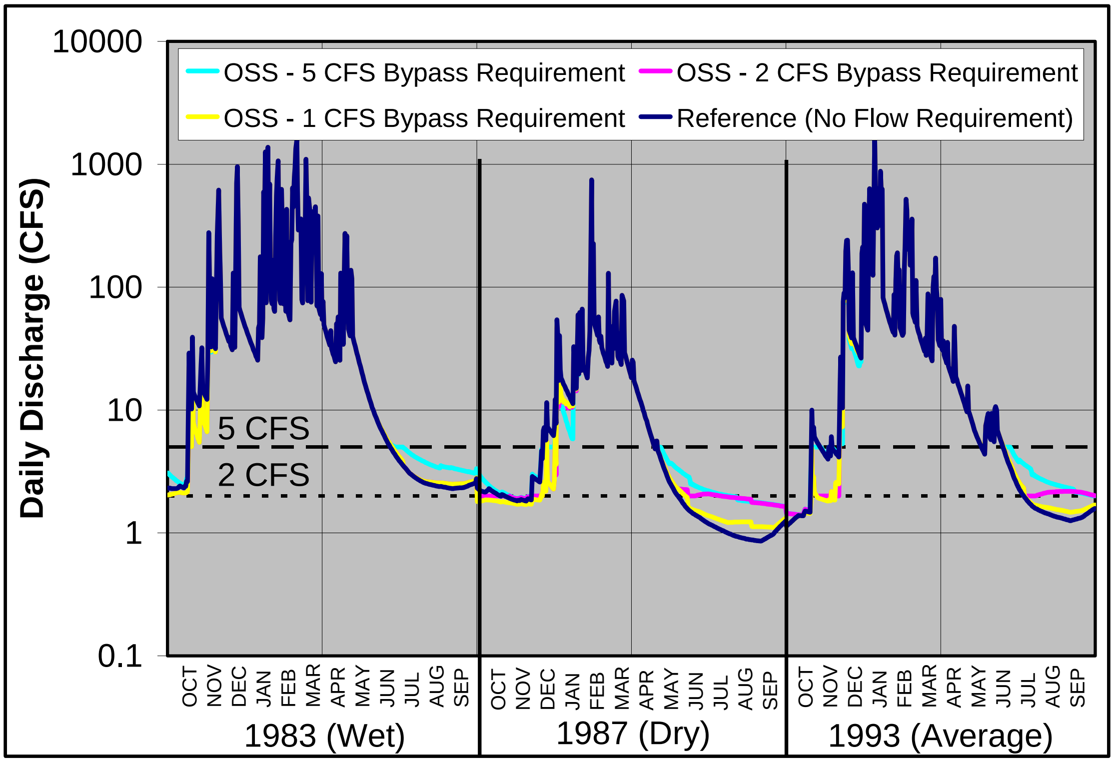

Figure 3-16. Effect of off-stream storage on average daily flow at USGS San Gregorio gauge.

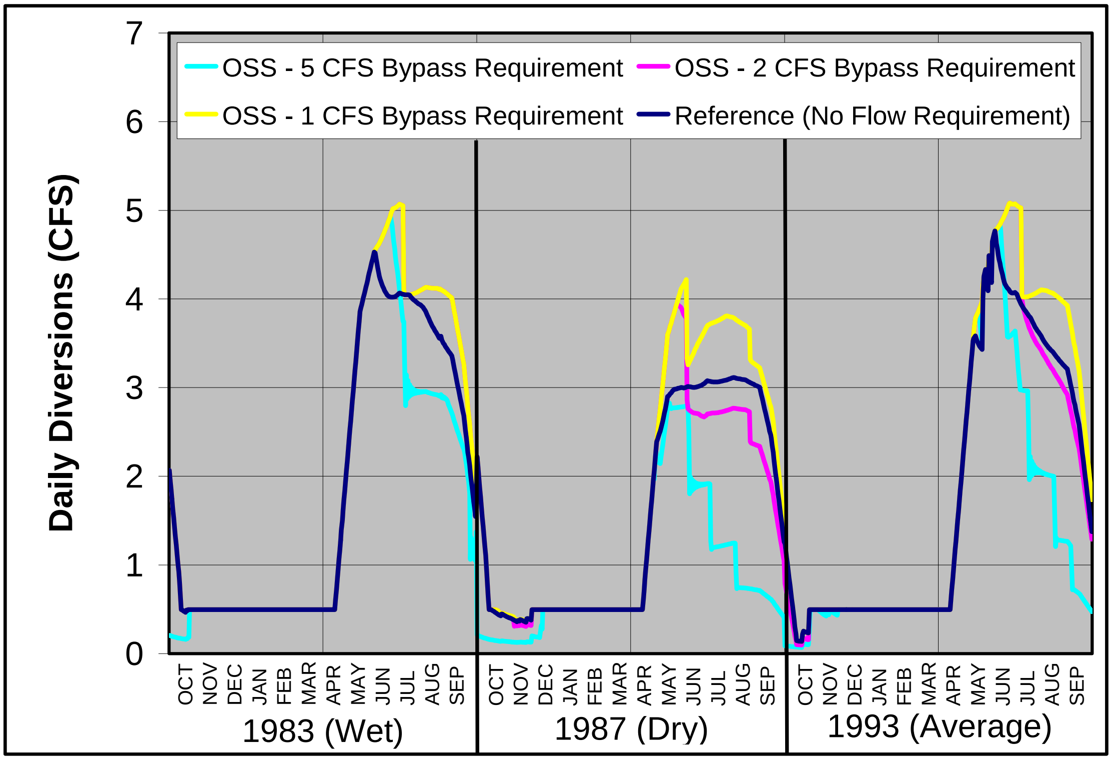

Figure 3-17. Effect of off-stream storage on total daily diversions.

A closer look at the WEAP model results discussed above suggests that it may be possible to re-configure and/or re-operate potential off-stream storage systems to more fully meet water demands and more effectively achieve flow bypass targets. Because of the unequal distribution of water demands in the San Gregorio watershed, the configuration within the WEAP model of off-stream storage as a system of isolated facilities with equal storage capacities and relatively even distribution throughout the basin appears to have led to the general under-utilization of total surface storage within the basin (Figure 3-18). As depicted in Figure 3-10, water demands are not equally distributed throughout the San Gregorio basin. Therefore, in a scenario with equal off-stream storage in each sub-basin, regions with relatively small water demands could meet those demands fully using only a portion of their stored water, while regions with higher demands used all of their stored water to meet only a portion of their demands. Thus, it may be possible to improve OSS performance by reconfiguring the distribution of sites in order to place larger storage facilities in proximity to the larger demand areas. In addition, actively managing OSS systems to achieve instream flow targets (i.e., allowing off-stream storage sites to discharge back to San Gregorio Creek to meet downstream demands) may also improve overall system performance.

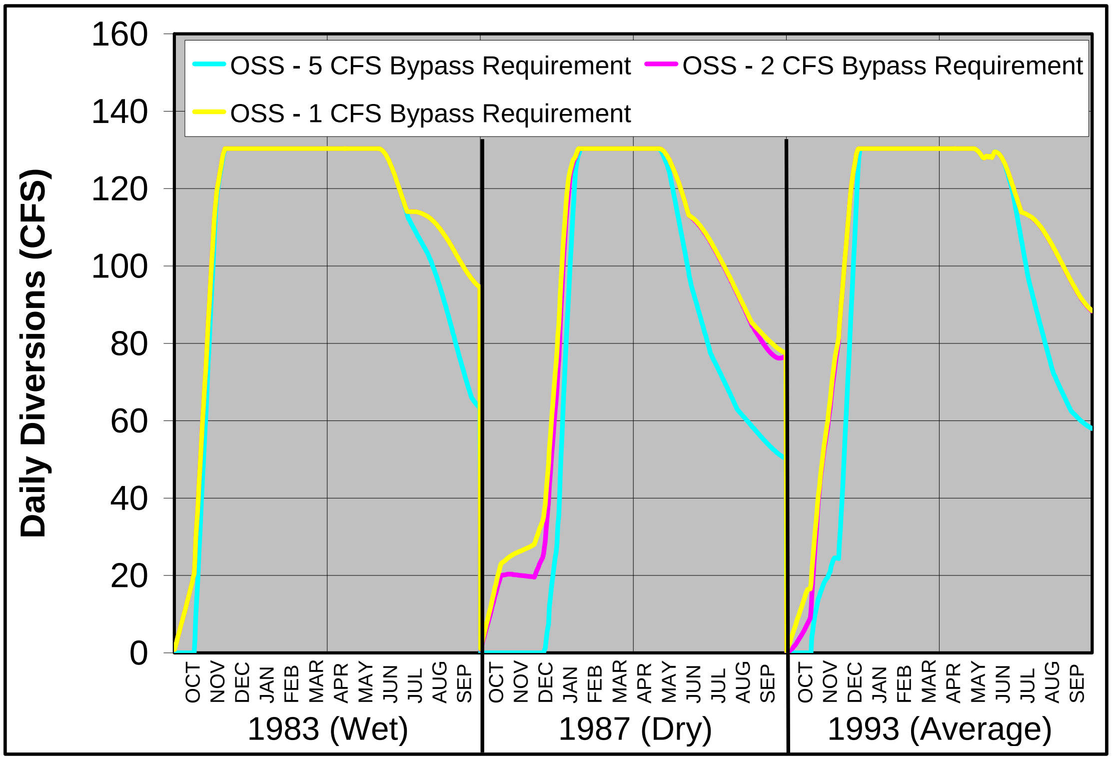

Figure 3-18. Total off-stream storage.

3.5 Hydrologic Assessment Summary and Recommendations

The San Gregorio Creek watershed is a drainage basin in western San Mateo County that has its headwaters in the Santa Cruz Mountains and drains into the Pacific Ocean. The watershed is subject to large seasonal and inter-annual climatic variability, which is reflected in similarly large variations in streamflow within the basin. Most of the total discharge from the basin occurs as brief peaks in streamflow after winter storm events. Baseflows are supported by groundwater discharge, with lowest flows occurring in the dry summer months.

Several researchers have conducted studies of San Gregorio Creek to monitor water quality and the status of aquatic habitat. Few of these efforts, however, have produced long-term records that allow for an accounting of water supply and delivery throughout the basin. Thus, we had to rely on modeling tools to estimate these flows. The Water Evaluation and Planning (WEAP) model provided us with such a tool to account for the movement of water throughout the San Gregorio Creek watershed. This tool allows us to assess the interactions between surface water diversions and streamflow reliability at different locations throughout the basin.

The WEAP tool was applied to consider different management strategies and to evaluate the impact of these strategies on supply reliability to satisfy minimum ecological flow requirements and to meet the water demands of the various diverters throughout the basin. The management strategies considered included establishing a minimum instream flow target at San Gregorio and constructing off-stream storage facilities to enhance water supplies during the irrigation season. Model results of these scenarios suggest that maintaining bypass flows in dry and average years requires some diversion reduction by water users with 'junior' water rights. Off-stream storage, however, presents a promising strategy for increasing dry season streamflows while protecting consumptive water supplies. Initial estimates suggest that several small, isolated facilities would allow water users to continue to divert at previous levels while bypass flows are met at levels called for under the adjudication agreement (2 cfs). These facilities could be constructed as a group or sequentially to allow for incremental improvement of summer stream flows. These model results also suggest that the overall system performance may be further improved if off-stream storage sites are permitted to discharge back to San Gregorio Creek to meet downstream demands, and/or the capacities of the OSS sites are sized relative to local demands such that larger storage facilities are placed in proximity to larger demands.

The WEAP tool was developed using existing data that was limited in its ability to fully account for water management within the San Gregorio Creek watershed. This allowed for the development of a tool that can consider the large-scale impacts of different water management strategies, but until more data is collected, can not estimate with certainty the local impacts of these actions. To refine the tool to allow analysis at a local level of detail would require the calibration of the model to a fuller set of metrics (i.e., tributary inflows, local diversions, etc.). It is not recommended that an effort be undertaken at this time to collect all the data necessary for a full accounting of water diversions, since this would require monitoring scores of small diversions to San Gregorio Creek, which is likely cost prohibitive. However, it may be feasible to collect some targeted data that would allow for a more refined estimation of water balances.

To begin, it would be of great value to collect data that quantifies inflows to San Gregorio from its major tributaries. It is recommended that gauging stations be installed on San Gregorio Creek downstream of each of the largest tributaries. This would lead to a better understanding of the hydrology of the basin.

Also, because only one long-term climate station exists within the basin, the WEAP model relied upon simulated climate data to estimate the distribution of precipitation and temperature, both of which vary considerably with elevation. It was found that the simulated data set was not always consistent with observed records. To rectify this, it is recommended that additional climate stations be installed to allow for a better understanding of the spatial variability of precipitation and temperature within the watershed. This effort would require strategically placing climate stations at different elevations within one or multiple sub-basins of the San Gregorio Creek watershed, with the goal of developing of equations that relate climatic measurements to a reference station.

4 LIMITING FACTORS ANALYSIS

4.1 Approach

This Watershed Management Plan uses an LFA approach to determine the likely causes of adverse impacts (i.e., the limiting factors) to the populations of four selected focal species. This was done to identify specific restoration and management actions that can be taken to address the limiting factors, as well as recommendations for focused studies that may be needed to further refine our understanding of limiting factors. An LFA integrates the effects of habitat carrying capacity and density-independent mortality (i.e., sources of mortality such as water temperature or disease with effects that are not dependent on the density of the population) across the entire life cycle of a species to determine mechanisms regulating population growth.

This LFA began by reviewing literature on the LFA focal species, and local reports of instream conditions and focal species populations from the WIS, to develop general conceptual models of life history and habitat constraints for each species. From the conceptual models, our knowledge of watershed conditions, and the results of the WEAP modeling, initial hypotheses about the factors potentially limiting the species' populations in the San Gregorio Creek watershed were developed. Several initial hypotheses were refined based on a focused field study conducted in October 2008 to assess juvenile salmonid summer habitat conditions and overwinter survival. These conceptual models and initial hypotheses are presented below.

After conducting an LFA, initial hypotheses are accepted, rejected, or refined, based on new understanding of the system, and new uncertainties are identified. Ultimately, the results of the LFA are used to develop restoration and/or management actions that address the factors identified as limiting production, and to suggest future studies to test additional hypotheses and uncertainties. These recommendations are presented in Section 5. The iterative process of hypothesis development, testing, and refinement provides an adaptive and efficient process for identifying restoration strategies and any additional priority studies for the conservation and support of focal species.

4.2 Focal Species Selection

A set of criteria and a vetting process were developed for selecting focal species for the LFA. The application of these criteria to a pool of candidate species allows a comparison of the species, which clarifies and simplifies the process of selecting a suite of focal species. One of the functions of the focal species approach is to facilitate the synthesis, analysis, and organization of information by concentrating efforts on a manageable number of species for which sufficient existing information is available. The process for selecting the following four focal species is detailed in Appendix E. Based on this process, the following four focal species were selected for analysis:

- California red-legged frog (*Rana draytonii*)
- Coho salmon (*Oncorhynchus kisutch*)
- Steelhead (*O. mykiss*)
- Tidewater goby (*Eucyclogobius newberryi*)

4.2.1 California red-legged frog

The California red-legged frog is currently found within the San Gregorio Creek watershed (CDFG 2009, USFWS 2002, Seymour et al. 2007, Seymour and Westphal 2000). It is a threatened species under the federal ESA (USFWS 1996) and a California species of special concern. The frogs are typically associated with deep, still or slow moving water with relatively deep pools and emergent or overhanging vegetation, usually cattails, rushes, or willows (Jennings and Hayes 1994). The ponds can be ephemeral or permanent bodies of water, though individuals also breed in slow-moving, pond-like parts of streams, marshes, and lagoons (Lannoo 2005). Little is known about the frog's terrestrial activities or associations with terrestrial vegetation or land cover, though studies suggest that non-breeding upland habitat and migration corridors are important habitat components for sustaining viable populations of frogs (Bulger et al. 2003, Fellers and Kleeman 2007). The California red-legged frog's range extends along the coast from Elk Creek in Mendocino south to northwestern Baja, Mexico, and inland through the northern Sacramento Valley into the foothills of the Sierra Nevada mountains (Shaffer et al. 2004). The species has been extirpated from 70% of its historical range (USFWS 2002). Threats to the species within its remaining range include several human-influenced impacts, including urban encroachment, introduction of exotic predators and competitors, habitat fragmentation, contaminants including pesticides and fertilizers, and the construction and filling of large reservoirs that may not be properly managed for native species (USFWS 2002). The red-legged frog was selected as a focal species because it meets criteria under Steps 1, 2, and 3 of the vetting process (see Appendix E), and there is regional information available to provide an understanding of habitat needs.

4.2.2 Coho salmon

Coho salmon historically existed in the San Gregorio watershed, but populations were severely reduced in the late 1970s to early 1980s after a severe drought in 1976–1977 (Anderson 1995). Coho salmon found in the San Gregorio Creek watershed belong to the Central California Coast evolutionarily significant unit (ESU) (NMFS 1997), which is listed as endangered under both the federal and California ESAs (NMFS 1996, 2005). NMFS released a draft recovery plan, including restoration actions for San Gregorio watershed, in March 2010[20]. Coho salmon generate high public interest because it appeals to the broader public as a charismatic megafauna

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[20] Available at: http://swr.nmfs.noaa.gov/recovery/Coho_Recovery_Plan_031810.htm

associated with wild places and California history. Coho salmon require freshwater streams with adequate spawning habitat, and rearing habitat to support one-year of development before juveniles migrate to the ocean. Juveniles typically grow for two years in the ocean prior to returning to freshwater to spawn and complete their life cycle. In general, coho salmon have undergone substantial population declines and no longer occupy many of the streams in California where they used to occur (Hassler et al. 1991, Brown et al. 1994). In the Central California Coast ESU, historical populations are estimated to have numbered between 50,000 and 125,000 naturally spawning fish, but current abundance is estimated to be less than 5,000 fish, most of which are considered to be either hatchery fish or their progeny (Brown and Moyle 1991, Bryant 1994, CDFG 1994). Small numbers of coho salmon are observed in San Gregorio Creek, although detailed information on their life history in the watershed is not available. Sufficient regional information is available however (Anderson 1995; CDFG 2002, 2004) to support their selection as a focal species.

4.2.3 Steelhead

Steelhead are currently found within the San Gregorio Creek watershed, belonging to the Central California Coast Distinct Population Segment (DPS) (NMFS 2006). This DPS is listed as threatened under the federal ESA (NMFS 2006); it is not listed by the state of California. Steelhead, like coho salmon, generate high public interest because of their appeal to the broader public as a charismatic megafauna, associated with wild places and California history, and it is prized by recreational anglers. The current abundance of steelhead in the San Gregorio watershed is influenced by ocean conditions, water diversions affecting rearing habitat, seasonal lagoon dynamics (Smith 1990), and increased fine sediment loads from surrounding land use practices that potentially degrade spawning and rearing habitat (Napolitano et al. 2003). In general, steelhead stocks throughout California have declined substantially. The most current estimate of the population of steelhead in California is approximately 250,000 adults, which is roughly half the adult population that existed in the mid-1960s (McEwan and Jackson 1996). Though steelhead stocks throughout the Pacific Northwest have been the object of much study, we know relatively little about the specific habitat preferences of the steelhead population that spawns in the San Gregorio Creek watershed. Nevertheless, we can use information derived from other sub-populations to understand the general habitat requirements of steelhead in the San Gregorio Creek watershed. Steelhead were selected as a focal species because they are a listed species, they satisfied multiple criteria in the third step of the vetting process (see Appendix E), and we know enough about their general life history stages and habitat requirements to understand how changes in the system may affect them.

4.2.4 Tidewater goby

Tidewater goby has been observed historically and are currently found in the San Gregorio Creek estuary (Smith 1990, CDFG 2009). It is an endangered species under the federal ESA (USFWS 1994) and a California species of special concern. The fish are an estuarine species that disperse infrequently through marine habitat, but have no dependency on marine habitat for its life cycle (Swift et al. 1989, Lafferty et al. 1999). Floods and estuary breaching events can disperse tidewater gobies to nearby suitable habitat, but survival is likely low and dispersal is limited. They are an important part of estuarine food webs, as they provide prey for larger fish and piscivorous birds (Swenson and McCray 1996). Current distribution is within the original observed range of the species, but 20% of these populations are extirpated and 50% are likely too small or too degraded to persist long term (USFWS 2005). Their main threats are changes in water quality, degradation and loss of winter refuge and summer habitat due to urbanization, channelization, and sandbar breaching, as well as predation from invasive species. It is estimated that tidewater goby has disappeared from 74 % of the coastal lagoons south of Morro Bay. In 1999, populations of tidewater goby north of Orange County were proposed to be removed from the federal endangered species list, and the USFWS completed a recovery plan for the fish in 2005 (USFWS 2005), providing a good source for understanding habitat needs of the species. The tidewater goby was selected as a focal species because there is extensive information about life history requirements, it is a listed species, and met multiple criteria under the selection process (see Appendix E).

4.3 Focal Species Limiting Factors Analyses

4.3.1 California red-legged frog limiting factors analyses

4.3.1.1 Distribution and status

California red-legged frogs were once classified as a subspecies of *Rana aurora draytonii*, but recent studies suggest that the northern red-legged frog (*Rana aurora*) and California red-legged frog are distinct species (Shaffer et al. 2004). They once occurred throughout the Sierra Nevada foothills and Coast Ranges, from sea level to 5,000 ft (1,500 m) elevation (Shaffer et al. 2004). Currently, there are six known populations in the Sierra Nevada foothills, and along the Coast Ranges they occur south of Elk Creek in Mendocino County to southern California (Shaffer et al. 2004). Vigorous populations still exist in parts of the California central coast; one of the largest single populations consists of an estimated 350 adult frogs at Pescadero Marsh, located about 4 mi (6 km) south of San Gregorio Creek (Jennings and Hayes 1990). However, recent data in Pescadero March indicate that failure of the sandbar to close in early summer threatens the breeding habitat there, and the population has likely declined as a result (J. Smith, pers. comm., 2008). Seymour and Associates conducted amphibian and reptile surveys exclusively on MROSD lands in 2000 and 2006; in the San Gregorio Creek watershed, they found California red-legged frogs primarily in artificial stock ponds in the La Honda Creek OSP, including the Driscoll Ranch area (Seymour and Westphal 2000, Seymour et al. 2007). La Honda OSP had a dense concentration of ponds as compared to their other study areas (23 ponds total), and a substantial number of those ponds (15 of the 23) harbored California red-legged frogs (Seymour et al. 2007). There is also a documented occurrence of California red-legged frog from 1991 (updated in 2002) in a pond off of Hwy 84, east of Stage Road (CDFG 2009). There are a number of other ponds on private lands throughout the San Gregorio Creek watershed that may also provide frog habitat; however, there is little information available regarding distribution and abundance of California red-legged frog on these lands.

California red-legged frogs are listed as threatened by the federal ESA and are designated as a species of special of concern by CDFG. USFWS has developed a California Red-legged Frog Recovery Plan (USFWS 2002); San Gregorio Creek is located within the Central Coast Recovery Unit (Recovery Unit 5) and is considered a hydrologic sub-area of the South San Francisco Bay Core Area (Core Area 18) of the recovery plan. Core Areas include watersheds that currently or historically supported red-legged frogs, are potential source areas to other watersheds or have high potential for re-establishment, and provide connectivity between populations.

4.3.1.2 Life history summary

California red-legged frogs typically breed from late November to late April in ephemeral or permanent bodies of water, such as slow-moving, pond-like parts of streams, marshes, and lagoons (Jennings and Hayes 1994); for successful breeding, water needs to remain long enough into the summer to support tadpole metamorphosis. Females lay one mass of 2,000–6,000 eggs per season that typically hatch within 6–14 days (Jennings and Hayes 1994, USFWS 2002, Scott and Rathbun 2007). However, hatching is highly temperature dependant, and reproduction in coastal populations often occurs at low temperatures, with relatively slow hatching that is often greater than 14 days (J. Smith, pers. comm., 2008). Tadpoles metamorphose for 11–20 weeks from May to September, and males reach sexual maturity at 2 years of age (3 in some years) and females at 3 years (USFWS 2002, Bulger et al. 2003). Adult males range from 3 to 5 in (80 to 120 mm) snout-urostyle length and adult females range from 4 to 6 in (90 to 140 mm) (Bulger et al. 2003). Their life span is not well known, but other red-legged frogs and other *Rana* spp. may live as long as 8–10 years (USFWS 2002, Lannoo 2005).

When not breeding, red-legged frogs occupy aquatic habitat, including natural and artificial ponds and reservoirs, streams and other watercourses, freshwater lagoons, springs, and seeps (Bulger et al. 2003, Fellers and Kleeman 2007). Adults may remain year-round at favorable breeding sites, but may also disperse to nearby breeding and non-breeding sites (Bulger et al. 2003, Fellers and Kleeman 2007). Dispersing adults can cover long distances (>0.6 mi [1 km]) from breeding sites (Fellers and Kleeman 2007). Movements are typically made along riparian corridors, but some individuals move directly from one site to another without preference for topography, watershed corridors, or riparian vegetation (Bulger et al. 2003, Scott and Rathbun 2007).

Adults tend to be largely nocturnal, although radio tracking studies allowing detailed movements to be observed have indicated basking during daytime (Fellers and Kleeman 2007). Juveniles can be active diurnally and nocturnally (USFWS 2002, Scott and Rathbun 2007). The frogs are active year-round in coastal areas, likely because of moderate temperatures (USFWS 2002, Bulger et al. 2003). Like all frogs, red-legged frog tadpoles are herbivorous and then become carnivorous after metamorphosis, with adults feeding mainly on invertebrates, such as terrestrial and aquatic insects, crustaceans, and mollusks; and vertebrates, such as small fish, tadpoles, mice, and Pacific chorus frogs (USFWS 2002, Lannoo 2005).

4.3.1.3 California red-legged frog conceptual model

A highly aquatic species invariably associated with water, California red-legged frogs inhabit still or slow water in streams, marshes, ponds, reservoirs, and canals (Stebbins 2003, USFWS 2002). They breed primarily in ponds with emergent vegetation (e.g., cattails, rushes, willows), which are used for oviposition and for refuge during rearing (Jennings and Hayes 1990). Females attach eggs to emergent vegetation, or roots or twigs at the water surface, typically to depths of 1 ft (0.3 m); eggs have also been observed at depths to 3.2 ft (1 m) (Reis 1999, USFWS 2002). Egg masses are deposited in pools with still water or low velocity, water temperatures of 8–14°C (46–56°F), and salinities <4.5 parts per thousand (ppt), although there are few studies on specific water quality tolerances (Jennings and Hayes 1990, Reis 1999). Adults may deposit eggs in environments too salty for successful hatching, if the environment was suitable for the ancestral population. For example, in Waddell Creek wave overwash increased salinities in a breeding pond to lethal levels, but eggs were laid anyway (J. Smith, pers. comm., 2008). The eggs are sessile, but predation on eggs is less common than on other life stages, suggesting a physical deterrent to predation in the egg mass jelly; however, newt predation on eggs has been documented and may be an important factor in red-legged frog population dynamics (Rathbun 1998, USFWS 2002).

Tadpoles occupy edgewater areas that are warmer (15–25°C [60–77°F]) and shallower (2–30 in [5–75 cm]) than other parts of the occupied pond or lagoon (Reis 1999). Colder water temperatures may extend the time required for metamorphosis by limiting food availability and delaying growth (Duellman and Trueb 1986). Tadpoles are also associated with emergent vegetation, which is used as escape cover from predators, suggesting that the physical structure of the vegetation may be more important than species type (Jennings and Hayes 1990). Reis (1999) observed red-legged frogs associated with pondweed (*Potamegeton* spp.), which potentially provides structural overhead cover as it forms dense mats on the water surface, sheltering red-legged frogs from predators (Reis 1999). Pondweed and associated invertebrates may also may be a food source, and contribute to higher dissolved oxygen levels (Reis 1999). In Pescadero Marsh, the most important abiotic factor identified for red-legged frog tadpole presence was salinity, with size-dependent mortality occurring at salinities >7 ppt (Reis 1999, USFWS 2002).

Connectivity of breeding habitat with post-metamorphic habitat used for feeding and refugia may be a critical factor in population dynamics (Fellers and Kleeman 2007). California red-legged frogs have been observed moving in straight lines between habitats (up to 2 mi [3 km] in some cases) (Bulger et al. 2003). Barriers (e.g., fences, roads, canals, pipes, high densities of non-native predators) that restrict movement through a watershed can disrupt natural re-colonization processes that occur during or after stochastic events such as drought or fire (Scott and Rathbun 2007). Distance between source populations or between small populations and suitable breeding habitat and refugia (i.e., stock ponds, sag ponds, seeps) may determine whether a population can persist over a long period of time (Bulger et al. 2003, Fellers and Kleeman 2007, Scott and Rathbun 2007).

California red-legged frog populations are likely to persist where multiple breeding and non-breeding aquatic areas are embedded within a matrix of upland dispersal habitat (USFWS 2002, Fellers and Kleeman 2007). It may be important to conserve a well-distributed array of natural habitat elements that provide cover for red-legged frog to a distance of at least 330 ft (100 m) from occupied aquatic sites (Bulger et. al., 2003), though it is more important to provide adequate connectivity between breeding, non-breeding, and dispersal habitats (Fellers and Kleeman 2007). Dense patches of shrubs and herbaceous vegetation are particularly important (Bulger et al. 2003). Along the riparian corridor, frogs occupy a range of microhabitats for cover and moisture, using blackberry thickets, logjams, and root tangles at the base of standing or fallen trees (Fellers and Kleeman 2007). Unoccupied ponds within a population have a high probability of being re-colonized, and extensive upland movement is not uncommon in red-legged frogs. Temporary refuge areas, such as creeks, streams, springs, ephemeral pools, and seeps may particularly important for juveniles after they disperse from breeding ponds following metamorphosis (Seymour et al. 2007). Along permanent streams, red-legged frogs are found in or near pools, and associated with complex cover (e.g., root masses, logjams, overhanging banks) (Fellers and Kleeman 2007).

4.3.1.4 Application of California red-legged frog conceptual model to the San Gregorio Creek watershed

The California Red-legged Frog Recovery Plan (USFWS 2002) identified the primary threats to survival of the species as habitat destruction; over-utilization for commercial, recreational, scientific, or educational purposes; disease and predation; and inadequacy of current regulatory mechanisms. The recovery plan identified the threats to California red-legged frogs in the Central Coast Recovery Unit (which includes San Gregorio watershed) as agriculture, livestock, mining, non-native species, recreation, timber, urbanization, and water management (USFWS 2002). However, the recovery plan clarifies that appropriately managed livestock grazing and water management provides important benefits for the California red-legged frog and other native species (USFWS 2002). The recovery plan also identifies specific conservation needs within the South San Francisco Bay Core Area: protect existing populations, control non-native predators, increase connectivity between populations, reduce erosion, implement guidelines for recreation activities to reduce impacts, implement forest practice guidelines, and reduce the impacts of urbanization (USFWS 2002).

There are limited data regarding the presence of California red-legged frogs along the stream network of the San Gregorio Creek watershed; although based on its presence in other habitats throughout the watershed, it is likely that California red-legged frogs utilize these stream habitats for refuge and dispersal. The frog may perhaps even breed in San Gregorio Creek if there are suitable areas with still or slow-moving water and emergent vegetation. There is also a possibility that the species may use freshwater wetland habitat north of the lagoon, adjacent to and east of Highway 1 (K. Atkinson, pers. comm., 2009), although this has not yet been documented. California red-legged frogs have primarily been found in artificial stock ponds on ranch lands, based on surveys conducted by Seymour et al. (2000, 2007) on MROSD holdings in the La Honda Creek sub-basin.

The presence of California red-legged frogs in the watershed may be primarily attributed to the creation and maintenance of the livestock ponds that provide suitable aquatic breeding habitat. Proper grazing of livestock may further enhance the suitability of these artificial ponds by clearing encroaching vegetation, maintaining open water characteristics of ponds, and helping to reduce an overabundance of emergent vegetation that may shade the shallower, tadpole-rearing sections of the pond (EBRPD 2007, Scott and Rathbun 2002). Livestock grazing also benefits upland habitat for burrowing mammals and, subsequently, frogs that may use the same burrows as refuge (EBRPD 2007). However, while stock ponds and grazing can provide suitable frog habitat, poorly managed livestock may trample or destroy California red-legged frog egg masses, and/or riparian and upland areas used as non-breeding habitat (Fellers and Kleeman 2007, Jennings 1988, Seymour et al. 2007). Since properly managed stock ponds are such an important component of California red-legged frog habitat in the watershed, it is necessary to encourage proper management of grazing and stock ponds by landowners. As part of the 2006 designation of critical habitat for the frog, the USFWS published a special rule under 4(d) of the ESA that encourages sensible ranching practices within the range of the California red-legged frog. The rule minimizes the regulatory restrictions and “take” prohibitions of red-legged frog during routine ranching activities (including stock pond management and livestock grazing), and is intended to increase the likelihood that more landowners will voluntarily allow California red-legged frogs to persist or increase on their private lands (71 FR 19243). In addition, the USFWS played a considerable role in bringing together ranchers, environmentalists, and regulators to help draft the California Rangeland Resolution (which, in part, recognizes the importance of rangeland as supporting important ecosystems), and to establish the California Rangeland Conservation Coalition (Barry et al. 2007).

Many non-native predators of California red-legged frog have been documented in the ponds in the watershed, including American bullfrog (*Rana catesbeiana*), sunfish (*Lepomis* spp.), largemouth bass (*Micropterus* spp.), and mosquitofish (*Gambusia affinis*) (CHC 2002, Seymour et al. 2007, USFWS 2002). Crayfish, another non-native predator, has also been observed in the watershed, but it is not known if the observations were at ponds (CHC 2002, N. Panton, pers. comm., 2010). Native predators include garter snakes (*Thamnophis* spp.), California newts (*Taricha torosa torosa*), rough-skinned newts (*Taricha granulosa*), river otters (*Lutra canadensis*), and herons. Properly managed, targeted maintenance activities can discourage invasion of non-native species. For example, since California red-legged frogs breed in winter and late spring, and bullfrogs breed in summer, ponds repeatedly drained in late summer can aid in reducing bullfrog production by eliminating tadpoles (though it is important to consider that adults may tend to survive and recolonize). Timely draining of ponds may also aid in removal non-native predatory fish. This tactic is beneficial assuming appropriate non-breeding habitat for red-legged frogs is nearby for retreat after breeding ponds dry. However, poorly managed pond maintenance may encourage invasion of non-native predators by providing migration pathways for non-natives (Seymour et al. 2007), so it is important that management activities take this into consideration.

4.3.1.5 Limiting factors hypotheses

Data from surveys conducted on MROSD lands in the watershed indicate an apparently successful population of California red-legged frogs in the La Honda Creek sub-basin of the San Gregorio Creek watershed (Seymour et al. 2007). However, information on the distribution and abundance of California red-legged frog within non-MROSD portions of the watershed are limited or non-specific (i.e., frogs were not identified to species). The lack of current and historical watershed-wide data on the presence, distribution, density and abundance, and breeding locations along the stream network, lagoon area, and ponds on private property of the San Gregorio Creek watershed leaves critical data gaps concerning watershed-wide habitat use, movement patterns, and population dynamics that limit our ability to identify specific limiting factors. Based on the USFWS (2002) recovery plan and our conceptual model of the species in the watershed, we hypothesize that the following are potential factors—which may or may not be limiting—that are important to consider for enhancement of habitat and encouragement of a sustainable, thriving California red-legged frog population within the entire San Gregorio Creek watershed:

1. Though stock ponds within the La Honda Creek sub-basin provide confirmed suitable breeding habitat, a lack of available slow-water/breeding habitat along San Gregorio Creek and on un-surveyed properties may limit the watershed-wide distribution of California red-legged frog.
2. Non-native predators in some stock ponds—and to a lesser degree in the creek channel—could be limiting the distribution and abundance of California red-legged frog population within the watershed.
3. Improper livestock grazing practices (including a lack of grazing in some cases) could be a factor limiting the greater abundance and wider distribution of California red-legged frog in the watershed.

4.3.2 Coho salmon limiting factors analyses

4.3.2.1 Distribution and status

Coho salmon found in the San Gregorio Creek watershed belong to the Central California Coast ESU (NMFS 1997), which includes coastal drainages from Punta Gorda in northern California south to and including the San Lorenzo River in central California (although coho salmon are occasionally observed further south), the drainages of San Francisco and San Pablo bays, excluding the Sacramento-San Joaquin River basin. This ESU is listed as endangered under both the federal and state ESAs (NMFS 1996, 2005). Critical habitat is designated to include all river reaches and estuarine areas accessible to coho salmon within the ESU's geographic area (NMFS 1999). NMFS released a draft recovery plan, including restoration actions for San Gregorio watershed, in March 2010.[21].

Coho salmon populations in California have generally declined and the species no longer occupies many of the streams in California where these fish used to occur (Brown et al. 1994, Hassler et al. 1991). Brown et al. (1994) estimated that coho salmon populations in California

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[21] Available at: http://swr.nmfs.noaa.gov/recovery/Coho_Recovery_Plan_031810.htm

have decreased to less than 6% of 1940 numbers. Coho salmon populations in the southern part of the species' range appear to have shown the greatest declines, with few coho salmon occupying coastal streams near or south of San Francisco Bay. In the Central California Coast ESU, where historical populations are estimated to have numbered between 50,000 and 125,000 naturally spawning fish, current abundance is estimated to be less than 5,000 fish, many of which are considered to be of hatchery origin (Brown and Moyle 1991, Bryant 1994, CDFG 1994). Coho salmon are reared in hatcheries on Scott Creek and formerly on San Lorenzo River, both in northern Santa Cruz County, for release in coastal streams between San Mateo and southern Monterey Bay (MBSTP 2009).

Coho salmon historically were common in coastal streams along the San Mateo and Santa Cruz County coasts (Anderson 1995). In the late 1800s, San Gregorio Creek had large enough runs of coho salmon to support commercial harvest (Skinner 1962, as cited in Titus et al. 2006). By the 1960s, coho salmon populations were limited to four streams in San Mateo County, including San Gregorio Creek. The current regional distribution includes populations in several small streams to the south, such as Pescadero, San Vicente, Gazos, Waddell, and Scott creeks, as well as coastal watersheds to the north, such as Redwood and Lagunitas creeks in Marin County. Coho salmon in the southern extent of their range have a relatively fixed three-year maternal brood year cycle that makes them particularly vulnerable to natural and anthropogenic catastrophic events (Anderson 1995). As such, along the San Mateo and Santa Cruz County coasts there are three distinct, separate brood year lineages within each watershed. Coho salmon produced during the 2007 brood year were produced by females produced three years earlier in 2004, which were produced three years prior in 2001. There is regular genetic exchange of individuals between brood year lineages because precocial two year old males are able to mate with returning three year old females. However, there is no numerical effect on fry production as the three-year female spawning cycle of wild fish appears fixed. This trait limits chances of demographic support between cohorts, placing individual year classes at risk of population losses from natural stochastic events (floods, drought) and anthropogenic influences (water quantity and quality). This risk may be especially high near the edge of a species distribution, where conditions approach tolerance limits, and in small populations, such as those found along the Central Coast. Additionally, difficult spawning or rearing conditions that affect one year class will affect the next brood year (three years hence). If difficult conditions remain or repeatedly occur, then lineages are in danger of severe reduction or extirpation.

In most central coast watersheds, all brood year lineages are severely reduced and few streams sustain naturally spawning populations (CDFG 2002). Waddell, Scott, and Gazos creeks did support relatively strong populations of the year class produced in 2005 and much weaker populations of the 2003 and 2004 year classes, although recent observations suggest the elimination of the 2007 (2004 produced) year class, as well as poor returns in 2008 and 2009 of the 2005 and 2006 year classes. Juvenile coho salmon have been observed in San Gregorio Creek in small numbers from the year class produced in 2005 (Smith 2009, J. Smith, pers. comm., 2010). Juveniles were observed in the stream in fall 2005, smolts were observed in the lagoon in spring 2006 (K. Atkinson, pers. comm., 2009), and juveniles were observed in Alpine Creek in fall of 2008 (B. Spence, unpublished data). It is believed that these fish were progeny of strays from Pescadero or Scott Creek, in which fish were planted, and not an indicator of a viable population (J. Nelson, pers. comm., 2008).

The draft coho salmon recovery plan developed by NMFS divided the ESU into diversity strata, and placed the San Gregorio Creek coho salmon population in the Santa Cruz Mountains diversity stratum that includes San Gregorio Creek south to Soquel Creek (NMFS 2010). The State Recovery Strategy for Coho Salmon (CDFG 2004) has divided each ESU into recovery units (Hydrologic Units [HU]) that are groups of watersheds related hydrologically, geologically, and ecologically, and that are thought to constitute unique and important components of the ESU. San Gregorio Creek is located within the San Mateo Creek Hydrologic Unit and along with Pescadero Creek to the south makes up the San Gregorio Hydrologic Sub Area (HSA). A summary of the life history and habitat requirements of coho salmon is provided below and the general coho salmon lifecycle is presented in Figure 4-1.

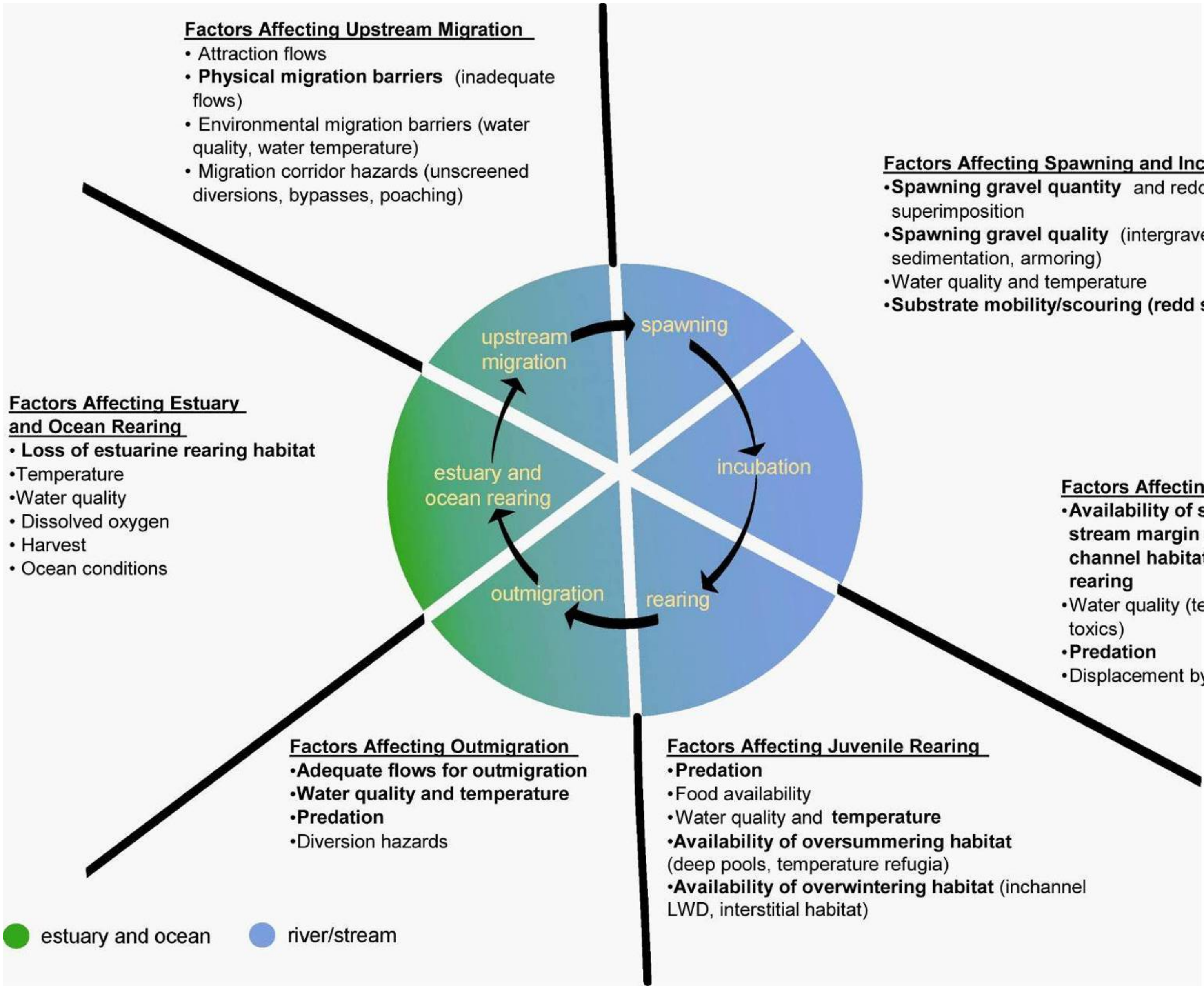

Figure 4-1. Coho salmon life cycle with potential factors affecting each life stage.

4.3.2.2 Life history summary

Adult female coho salmon typically migrate to the vicinity of their natal stream during the fall of their third year and males during the fall of their second or third year (Shapovalov and Taft 1954, Sandercock 1991). These three-year-old adults have spent one winter in fresh water and one winter in the ocean. Coho salmon do not enter the stream system all at the same time, but instead arrive throughout the spawning season in a pattern that reflects storms that increase flow in the spawning streams (Shapovalov and Taft 1954). There may be some selective advantage to spawning later in the season, since the redds of earlier-spawning fish may be subsequently disturbed by the redd-building activities of later-arriving females (redd superimposition), and later spawning fish may avoid early winter storms that can cause high flows scouring redds. The early part of a coho salmon run tends to be dominated by males, with females returning in greater numbers during the latter part of the run (Shapovalov and Taft 1954, Moyle et al. 1989).

Spawning sites are typically in areas where there are beds of loose, silt-free, coarse gravel, and nearby cover for adults (Moyle et al. 1989). Redds are usually located in the transitional area at the downstream end (or tail) of pools as they feed into riffles where the water changes from a smooth to a turbulent flow (Briggs 1953, Hazzard 1932, Hobbs 1937, Smith 1941, Stuart 1953). Redd construction may last as long as five days, during which time the female will dig up to seven egg pockets in succession, progressing in an upstream direction (Shapovalov and Taft 1954, Tautz 1977, van den Berghe and Gross 1984). Following deposition in the gravel, coho salmon eggs incubate for 35–50 days at temperatures of approximately 9–11°C (48–52°F) (Shapovalov and Taft 1954), with incubation time being inversely related to water temperature. After hatching, salmon larvae (alevins) remain in the gravel while undergoing further development and absorption of the yolk sac. Emergence begins 2–3 weeks after hatching, and may continue for an additional two–seven weeks (Shapovalov and Berrian 1940).

Upon emergence from the gravels, coho salmon fry seek low-velocity areas along shallow stream margins (Shapovalov and Taft 1954). As they grow, juvenile coho salmon move to deeper habitats, although they continue to prefer low-velocity habitat throughout the rearing period. Juvenile coho salmon establish territories or form hierarchical groups in pools based on optimal foraging positions (Dolloff and Reeves 1990, Fausch 1993).

During winter, both instream cover and off-channel areas providing slow water are essential for protection against displacement by high flows, and for cover from predation (Bustard and Narver 1975, Hartman et al. 1982, Mason 1976). However, off-channel habitats on inundated floodplains or in abandoned side-channels are generally rare in semi-confined California coastal streams, and LWD tends to provide most winter habitat (Bell 2001). Deep (>18 in [45 cm]), slow (<0.5 ft/s [15 cm/s]) areas within or near (<3.2 ft [1 m]) cover of roots, large wood, and flooded brush appear to constitute preferred habitat (Bustard and Narver 1975, Hartman 1965), especially during freshets (Bell et al. 2001, McMahon and Hartman 1989, Tschaplinski and Hartman 1983). Following winter peak flows, juvenile coho salmon emerge from winter hiding areas and feed heavily to grow in size in preparation for downstream migration.

Coho salmon smolt outmigration generally occurs in the spring approximately one year after they emerge from gravels (an age referred to as "1+")[22]. In some California streams a smaller portion of the outmigration is made up of age 2+ fish (Bell and Duffy 2007, Smith 2009). Downstream migration of age 0+ fry also occurs, but these fish are believed to have low probability of

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[22] We follow conventional methods for assigning fish ages to year classes. Age 0+ refers to fish in their first year of life, sometimes called young-of-the-year; age 1+ to fish in their second year of life, and so on. A fish changes from age 0+ to age 1+ on January 1.

surviving to adulthood (Crone and Bond 1976, Hartman et al. 1982, Otto 1971). Shapovalov and Taft (1954) found the average size of outmigrating smolts to range from 4.1 to 4.6 in (103 to 116 mm) in nearby Waddell Creek, California.

4.3.2.3 Coho salmon conceptual model

This section describes a general conceptual model linking the life history and habitat requirements of coho salmon. The general model combines hypotheses that are well supported by the literature with elements that are the subject of ongoing research. We expect that there will be cases where our general conceptual model does not hold up, requiring subsequent modification and refinement to fit the conditions of particular watersheds. However, the general conceptual model provides a useful starting point for developing and testing hypotheses specific to contemporary conditions within the San Gregorio Creek watershed.

Because juvenile coho salmon in central California generally smolt at age 1+ (Shapovalov and Taft 1954, Randall et al. 1987) and must spend at least one summer and winter in fresh water prior to outmigrating to the sea, they tend to establish territories[23] in suitable rearing habitat soon after emergence (as opposed to fall Chinook, chum, pink, and sockeye salmon, which only spend a few weeks or months in the rearing stream) (Mason 1966). Territories are established to ensure access to sufficient food supply (Kalleberg 1958). The role of territories in regulating individual growth is an important mechanism for partitioning a finite food resource among juvenile coho salmon (especially in summer when low stream flows reduce invertebrate production and higher temperatures increase metabolic demand). Size at smolting has been correlated with ocean survival of anadromous salmonids (Bilton et al. 1982, Peterman 1982, Ward et al. 1989) and studies have associated higher smolt survivals with juvenile coho salmon migrating at sizes of at least 100 mm fork length (Crone and Bond 1976, Drucker 1972). This appears to be especially true for coho salmon when ocean conditions are less than optimal (Holtby et al. 1990). If territories were not established and defended by individuals, theoretically the result would be either mortality due to starvation or a large number of small smolts that would have very poor ocean survival. The size of individual territories (and thus rearing density) may vary from location to location as a function of food availability and temperature, with territories becoming smaller in more productive or physically complex habitats or colder streams (Dill et al. 1981, Mason 1976).

The maximum number of juvenile coho salmon that even very good summer habitat can support is usually small relative to the number of fry that even a few successful redds can produce. Because of this, spawning gravel availability and egg mortality (e.g., as a result of poor gravel quality, redd dewatering, fungal infections, redd scour) rarely have an important effect on coho salmon population dynamics. In other words, any density-dependent mortality that might result from redd superimposition and density-independent mortality resulting from redd scour and poor gravel quality (among other factors) are usually irrelevant because, despite these sources of mortality, far more fry are typically produced than can be supported by the available rearing habitat (although this may not be the case with depressed populations). Typically, the density-dependent mortality or emigration that occurs when juvenile coho salmon establish territories sets the carrying capacity for juvenile rearing and overshadows other sources of mortality affecting eggs and juveniles. Therefore, the availability of suitable juvenile rearing habitat (either in the

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[23] We use the terms “territory” and “territory size” not only in its traditional sense—as a particular defended area—but also in cases where defense of a particular area may not occur but agonistic behavior by dominant individuals (e.g., nips, fin extensions, charges) effectively determine the maximum density of rearing juvenile coho in a pool.

summer or winter) is the factor that usually governs the ultimate number of coho salmon smolts produced from a stream.

During winter, juvenile coho salmon are typically associated with low-velocity habitats (Hartman 1965, Lister and Genoe 1970, Mundie 1969, Shirvell 1990). When temperatures drop and base flows rise, juvenile coho salmon often make seasonal or temporary shifts to off-channel habitats (Bell 2001, Scarlett and Cederholm 1984). This type of winter habitat provides foraging opportunities at base flows and refuge from displacement by high flows (Bell et al. 2001). Since coho salmon tend to spawn and rear in small- or medium-size streams in reaches with moderate gradients (i.e., <3%), the coarse cobble and boulder substrates that are often used as winter cover by other salmonids, such as steelhead and coastal cutthroat trout, are frequently not available. Over-wintering coho salmon, therefore, are often found in slower velocity habitats such as floodplains, sloughs, off-channel water bodies, beaver ponds, and complex in-channel habitats associated with large wood. We postulate that such habitats were abundant in many streams in northern California and the Pacific Northwest under historical conditions.

Under historical conditions, rearing habitat may have been more limited during the summer than winter, because territorial behavior largely disappears in winter, particularly where winter temperatures are very cold, and because floodplains and off-channel habitats were more extensive prior to human disturbance. If winter habitat was even moderately abundant under historical conditions, greater habitat limitations would be expected during the summer when low flows and warmer temperatures would act in concert to decrease habitat area and food availability, which set a stream's carrying capacity. However, because of the profound changes that have occurred in streams throughout coastal California and the Pacific Northwest, such as large-scale removal of in-channel wood, loss of large wood input through logging in riparian areas, channelization of previously complex drainage patterns, and the construction of levees disconnecting floodplains from the channel, the availability of suitable winter habitat has been greatly diminished. While summer habitat conditions have also deteriorated due to land management activities, it is likely that impacts in many watersheds have disproportionately affected winter habitat. Thus, in our conceptual model for coho salmon, we initially assume that under current conditions, winter habitat is in shorter supply than summer habitat.

4.3.2.4 Application of coho salmon conceptual model to the San Gregorio Creek watershed

Based on our conceptual model, San Gregorio Creek historically likely had all of the habitat elements to support a viable coho salmon population. The stream is gravel-bedded, the channel network has over 31 mi (50 km) of low-gradient (<3%) habitat, the watershed was forested and mostly within the marine fog influence that likely maintained cool stream temperatures. In the late 1800s San Gregorio Creek had large enough runs of coho salmon to support commercial harvest (Skinner 1962, as cited in Titus et al. 2006). Under current conditions, however, coho salmon are only occasionally observed in the basin and are not a viable population (J. Nelson, pers. comm., 2008). Since there is currently not a sustainable population in the watershed, the primary question is not, "what factors limit the population," but rather, "what factors led to their drastic decline in the watershed." It is likely that the factors that led the population to be dramatically low still exist and prevent coho salmon from persisting in San Gregorio Creek. In recent years (e.g., 2007 and 2008) ocean conditions also appear to be a factor in severe declines of coho salmon throughout their range in California. During periods of poor ocean conditions, marine survival rates for coho salmon can be extremely low (<1%), exacerbating the effects of freshwater habitat limitations that may have existed for decades (Quinn 2005). Although increasing the abundance of a population within a watershed is very challenging with poor marine survival, based on our conceptual model, complete extirpation rarely occurs from poor ocean conditions alone. When smolt production is high, even very low marine survival rates are enough to maintain a population, whereas if smolt production is low populations can be threatened with even moderate marine survival. Under current conditions coho populations have continued to persist over the last 100 years in at least a handful of other California coastal streams where freshwater habitat conditions have remained suitable (e.g., Lagunitas Creek in Marin County and Pudding Creek in Mendocino County), despite their populations occurring in similar ocean environments as fish produced from San Gregorio Creek. Drastic declines of the nature occurring in San Gregorio Creek more typically would occur when chronic high summer water temperatures and/or channel dewatering eliminate summer rearing habitat, and/or very poor winter survival limits smolt production. Each of these potential scenarios is further explored below.

By summer, particularly in dry years, flows in many portions of San Gregorio Creek are extremely low, decreasing access to habitat during the rearing period. We explored the plausibility that channel dewatering could have caused population declines and could be continuing to prevent recovery of coho salmon in the basin. For the most part, the pool habitat preferred by rearing coho salmon in the summer is available (albeit low quality as discussed in Section 4.3.3.4 below) and connected in the watershed, although productivity could be decreased by low flows (Harvey et al. 2006). When low flows restrict the amount of area for rearing, competition for food and space is increased in the remaining habitat. Low flows also decrease invertebrate production in riffles (Harvey et al. 2006). Therefore growth rates in particular could be reduced by low flow summer conditions (i.e., reduced food supply, increased density in pools), especially if water temperatures are increased as a result of low flows. Low flow conditions in the later summer and fall likely occurred under historical conditions due to the climate and setting of the watershed, but may be more common and prolonged due to riparian water and groundwater withdrawals, and may be exacerbated by land cover changes affects patterns of runoff and infiltration of rainfall into the soil and bedrock. While the adjudication of the watershed established a minimum bypass requirement of 2 cfs during most of the summer and fall, this requirement does not apply to existing water diversions and flows are often less than 2 cfs in summer and fall. In addition, the CDFG Recovery Plan states that the prescribed bypass flows are too low to assure viable coho salmon populations. CDFG (1995) identifies drought years in the late 1970s as being partially responsible for the decline of coho salmon in the watershed. However, even in 1970, Coots (1971) failed to observe coho salmon during downstream migrant trapping and stream surveys, and noted that in general coho salmon only “occasionally enter the creek to spawn.” It is unlikely that a drought in the late 1970s is responsible for the demise of coho in the watershed, as that at most would only affect a cohort or two. In addition to low flows, notable fluctuations in flow are occasionally measured at the USGS San Gregorio stream gauge (Section 2.4.2). Although flow fluctuations can be detrimental to rearing coho salmon, there is currently no available data on the magnitude or impact of fluctuations within habitats where fish are rearing (typically far upstream of the USGS gage).

In summary, based on historic flow records and current observations of available habitat during summer, it is likely that low summer flows are a contributing factor to the low abundance of coho salmon, but unlikely that channel dewatering alone led to the decline of coho salmon in the watershed (unless there was an undocumented higher amount of water diversion that occurred in the basin in the 1960s). Furthermore, as with other coastal coho salmon populations (e.g., Lagunitas and Pudding creeks), it is unlikely low summer flows (natural or otherwise) and consequent habitat reductions are preventing an increase in the population, although it may be a contributing factor. Overall, as was demonstrated for Lagunitas Creek (Stillwater Sciences

2008), when adult returns were adequate to seed available habitat, the relative amount of suitable winter habitat appears to be far less than summer habitat.

High summer water temperatures can be a density-independent factor leading to severe restrictions in summer distribution, and can preclude coho salmon from a watershed (Welsh et al. 2001). Coho salmon rarely exist in streams with an MWAT greater than 17°C (62°F) (Welsh et al. 2001). SFBRWQCB (2007a) continuously measured temperature at six sites for several weeks in summer 2002 and never recorded MWATs above 15 °C (60°F) outside of the seasonal lagoon. Similarly, continuous water temperature data collected by SGERC from 2003 to 2009 did not record any MWATs above 17°C (63°F), with the exception of the seasonal lagoon. Although temperatures occasionally exceed optimal conditions for coho salmon growth (MWAT of 14.8°C [59°F]), based on available data (see Section 2.6.3) it does not appear likely that water temperatures are precluding coho salmon from the watershed, or ever would have.

Displacement or mortality caused by high winter flows frequently limits production of juvenile coho salmon that do not have access to protected microsites associated with LWD, large substrates such as boulders, interstitial spaces, off channel habitat, or other features that provide velocity refuges. Whereas the general coho salmon conceptual posits that off-channel habitat is important over-wintering habitat for juvenile coho salmon, California coastal streams do not naturally have channel morphology conducive to forming extensive flood plains or off-channel rearing areas. Therefore LWD is an even more critical habitat element than in more northern streams to form pools or areas of refuge from high flows. Recent CDFG stream surveys indicate a lack of LWD within the San Gregorio Creek watershed (CDFG 1996a, 1996b, 1996c, 1996d, 1996e, 1996f, 1997a, 1997b). Although the causes of low abundances of LWD in San Gregorio Creek are not known, it appears that shifts in land use that occurred early in the last century have reduced potential recruitment, and anecdotal information suggests that wood is often removed from streams to reduce flooding risk. Land use in the basin may also have reduced low gradient flood plain habitat in the lower basin, but this has not been fully assessed. In addition, Highway 1 crosses San Gregorio Creek upstream of the mouth, and during roadway construction, the marsh and lagoon were partially filled and the creek displaced to the south under a bridge. The marsh now connects with the creek through a culvert, but downstream channel incision causes the marsh to drain during periods of low flow (Swenson 1997). It is likely that under historical conditions the marsh now partially connected through the culvert provided low velocity rearing habitat during high flows. The lack of LWD, loss of connection to the floodplain, and subsequent effects on overwintering habitat, is a potential cause of the dramatic reductions in coho salmon abundance in the basin, and a likely factor limiting their ability to increase in abundance once more.

The general coho salmon conceptual model posits that spawning gravel availability and egg mortality rarely have an important effect on coho salmon population dynamics. In other words, any density-dependent mortality that might result from redd superimposition and density-independent mortality resulting from redd scour and poor gravel quality (among other factors) are usually irrelevant because, despite these sources of mortality, far more fry are typically produced than can be supported by the available rearing habitat. For example, with as few as 40 fish producing only 20 redds with average fecundity of 2,500 eggs (Moyle 2002), even extremely low survival to emergence of 20% (Quinn 2005) would produce 10,000 fry, more than enough to seed available summer habitat. However, loss of production from the inability of coho salmon to migrate to spawning habitat could have a large impact within even a few cohorts, since in these situations all potential spawning can be lost. Several potential migration barriers have been identified in the watershed (Cox and Robins 2006, Ross Taylor and Associates 2004). These barriers prevent migrating coho salmon from accessing approximately 3 mi of potential spawning and rearing habitat, which could reduce production in the basin. Coho salmon upstream migration and spawning typically occurs after the onset of winter rains, but may have been impacted in San Gregorio by impediments during dry years which are often associated with delayed lagoon breaching, or during years when the onset of rains occurs after the peak of migration.

In depressed populations, such as in San Gregorio Creek, production from limited spawning may not be adequate to seed summer rearing habitat. When this occurs, every constructed redd is critical to produce enough progeny to seed available habitat, and the recovery of the population is effectively reduced by density-independent sources of mortality, such as flow migration barriers for adults and egg mortality from redd scour. In this instance egg-to-fry survival will prevent full seeding of available habitat, but is otherwise not the factor that likely drove the population to a depressed condition. Smith (2008) noted significant mortality due to redd scour in Gazos, Waddell, and Scott creeks in 1992, 1995, 1998, and 1999.

The mouth of the San Gregorio Creek watershed is protected by a seasonal lagoon, which forms naturally in response to tidal and rainfall cycles. This lagoon is used by age 1+ coho salmon during the spring while migrating to the ocean (Smith 1990; K. Atkinson, pers. comm., 2009), and the presence of the sandbar and the timing of breaching and closure affects coho salmon migration timing. Anthropogenic alteration of the lagoon, from increased sediment loads or lower stream flows, may influence sandbar formation through delayed bar opening in the winter or accelerated bar closure in the spring and affect fish migration (CDFG 2004). During wet years migration appears unimpeded for both smolts and adults, especially when breaching is exacerbated by the public. However, during dry years the formation of the berm appears to block the potential migration for both adults and smolts (K. Atkinson, pers. comm., 2009).

4.3.2.5 Limiting factors hypotheses

Based on our conceptual model, San Gregorio Creek historically likely had all of the habitat elements to support a viable coho salmon population. However, currently, the San Gregorio Creek watershed does not support viable numbers of coho salmon for any brood year class (CDFG 2002). As discussed above, many factors have the potential to affect all life stages of coho salmon in San Gregorio Creek. Rather than listing all elements that potentially influence the population, we have used our conceptual model of coho salmon to generate the following hypotheses, which isolate the highest priority and most likely causes of the dramatic declines in abundance of coho salmon in the watershed[24]:

1. Lack of LWD and off-channel habitat limit the area and quality of winter rearing habitat, reducing winter survival enough to have caused drastic declines of coho salmon prior to the 1970s, limit current production, and unless addressed will continue to delay potential recovery of the population in the watershed.
2. Low instream flows during fall resulting in delayed lagoon bar breaching prevent migration to spawning habitat in some years, limit current production, and unless addressed will continue to delay potential recovery of the population in the watershed.
3. Poor marine conditions reduce coho salmon ocean survival and thus exacerbate freshwater habitat limitations in San Gregorio Creek, reducing abundance but not ultimately limiting production or recovery.

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[24] Although developed prior to the release of the NMFS draft coho salmon recovery plan, the limiting factor hypotheses correspond with NMFS draft restoration priorities for San Gregorio Creek to improve baseflow, increase and improve the number of off channel habitats, increase the amount of large wood in streams, decrease the number of roads near the stream and reduce impacts from remaining roads, and improve pool habitat (NMFS 2010).

4. Reduced stream flows during summer reduce summer abundance and potential growth, but are not ultimately limiting production or recovery.
5. Spawning success (survival to emergence) currently reduces coho salmon abundance in San Gregorio Creek but is not likely limiting production or recovery.

4.3.3 Steelhead limiting factors analyses

4.3.3.1 Distribution and status

Steelhead found in the San Gregorio Creek watershed belong to the Central California Coast DPS (NMFS 2006), which includes coastal drainages from the Russian River to Aptos Creek and the drainages of San Francisco and San Pablo Bays, excluding the Sacramento-San Joaquin River watershed. Steelhead are distributed within the mainstem San Gregorio Creek, within all significant tributaries, and in the lagoon (Figure 4-2). This DPS is listed as threatened under the federal ESA (NMFS 2006).

In the late 1800s, San Gregorio Creek had large enough runs of steelhead to support commercial harvest (Skinner 1962, as cited in Titus et al. 2006). By 1912, stocking of steelhead was reported (Smith 1912), and in the 1930s large numbers (>20,000 annually) of juveniles were planted (Titus et al. 2006). In the 1960s, the maximum steelhead run was estimated at about 1,000 adults (CDFG 1962) although the method for this estimate is not known. In 1961, the abundance of adults was estimated at 300 individuals (CDFG 1962); and in 1970, 216 adults returning to the ocean were captured at an outmigrant trap (Coots 1971). Stocking occurred as recently as 1985, when over 8,000 juveniles were planted (Titus et al. 2006). Current adult population size estimates for San Gregorio Creek are not available. However, based on comparing recent estimates of juveniles in the lagoon (approximately 2,500 juveniles; K. Atkinson, pers. comm., 2009) with estimates from the late 1980s (approximately 10,000 juveniles; Smith 1990) and late 1960s (approximately 5,000 smolts; Coots 1971), it appears a sustainable steelhead population persists. In general, steelhead stocks throughout California have declined substantially. Although data for the Central Valley of California is more accurate than for coastal streams, the most current estimate of the population of steelhead in California is approximately 250,000 adults, which is roughly half the population that existed in the mid-1960s (McEwan and Jackson 1996).

A summary of the life history and habitat requirements of steelhead is provided below and the general steelhead life cycle is presented below and in Figure 4-3.

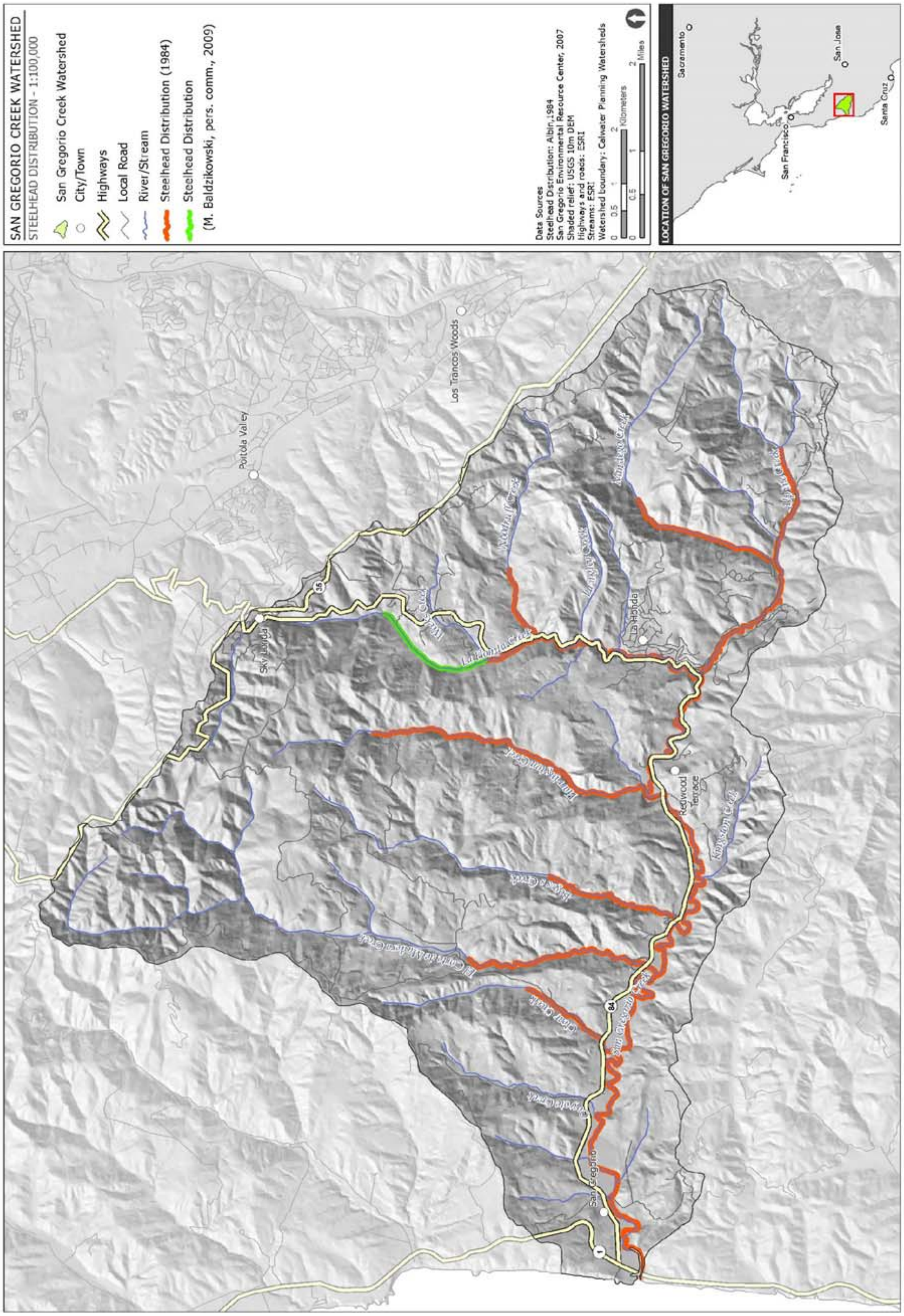
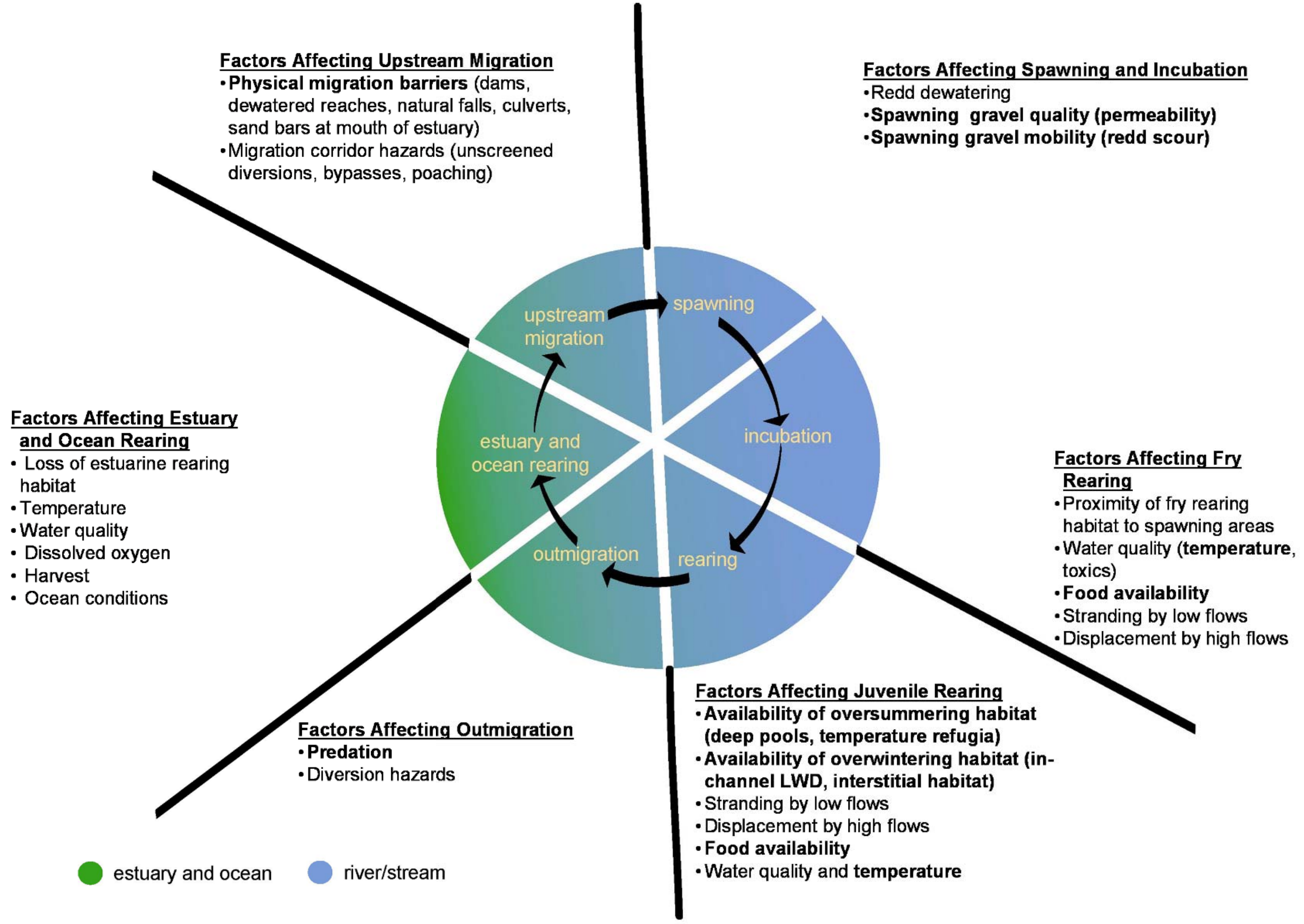


Figure 4-2. Steelhead distribution in the San Gregorio Creek watershed.



Factors Affecting Upstream Migration
- **Physical migration barriers** (dams, dewatered reaches, natural falls, culverts, sand bars at mouth of estuary)
- Migration corridor hazards (unscreened diversions, bypasses, poaching)

Factors Affecting Spawning and Incubation
- Redd dewatering
- **Spawning gravel quality (permeability)**
- **Spawning gravel mobility (redd scour)**

Factors Affecting Estuary and Ocean Rearing
- Loss of estuarine rearing habitat
- Temperature
- Water quality
- Dissolved oxygen
- Harvest
- Ocean conditions

Factors Affecting Fry Rearing
- Proximity of fry rearing habitat to spawning areas
- Water quality (**temperature**, toxics)
- **Food availability**
- Stranding by low flows
- Displacement by high flows

Factors Affecting Outmigration
- **Predation**
- Diversion hazards

Factors Affecting Juvenile Rearing
- **Availability of oversummering habitat (deep pools, temperature refugia)**
- **Availability of overwintering habitat (in-channel LWD, interstitial habitat)**
- Stranding by low flows
- Displacement by high flows
- **Food availability**
- Water quality and **temperature**

Figure 4-3. Steelhead life cycle with potential factors affecting each life stage.

4.3.3.2 Life history summary

Steelhead is the term commonly used for the anadromous life history form of *O. mykiss*, and rainbow trout is the term for the resident life history. Both steelhead and rainbow trout are expressed within the San Gregorio Creek watershed, although detailed information on the relative proportion of each ecotype is not available. The relationship between anadromous and resident life history forms of this species is the subject of ongoing research. Current evidence suggests that the two forms are capable of interbreeding and that, under some conditions, either life history form can produce offspring that exhibit the alternate form (i.e., resident rainbow trout can produce anadromous progeny and vice-versa) (Burgner et al. 1992, Hallock 1989, Shapovalov and Taft 1954). The fact that little to no genetic difference has been found between resident and anadromous life history forms inhabiting the same watershed supports this hypothesis (Busby et al. 1993, Nielsen 1994, but see Zimmerman and Reeves 2001).

Steelhead return to spawn in their natal stream, usually in their third or fourth year of life, with males typically returning to fresh water earlier than females (Behnke 1992, Shapovalov and Taft 1954). A small percentage of steelhead may stray into streams other than their natal stream. Based on variability in the timing of their life histories, steelhead are broadly categorized into winter and summer reproductive ecotypes. Only the winter ecotype (winter-run) occurs in San Gregorio Creek. Winter-run steelhead generally enter spawning streams from late fall through spring as sexually mature adults, and spawn in late winter or spring (Shapovalov and Taft 1954). Based on anecdotal observations, and one study (Coots 1971), spawning in the San Gregorio Creek watershed occurs in two peaks, one in early winter (December) and another in early spring (March–April).

Female steelhead construct redds in suitable gravels, often in pool tailouts, or in isolated patches in cobble-bedded streams. Steelhead eggs incubate in the redds for 3–14 weeks, depending on water temperatures (Barnhart 1991, Shapovalov and Taft 1954). After hatching, alevins remain in the gravel for an additional two–five weeks while absorbing their yolk sacs, and then emerge in spring or early summer (Barnhart 1991).

After emergence, steelhead fry move to shallow-water, low-velocity habitats, such as stream margins and low-gradient riffles, and forage in open areas lacking instream cover (Fontaine 1988, Hartman 1965). As fry grow and improve their swimming abilities in the late summer and fall, they increasingly use areas with cover and show a preference for higher velocity, deeper mid-channel areas near the thalweg (the deepest part of the channel) (Fontaine 1988, Everest and Chapman 1972, Hartman 1965). Juvenile steelhead occupy a wide range of habitats, using deep pools as well as higher-velocity riffle and run habitats (Bisson et al. 1982, Bisson et al. 1988). During periods of low temperatures and high flows that occur in winter months, steelhead prefer low-velocity pool habitats with large rocky substrate or woody debris for cover (Fontaine 1988, Hartman 1965, Raleigh et al. 1984, Swales et al. 1986).

The benefits of LWD for juvenile salmonids are well documented (Hartman 1965, Shirvell 1990). During the winter, LWD, in combination with other features such as vegetated overhanging banks and interstitial spaces between cobbles and boulders, provide protection from high water velocities that can cause downstream displacement to less suitable habitat (Bustard and Narver 1975, Everest 1969, Grette 1985, Hartman 1965). Although LWD features provide valuable winter refuge for steelhead, unembedded cobble/boulder substrate is a key attribute supporting winter survival for juvenile steelhead in streams experiencing periodic high flows brought on by storm events (Chapman and Bjornn 1969, Hartman 1965, Meyer and Griffith 1997). This is because the most effective velocity refugia for steelhead may be located within the streambed itself, as compared with a concealment cover type such as LWD, which will be more typically used during winter base flows.

Juvenile steelhead (parr) rear in fresh water before outmigrating to the ocean as smolts. The duration of time parr spend in fresh water appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead in northern and central California typically spend two years in freshwater prior to smolting (Shapovalov and Taft 1954). However, Smith (1990) found that steelhead juveniles rearing in the San Gregorio Creek lagoon are able to reach smolt size within one year. In 1970, Coots (1971) documented that 60% of smolts were age 1+, 39% were age 2+, and less than 1% were age 3+ or older. Based on scale analysis of 22 adult females captured in San Gregorio Creek in 2008, fish smolted (and survived to spawn) as 1+, 2+, or 3+, with variable amounts of lagoon and stream rearing (K. Atkinson, pers. comm., 2009). Overall most of the scales analyzed indicated age 2+ or older smolts, and most fish that smolted younger than age 2+ reared primarily in the lagoon.

Juvenile downstream migration in San Gregorio Creek typically occurs from March through July, and was observed in 1971 to peak in late April and early May (Coots 1971). Emigration appears to be more closely associated with size than age, with 6–8 in (150–200 mm) being most common for downstream migrants. Depending partly on growing conditions in their rearing habitat, steelhead may migrate downstream to estuaries as age 0+ or age 1+ juveniles or may rear in streams for up to four years (most frequently two years) before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). In nearby Scott Creek, three life history pathways have been documented, including smolts that rear only in the upper watershed, those that rear primarily in the lagoon/estuary, and those that rear partially in the upper watershed and partially in the lagoon/estuary (Hayes et al. 2008). In San Gregorio the upper watershed rearing life history appeared to dominate in 1971 observations (Coots 1971). Regular sampling of the lagoon in 2005 and 2006, as well as interpreting adult scales (n=22), has documented that steelhead migrate to the lagoon at age 0+, 1+, or 2+, and either smolt directly to the ocean as age 1+ and age 2+, or rear in the lagoon (K. Atkinson, pers. comm., 2009). Based on CDFG sampling in 2005 and 2006, steelhead rearing in the lagoon consisted primarily both age 0+ and age 1+ (>90%) and occurred for up to approximately eight months. The highest population estimates in the lagoon during 2005 and 2006 were reported in early July, and most steelhead had left the lagoon by February. A variety of freshwater life histories were identified based on the scale analyses discussed above, including smolting as age 1+ after one year of rearing in lagoon (n=6–7); smolting as age 2+ after one year of rearing in the stream and one year in the lagoon (n=6–7); smolting as age 1+ after rearing for one year in the stream (n=2); smolting as age 2+ after rearing for two years in the stream (n=5–7); and smolting as age 3+ after rearing for three years in stream (n=1) (K. Atkinson, pers. comm., 2009). This diversity of lagoon and/or partial lagoon rearing life histories are dependant on sandbar formation and maintenance, and rearing is documented to be more extensive when lagoon is not artificially breached during summer (Smith 1990; K. Atkinson, pers. comm., 2009).

4.3.3.3 Steelhead conceptual model

Coho salmon and steelhead share several life history traits that influence factors potentially limiting their populations. Perhaps the most important aspect for understanding their population dynamics is that the average fecundity is high relative to the amount of suitable juvenile rearing habitat usually available within a stream. This means that rather than being controlled by reproductive success, population growth tends to be limited by physical habitat constraints during the juvenile freshwater rearing stage. The degree of juvenile habitat constraints can differ between watersheds with and without lagoons, depending on the seasonal suitability of lagoon rearing habitat. In many California watersheds, lagoons develop on the coastal plain between the coastal mountain front and the ocean. A lagoon is a seasonal body of water created when a sand bar separates freshwater outflow from the ocean. In some cases, lagoons create habitat that complements stream habitat. Below we discuss potential factors that limit steelhead protection in stream and lagoon habitat.

Because juvenile steelhead must spend at least one summer and winter in freshwater prior to outmigrating to the sea, they tend to establish territories[25] in suitable rearing habitat soon after emergence from the gravel. The maximum densities of oversummering age 0+ steelhead that a reach of stream can support are determined by territorial behavior, both intraspecific and interspecific with other salmonids when they are present.

The relatively extended freshwater rearing of steelhead has important consequences for the species' population dynamics. The maximum number of steelhead that a stream can support is limited by food and space through territorial behavior, and this territoriality is necessary to produce steelhead smolts that are large enough to have a reasonable chance of ocean survival. Because of this life history and habitat requirements, the number of age 0+ fish that a reach of stream can support is typically small relative to the average fecundity of an adult female steelhead. For example, a female steelhead may produce, on average, about 5,000 eggs. Typical age 0+ densities in some of the most productive California steelhead streams (e.g., tributaries to South Fork Eel River) are approximately 0.10 fish/ft^2 (1.1 fish/m^2) (Connor 1996). Therefore, with survival-to-emergence as low as 25%, the number of fry produced from one female (5,000 x 0.25 = 1,250) may be sufficient to fully seed the available rearing capacity of nearly 0.25 mi (0.4 km) of San Gregorio Creek at some of the highest densities observed in California. Therefore, the availability of suitable juvenile rearing habitat (either in the summer or winter) is the factor that usually governs the number of steelhead smolts produced from a stream.

Within the freshwater rearing stages of their life histories, the physical habitat requirements for different age classes of steelhead are relatively similar, except that as fish grow they require more space for foraging. We postulate that age 0+ steelhead rearing habitat did not typically limit steelhead production under historical conditions in either winter or summer. Age 0+ steelhead can use shallower habitats and finer substrates (e.g., gravels) and slower feeding habitat to meet their energetic demands than age 1+ steelhead, which, because of their larger size, have higher energetic demands and need coarser cobble/boulder substrate or LWD for velocity cover while feeding and as escape cover from predators. Because age 0+ steelhead can generally utilize the habitats suitable for age 1+ steelhead, but age 1+ steelhead can not use the shallower and/or finer substrate habitats suitable for age 0+ steelhead, it is unlikely that summer habitat will be in shorter supply for age 0+ than age 1+ steelhead. There may be stream systems or reaches where all available habitat is suitable for both age 0+ and age 1+ steelhead, but even in these instances the density of age 0+ steelhead that the habitat will support will be higher than for the larger age 1+ steelhead simply due to allometric increases in territory size. In situations where summer habitat is suitable for both age classes, competition for space between age 0+ and age 1+ steelhead may restrict the numbers of age 0+ steelhead that the habitat will effectively support. But in general, a reach of stream would commonly support far fewer age 1+ than age 0+ steelhead in the summer.

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[25] We use the terms "territory" and "territory size" not only in its traditional sense—as a particular defended area—but also in cases where defense of a particular area may not occur but agonistic behavior by dominant individuals (e.g., nips, fin extensions, charges) effectively determine the maximum density of rearing juvenile coho in a pool.

As with summer habitat, a reach of stream will typically support far fewer age 1+ than age 0+ steelhead in the winter. Overwintering steelhead may also suffer high mortality when they are displaced by winter floods. Refuge from flood events requires access deeper into the streambed to avoid turbulent conditions near the surface or even within first layer of substrate (the implications of this for embeddedness are discussed later). Because steelhead tend to spawn in a wider variety of habitats than coho salmon, including higher gradient reaches (i.e., >3%) with confined stream channels, off-channel water bodies such as sloughs and backwaters are typically rare. As a result, steelhead show less propensity then other species (e.g., coho salmon) for using off-channel slackwater habitats in winter, and a greater propensity for using in-channel cover provided by cobble and boulder substrates, which are typically common and usually immobile at all but the highest flows in these areas. Steelhead will use cover in the form of LWD or off-channel habitat when it is available, especially in low-gradient reaches where interstitial spaces among cobble boulder are less abundant, or in watersheds, such as San Gregorio Creek, where natural or anthropogenic factors result in high embeddedness.

Winter rearing habitat comprised of unembedded cobbles and boulders may occur within discrete portions of the channel network according to reach-scale sediment supply and transport capacity, channel confinement, and local hillslope processes. Cobble-boulder rearing habitats are supported by channels with adequate stream power to maintain a bed composed of larger particles (> 3 in [90 mm]), are confined (thus encouraging in-channel deposition of cobbles and boulders), and are coupled to hillslopes so hillslope processes are a proximal source of large particles.

Step-pool reaches are also relatively confined and deep enough to contain cobble-boulder substrates within their wetted channel. A channel should be at least as deep as the smallest cobble grains within a cobble-boulder habitat complex to be usable as juvenile fish rearing habitat. Confinement also restricts the cobble-boulder substrates to the wetted channel. Wider reaches found lower along the continuum, such as plane-bed and pool-riffle not only lack the gradient to support discrete, unembedded cobble-boulder habitat complexes, but are also flanked by gravel bars over which cobbles and boulders may distribute rather than remaining in the center of the channel.

The formation and persistence of cobble-boulder habitat complexes may also depend on a proximal source of large particles, favoring channels that are coupled with hillslopes and active hillslope processes (Coulombe-Pontbriand and Lapointe 2004). Along the continuum of channel types, the degree of channel-hillslope coupling decreases in the downstream direction, with step-pool channels tightly coupled with the adjacent hillslopes, but with the degree of coupling reducing as alluvial floodplains develop (Montgomery and Buffington 1997). The adjacent hillslopes may provide numerous, chronic and episodic, sources of coarse sediment to step-pool channels.

In watersheds where, as a result of anthropogenic disturbance, there are increased inputs of coarse and fine sediment to the stream channel and decreased LWD, there is often greater disparity between the amount of summer habitat for age 0+ and age 1+ steelhead. Pool frequency is reduced with the removal of LWD, especially in forced pool-riffle and plane-bed stream reaches. The remaining pools may become shallower as a result of aggradation and the lack of scour-forcing features such as LWD, and lack cover as well. The filling of interstitial spaces of cobble/boulder substrates by gravels and sand can affect summer habitat for both age 0+ and age 1+ steelhead, especially in watersheds such as San Gregorio Creek where natural geology is composed of highly erodible material. But because of the larger size and more secretive nature of age 1+ steelhead, their habitat will be reduced at lower levels of embeddedness than for age 0+ steelhead. Because age 0+ steelhead are smaller and can utilize a wider range of substrate than age 1+ steelhead, it will often be the case that there is more winter habitat available for age 0+ than for age 1+ fish.

Likewise, in the winter, habitat may often become unsuitable for age 1+ steelhead at lower magnitudes of sedimentation than for age 0+ steelhead. At higher levels of embeddedness, substrate will become much less suitable for both summer and winter rearing, but it will often be more limiting in winter because refuge from entrainment during winter freshets typically occurs deeper within the substrate.

The presence of lagoon habitat in some watersheds affects steelhead production dynamics. In stream reaches, the abundance of juvenile steelhead tends to be regulated by density-dependent demographic processes that result from competition between individuals. Competition for food and space results in downstream emigration or mortality of juvenile steelhead that are smaller or less aggressive. In watersheds without lagoon habitat, emigrants are presumed to be lost from the population (Shapovalov and Taft 1954). However, in some coastal watersheds lagoons provide suitable rearing habitat for a portion of the density-dependent emigration from stream habitat for months or even years. It appears that if lagoons are well-mixed (i.e., not salinity stratified), or comprised of mostly freshwater, they can maintain a relatively cool, well oxygenated, and food-rich environment that provides high quality habitat for juvenile steelhead (Hayes et al.2008, Smith 1990). Conversely, when lagoons are highly saline, or salinity-stratified, they collect heat in the lower saltwater layer, have relatively lower dissolved oxygen levels, and typically have unsuitable conditions for rearing (Smith 1990; K. Atkinson, pers. comm., 2009).

Ocean survival is dependent upon the size of smolts (Bond et al. 2008), and in general steelhead smolts that rear in the upper watershed tend to have much greater survival to adulthood if they outmigrate as age 2+ or older smolts. Although age 1+ smolts are sometimes common, studies on their survival typically report that they contribute little to the numbers of returning adults (Moyle 2002), except in cases when they grow to large sizes such as in lagoons (Bond et al. 2008). This differential survival is likely due to the advantages that larger fish have in evading predation, either through superior swimming ability or by growing larger than the gape of potential fish predators.

Downstream migrating steelhead exhibit three possible life history strategies based upon usage of lagoon and stream rearing habitat: stream rearing, lagoon rearing, and combination stream and lagoon rearing (Hayes et al 2008). Stream-reared steelhead spend one–two years in the stream, and then migrate to the ocean with minimal lagoon residence. Lagoon-reared steelhead spend only a few months in the stream before migrating to the lagoon where they will rear for typically one year. The combination strategy will rear for 1–2 years in the stream and 1–10 months in the lagoon before emigrating to the ocean. Conditions for growth can be very good in lagoons relative to stream habitat, and thus fish in lagoons tend to achieve a larger size-at-age then their stream-reared counterparts (Smith 1990, Hayes et al. 2008). Since larger smolts tend to have higher ocean survival, growth during lagoon rearing may increase ocean survival of steelhead smolts. Lagoon systems, therefore, can provide a potential demographic boost in two ways. First, lagoons may relax to some degree the density-dependent bottleneck occurring in stream habitat. Second, by providing a high growth environment and adjustment to a saline environment lagoons may increase smolt sizes and consequently improve ocean survival for both stream reared and lagoon reared fish.

Although much of the above discussion describes stream and lagoon habitat separately, they should not be viewed as disconnected habitat features. Just as upstream conditions such as freshwater inflow and sediment delivery affect lagoon characteristics, demographic processes such as immigration and emigration link steelhead population dynamics within stream and lagoon habitat. Thus, under our conceptual model, steelhead populations are typically limited by a combination of density-dependent processes occurring within stream reaches, and the degree to which seasonal rearing opportunities and water quality in lagoon habitat augment carrying capacity in the watershed. We initially assume that either summer age 1+ or winter age 1+ habitat conditions limit the capacity of stream reaches. We assume that the ability of lagoon habitat to support steelhead in excess of stream carrying capacity is dependent on the degree to which freshwater inflow interacts with, or displaces, saline water to prevent salinity stratification, which is affected by annual variability in timing of sandbar formation and amount of freshwater inflow.

4.3.3.4 Application of steelhead conceptual model to the San Gregorio Creek watershed

The relationship of the freshwater habitat in the upper San Gregorio Creek watershed to the formation of a lagoon in the lower watershed defines a steelhead conceptual model that is applicable to a limited number of California coastal streams. In this model, primarily density-dependent factors limit production in the upper watershed (e.g., availability of winter rearing habitat), while annual variability in water quality (e.g., high water temperatures in summer and fall, artificial bar breaching) and other environmental factors affect the carrying capacity in the lagoon. Details of the primary mechanisms limiting steelhead production are discussed below.

Spawning habitat

In some watersheds, water diversions compromise the success of spawning salmonids by preventing migratory access to spawning habitat. Based on the compilation of all available flow data for the USGS gauge in San Gregorio (Figure 2-6), it appears that when steelhead migration is initiated in early December, flows are typically adequate to allow migration. However, detailed analysis of how much flow is required to achieve access throughout their range in San Gregorio watershed has not been conducted. In addition, lagoon sandbar formation and breaching patterns can affect steelhead migration, possibly resulting in a later run of steelhead if the bar is not open. Poaching of adult spawning or spawned steelhead has been documented to occur and may reach levels that affect steelhead production in some years (T. Frahm, pers. comm. 2009).

Several potential barriers to upstream migration have been identified in the San Gregorio Creek watershed (Cox and Robins 2006, Ross Taylor and Associates 2004), which may restrict the ability of migrating steelhead to access approximately three miles of potential spawning habitat.

For most steelhead populations, spawning gravel quality and quantity, as assessed by gravel permeability and population modeling, does not limit steelhead production (Stillwater Sciences 2004, 2006, 2008). Increases in smolt production can be expected relative to increases in embryo survival only when embryo survival is already low (e.g., lower than 10%), and even 10% survival may be sufficient to produce the maximum number of smolts. San Gregorio Creek may not be fully saturated at 10% egg survival when considering the carrying capacity of the estuary, because age 0+ fry that are displaced to the lagoon rear and smolt successfully (K. Atkinson, pers. comm., 2009). Therefore spawning habitat quality may be more important than in other coastal steelhead streams. While the San Gregorio Creek watershed is currently listed as impaired for both bacteria and sediment under Section 303(d) of the Clean Water Act (SFBRWQCB 2006), bacteria and turbidity in the watershed do not chronically exceed levels that would impact salmonids (see Section 2.6). Survival to emergence is dependent on successful incubation of eggs, which are especially vulnerable to low dissolved oxygen levels and high water temperature.

Adequate flows are also required to maintain suitable conditions for incubating eggs. Based on available flow data it appears that in most years under current conditions flows are sufficient to prevent dewatering of redds and deliver adequate levels of dissolved oxygen.

The most recent stream surveys for San Gregorio Creek and its tributaries note abundant suitable spawning habitat, albeit with high levels of substrate embeddedness at pool tail outs that potentially affect steelhead spawning and fry survival to emergence (Baglivio and Kahles 2006a, 2006b, 2006c; Brady et al. 2004; CDFG 1996c, 1996d). Based on availability of suitable substrate, and in light of relatively restricted rearing habitat (described below), spawning habitat is not assumed to be a primary mechanism limiting steelhead production in the San Gregorio Creek watershed under current conditions.

Summer rearing habitat

Summer rearing habitat has been posited to limit steelhead production in San Gregorio Creek (Coots 1971), due to poor instream habitat and extensive water diversions. Stream surveys for the San Gregorio Creek watershed in 1995 and 1996 (CDFG 1996a, 1996b, 1996c, 1996d, 1996e, 1996f, 1997a, 1997b) recorded that pools were abundant but that most were shallow with low shelter value and relatively little instream cover from LWD or other sources. The documented lack of LWD is likely preventing the scour formation and maintenance of deep pools, resulting in a plane-bed channel. CDFG surveys report that most cover was provided by cobbles and boulders, rather than LWD. A lack of LWD and deep pools appears to exist in the tributaries as well, based on surveys in 2006 and 2007 in Bogess, Harrington, and La Honda Creeks (Baglivio and Kahles 2006a, 2006b, 2006c; Pearce et al. 2007), where again pools were abundant, but most were <2 ft (0.6 m) deep, although slightly more instream cover was noted than in the mainstem surveys.

Pool filling appears to be occurring from sediment transport from upslope sources and has been noted to reduce available habitat throughout the San Gregorio Creek watershed since the 1970s from logging, agriculture, and urbanization (Titus et al. 2006). As recently as 1985 a massive landslide in La Honda Creek was observed to result in pool filling and a localized fish kill (L. Ulmer, CDFG, unpublished file letter, 13 October 1987, as cited in Titus et al. 2006). Reduced pool volume and reduced instream flows can limit production of steelhead by reducing food availability, space, and increasing metabolic demand from higher water temperatures. The ability of fish to convert energy sources to physical growth is a function of their food intake and metabolic rate. High water temperatures increase energy allocated to catabolic processes, and thus less energy remains to allocate to growth. Therefore the key environmental parameters that potentially affect growth are food availability (e.g., invertebrate drift) and water temperature. Both of these key variables can be affected by instream flows, since flow delivers invertebrate drift, and solar radiation increases temperatures in small volumes of water more quickly than in large volumes of water. Other parameters, such as fish density and channel morphology, may also indirectly affect growth. For example, as fish density increases in shallow pools (either from pool filling or reduced flows), food resources are portioned among more individuals, leaving less caloric energy available for each fish. Channel morphology can affect water temperature by influencing the volume of water within the channel exposed to solar radiation, and can affect invertebrate drift, since most invertebrate production originates from riffles. Water temperature and food availability, both influenced by channel morphology and flow, may combine to produce a synergistic effect on fish growth. At low flows during summer and fall, when water temperature may be high and food delivery may be low, fish growth may be reduced, and in chronic situations fish either perish or do not reach large enough sizes to smolt successfully.

In extreme conditions high water temperatures can limit the production of steelhead. Sullivan et al. (2000) found that juvenile steelhead growth opportunities were maximized, and long-term growth deficits were most effectively overcome, when maximum weekly water temperatures were between 14.5 and 21°C (58.1 and 69°F). San Gregorio is a forested watershed influenced by marine fog. SFBRWQCB (2007a) continuously measured temperature at six sites for several weeks in summer 2002 and recorded MWATs below 14.8°C (59°F) at all sites except San Gregorio Creek near Stage Road (site SGR-010), which had an MWAT of 15.3°C (60°F). However, more recent data collected by SGERC in 2009 shows MWATs several sites within San Gregorio and La Honda Creeks in excess of 14.8°C (59°F) (Section 2.6.3) and maximum instantaneous water temperatures at the un-shaded lagoon site were found in excess of 25°C (77°F) on 6 and 7 August 2009. Based on available data, it appears that water temperatures have the potential to reduce growth of steelhead in San Gregorio Creek in at least some years, depending on food availability. If food availability is high, such as in the lagoon, elevated water temperatures are less likely to have a deleterious effect on steelhead growth.

Based on habitat preferences of juvenile steelhead, we expect that if low flows reduce riffle habitat and other shallow water areas, then low flows potentially reduce the abundance of age 0+ during summer, while the lack of deep pools potentially limit abundance of age 1+ during summer. In fall 2008 direct observation surveys in La Honda Creek, Harrington Creek, Bogess Creek, and the mainstem San Gregorio Creek, found that age 0+ occurred in all sampled reaches, albeit in lower densities than is typically observed in other basins in the region, but extremely low densities of age 1+ juveniles relative to the number of age 0+ (Stillwater Sciences 2008, unpubl. data). While 2008 was a relatively dry water year, these findings are consistent with CDFG surveys in the basin and with observations by NMFS in 2006, 2007, and 2008, including observations in Alpine Creek and Mindego Creek (B. Spence 2009, unpubl. data). In most sampled reaches there were three to fifteen times more age 0+ than age 1+ juveniles, with an average ratio of greater than 7:1. In addition, in many suitable pools (i.e., >2 ft deep) no age 1+ juveniles were observed. Based on this data it appears that summer habitat is generally available for age 0+ rearing (although it could be improved), and that age 0+ and age 1+ winter habitat (discussed in more detail below) are driving forces limiting the production of steelhead from the watershed. For example, if summer habitat for age 0+ were a driving factor limiting the population, we would have observed relatively lower abundances of age 0+ than were observed. In some tributaries, such as La Honda Creek, this appears to be the case, suggesting that reproductive success or summer habitat may be especially poor there. Similarly, if age 1+ summer habitat were limiting the population we would expect to observe higher densities (regardless of abundance) than were observed in most locations, although there were some stream reaches where age 1+ appeared to use all available summer habitats (Stillwater Sciences 2008, unpubl. data).

In addition to low flows, notable fluctuations in flow are occasionally measured at the USGS San Gregorio stream gauge (Section 2.4.2). Although flow fluctuations can be detrimental to rearing steelhead, there is currently no available data on the magnitude or impact of fluctuations within habitats where fish are rearing (typically far upstream of the USGS gage).

It appears that although the summer rearing carrying capacity for age 1+ is restricted by deep pool habitat, under current conditions there are not enough age 0+ surviving the winter to seed what is available in at least some of the tributaries sampled, resulting in low densities of age 1+. In addition, low flow conditions could result in reduced delivery of food (in addition to potential limitations on invertebrate productivity) from riffles to pools, and therefore reduced growth rates of rearing steelhead. Juvenile steelhead rearing in the upper watershed (Alpine Creek) have been observed to be significantly smaller than fish of the same age rearing in the lower mainstem, which in turn are significantly smaller than fish of the same age rearing in the lagoon (K. Atkinson, pers. comm., 2009).

Winter habitat

Consistent with the general conceptual model for steelhead, it appears that winter habitat is likely one of the primary factors limiting production in the watershed. As discussed above, fall abundance estimates indicate a strong likelihood for a winter habitat limitation for age 0+ and age 1+ fish. In addition, based on downstream migrant trapping and sampling of the lagoon, age 0+ and age 1+ fish enter the lagoon during winter, which could be linked to displacement of fish unable to locate suitable winter habitat (Coots 1971). Overall, it appears that a combination of age 1+ summer habitat and winter habitat for both age 0+ and age 1+ are driving forces limiting the production of steelhead from the watershed.

As discussed in the steelhead conceptual model (Section 4.3.3.3), the benefits of LWD for juvenile salmonids are well documented. During the winter, LWD, in combination with other features such as vegetated overhanging banks and cover consisting of interstitial spaces in cobble/boulder substrate, provide protection from high water velocities that can cause downstream displacement to less suitable habitat. Although LWD features provide valuable winter refuge for steelhead, unembedded cobble/boulder substrate is a key attribute supporting winter survival for juvenile steelhead in streams experiencing periodic high flows brought on by storm events. This is because the most effective velocity refugia for steelhead may be located within the streambed itself, as compared with a concealment cover type such as LWD, which will be more typically used during winter base flows. Results of experiments by Redwood Sciences Laboratory and Stillwater Sciences in an artificial stream channel show the effect of coarse substrate embeddedness on the use of interstitial space by age 0+ juvenile steelhead during high flows. At flow velocities of 3–4 ft/s, densities of 0.65 fish/ft^2 were observed when cobbles were unembedded (Redwood Sciences Laboratory and Stillwater Sciences, unpublished data). When cobbles were at least 30% embedded with small gravels, a lack of sufficient interstitial space precluded use by juvenile steelhead of coarse substrates for refuge (i.e., a fish density of 0). Comparison of results from this flume study and other studies conducted under stable winter baseflow regimes suggests that completely unembedded coarse material provides similar carrying capacities during both base and storm flows. However, with increasing embeddedness, carrying capacities for habitats subjected to high flows decrease much more quickly than in habitat at winter base flow.

Many of the stream surveys and inventories in the watershed indicate some level of substrate embeddedness by fine sediment (Baglivio and Kahles 2006a, 2006b; CDFG 1985a, 1985b, 1997a, 1997b). Much of the geology underlying the San Gregorio Creek watershed has moderate to very high erodibility (Section 2.5.1), so there is naturally a greater potential for fine sediment in the creek channels and winter habitat in the form of interstitial space may be naturally less abundant than in other coastal streams. Further, there are many anthropogenic sources of fine sediment in the watershed (Best 2002, 2007; Brady et al. 2004; PWA 2003). In this case LWD may be more important as winter habitat than in a stream system with naturally available unembedded substrate. However, as described previously, recent CDFG stream surveys indicate a lack of LWD within the San Gregorio Creek watershed (CDFG 1996a, 1996b, 1996c, 1996d, 1996e, 1996f, 1997a, 1997b). Based on fish observations in fall 2008, and the reduced availability of winter habitat, there is evidence that winter habitat for age 0+ and in particular age 1+ is limiting steelhead in San Gregorio watershed.

Lagoon habitat

Steelhead smolts tend to have much greater survival to adulthood if they outmigrate at a larger size (Bond et al. 2008). In most steelhead streams, fish large enough to have high survival are those that outmigrate as age 2+, and age 1+ smolts, although common, contribute little to the numbers of returning adults (Moyle 2002). However, in San Gregorio Creek, similar to other nearby watersheds (e.g., Scott Creek) the lagoon habitat appears to provide highly suitable conditions where fish can growth to large sizes and smolt successfully as age 1+. Smith (1990) found that when the San Gregorio Creek lagoon was allowed to form naturally without artificial breaching, over 10,000 juvenile steelhead reared in the estuary, and steelhead rearing there were able to reach smolt size within one year (i.e., smolt as age 1+). More recent sampling of the lagoon in 2005 and 2006, as well as interpreting adult scales (n=22), has documented that extensive use of the estuary continues, mostly by age 0+ and age 1+. Based on scale analysis of 22 adult females captured in San Gregorio Creek in 2008, nearly half of the fish smolted (and survived to spawn) as age 1+, having reached a large enough size to smolt after rearing for 6 months to a year in the lagoon (K. Atkinson, pers. comm., 2009). Overall, around half of the scales collected in 2008 indicated a stream only life history, and the other half indicated lagoon rearing for at least 6 months.

In the recent past along the California coast, lagoons and waterways have been channelized and straightened to accommodate infrastructure, prevent flooding, and to reclaim farmland (USFWS 2005). Highway 1 crosses San Gregorio Creek upstream of the mouth, and during roadway construction the marsh and lagoon were partially filled and the creek displaced to the south under a bridge. The marsh now connects with the creek through a culvert, but downstream channel incision causes the marsh to drain during periods of low flow (Swenson 1997). Most lagoon volume is now contained in the stream channel upstream of the Highway 1 Bridge, adjacent to the marsh (Smith 1990). Stream channelization has potentially disconnected marsh habitat from the main channel, eliminating additional lagoon habitat.

Lagoon-rearing and/or partial lagoon-rearing life histories are dependant on sandbar formation and maintenance, and rearing is documented to be more extensive when lagoon is not artificially breached during summer (Smith 1990; K. Atkinson, pers. comm., 2009). Climatic conditions, such as precipitation, tides, and storm events, affect sandbar formation and maintenance. Changes in hydrologic regime, such as caused by diversion, and increased sedimentation can also influence the physical and chemical composition of the closed estuaries or lagoons. Water diversion may affect the dynamics of lagoon formation, causing extended periods of saltwater and freshwater stratification that lead to thermal stratification, with warmer temperatures and anoxic conditions along the bottom that lower dissolved oxygen levels and reduce food supplies (Capelli 1997, Smith 1990). Growth and survival of steelhead are increased when lagoons are well-mixed by conversion to freshwater by inflows after bar formation, which reduces bottom temperatures and increases dissolved oxygen. A fully open tidal lagoon is also well-mixed and can be cooled by the tides, but the size of the mixed, cool portion is relatively small (the effect does not penetrate far upstream) compared to the size of an impounded freshwater lagoon (Smith 1990). While the San Gregorio Creek watershed is currently listed as impaired for both bacteria and sediment under Section 303(d) of the Clean Water Act (SFBRWQCB 2006), bacteria and turbidity in the watershed do not chronically exceed levels that would impact salmonids (see Section 2.6). San Gregorio Creek lagoon and beach rarely exceed bacterial levels that result in beach closures or public warnings based on San Mateo County and Surfrider Foundation monitoring. SGERC and CDFG data indicate that temperatures in the lagoon can exceed critical thresholds for coho salmon and steelhead in the later summer, particularly when the lagoon is stratified with high saline, lower DO, high water temperature (> 25°C) at the bottom (K. Atkinson, pers. comm., 2009). Elevated temperatures, however, in conjunction with high food availability likely contribute to the productivity of the lagoon and its value as salmonid rearing habitat (K. Atkinson, pers. comm., 2009). Overall, the lagoon habitat is crucial to the life history of steelhead in this watershed, and is likely increasing the carrying capacity of the watershed, alleviating some of the limitations from poor habitat conditions in the upper watershed.

4.3.3.5 Limiting factors hypotheses

Our conceptual model of steelhead in San Gregorio Creek results in the following hypotheses, and the general understanding that primarily density-dependant factors likely limit production in the upper watershed (e.g., availability of winter rearing habitat), while primarily density-independent factors affect production in the lagoon (e.g., water quality):

1. A lack of winter habitat for age 0+ steelhead limits the abundance of the age 1+ population, resulting in under-seeding of available summer rearing habitat.
2. A lack of winter habitat for age 1+ steelhead limits the production of the population.
3. A natural lack of boulders in some reaches, a lack of LWD, and embeddedness of cobble/boulder substrates by fine sediment are the main causes of limited winter habitat.
4. Low summer instream flows limit potential rearing habitat for age 0+ steelhead and invertebrate production from riffles.
5. Reduced LWD, fine sediment filling of pools, and low instream flows limit formation and maintenance of complex pool habitat for age 1+ steelhead.
6. Amount and quality of lagoon habitat alleviates the effects of habitat restrictions in the upper watershed during years when the lagoon can form, and limit steelhead production when the lagoon can not form due to breaching or lack of freshwater.

4.3.4 Tidewater goby limiting factors analyses

4.3.4.1 Distribution and status

Tidewater goby historically occurred in at least 134 localities along the California Coast, in coastal lagoons, marshes, and estuaries from Tillas Slough in the Smith River of Del Norte County to Agua Hedionda Lagoon in San Diego County (Moyle 2002, USFWS 2005). The fish still occur within this range, but over half of the populations at these localities are extirpated or extremely small with uncertain long-term persistence (USFWS 2005). The dramatic decline in these species resulted in USFWS listing tidewater goby as a federally endangered species in 1994 (USFWS 1994).

The San Gregorio Creek lagoon was proposed as critical habitat for the tidewater goby in 2006 and again in 2008 (USFWS 2006, 2008). Critical habitat contains features that are essential for the conservation of a threatened or endangered species and may require special management consideration or protection (USFWS 2005). The lagoon is also part of the Greater Bay (GB) recovery unit, which extends from Salmon Creek in Sonoma County to the Salinas River in Monterey County, and is within the GB-5 sub-unit that includes San Gregorio, Pescadero, and Bean Hollow creeks. All three watersheds in sub-unit GB-5 support populations of tidewater goby. Recovery units are based upon morphological characteristics supported by genetic testing (Ahneldt et al. 2004, Dawson et al. 2001, both as cited in USFWS 2005), and sub-units are considered to be genetically different from one another (USFWS 2005). The population in San Gregorio is genetically distinct from the population in Pescadero Creek based upon microsatellite analysis (Mendonca et al. 2001). San Gregorio also has very low microsatellite genetic diversity, indicating that it has gone through a major population bottleneck.

The Recovery Plan (USFWS 2005) notes that there is a regular and abundant presence of tidewater goby within the San Gregorio Creek lagoon. Smith (1990) sampled lagoon fish populations in 1985, 1986, and 1988, finding large resident populations of tidewater goby. Swenson (1997) estimated relatively high densities of 1.0–2.5 gobies per ft^2 (10–25 m^2) in the lagoon and 0.3–0.8 per ft^2 (3–75 m^2) in the creek, with an overall population estimate of a few hundred thousand in the entire San Gregorio Creek system. Observations in the 1980s (Smith 1990) and occasional observations since have found that the gobies do well during summer in years when the sandbar remains in place (compared to when the summer sandbar is breached) and have much lower numbers (during spring) following years of severe winter storms (J. Smith, pers. comm., 2008; K. Atkinson, pers. comm., 2009).

4.3.4.2 Life history summary

Tidewater goby are a short-lived (generally 1 year) and highly fecund species that disperse infrequently via marine habitat but have no dependency on marine habitat for its life cycle (Swift et al. 1989, Lafferty et al. 1999). They can tolerate large temperature (8–25°C [46–77°F]) and salinity (0–41 ppt) ranges, and appear to require stable lagoon or off-channel habitats, particularly during their relatively short larval stage (Chamberlain 2006, Lafferty et al. 1999, Moyle 2002, Swift et al. 1989).

Reproduction and spawning can occur at all times of the year, but typically take place during spring and summer (April to August or later) in slack, shallow waters of seasonally disconnected or tidally muted lagoons, estuaries, and sloughs. Juveniles and adults can be found year-round, although they are most abundant in summer and fall (Swift et al 1989). Spawning generally occurs in well oxygenated water that is 8–15 ppt salinity, 17–22°C (62–71°F), and 8–39 in (20–100 cm) deep (Moyle 2002, Swenson 1999, USFWS 2005) but occurs in a much wider range of salinity and temperature conditions. Males dig burrows 4–12 in (10–30 cm) vertically into unconsolidated, clean, coarse sand (0.02 in [0.5 mm] diameter) after estuaries close to the ocean (Swift et al. 1989, USFWS 2005). Burrows are at least 3–4 in (7–10 cm) from each other (USFWS 2005). Female tidewater gobies aggressively spar with each other for access to males with burrows for laying their eggs (USFWS 2005). Females can lay 150–1,100 eggs per clutch and can lay up to 6–12 clutches per year (Moyle 2002, Swenson 1999, Swift et al. 1989). Swenson (1995, 1999) found that size at spawning was a reasonable predictor of female fecundity in terms of the number of ovarian eggs. Male tidewater gobies remain in the burrow to guard the eggs, which are attached to sand grains in the burrow ceiling and walls (USFWS 2005). Embryos require 9–11 days to hatch, during which time the male tidewater defends the burrow, rarely emerging (USFWS 2005). The reproductive behavior of these species is unique from other gobiid species; sex-roles are reversed with females exhibiting aggressive behavior (Swenson 1997). After hatching, tidewater goby larvae emerge from spawning burrows and are pelagic and remain within the middle of the water column until they reach approximately 0.6–0.7 in (16–18 mm) length, and sink down to the lagoon floor to enter the benthic juvenile life stage until reaching sexual maturity at 0.9–1.1 in (24–27 mm) (Moyle 2002).

4.3.4.3 Tidewater goby conceptual model

The tidewater goby lifecycle is closely tied to the dynamics of estuary closure and lagoon formation (Figure 4-4). Lagoons form in response to seasonal rainfall and water patterns, and tidal influences, with sandbar closure during dry periods (spring and summer) and breaching during wet periods (fall and winter). During wet months, high energy waves erode and breach sandbars, while high stream flows widen and deepen the estuary mouth (Capelli 1997, Smith 1990). In dry months, low energy waves deposit sand and build up sandbars. After sandbar formation, water surface elevation rises as the impounded lagoon fills with freshwater streamflow. The freshwater interacts with already present saltwater, occasional surf wash, and saltwater that has percolated through the sandbar to create a brackish environment or even a freshwater environment if inflow is sufficient (Capelli 1997, Smith 1990). Sandbars generally breach at the onset of fall and winter storms, converting the estuaries to freshwater during high flows and brackish estuaries during low inflows if there is a substantial embayment despite removal or all or most of the sandbar.

Tidewater goby spawning begins after estuary closure with individuals that were present during the previous year's estuary closure and the wet months of estuary opening (Swift et al. 1989). Considerable mortality among early season spawners and the absence of large individuals later in the season suggests that the late season spawning population consists of individuals derived from more recent (within season) spawning (Swift et al. 1989). This pattern is also suggested by a bimodal late-winter length-frequency distribution (0.6–0.8 in [15–20 mm] and 1.2 in [30 mm]) that shows the average length of each group increasing through the spring and summer, but the abundance of small fish (first year spawners) increasing and the abundance of large fish (second-year spawners) decreasing (Moyle 2002). Tidewater goby are generally an annual species, with individuals occasionally living longer than one year (Moyle 2002). Spawning generally ends after sandbars are breached by fall and winter storms.

Late spring/early summer spring spawning populations require hydraulic refuge to survive fall and winter storms and estuary breaching. These individuals may retreat upstream to freshwater marshes, channel margins, sloughs or other backwater habitats, and vegetation (Swenson 1997, Swift et al. 1989). The availability of these low velocity habitats is critical during wet periods as tidewater gobies are weak swimmers and are easily displaced. All central coast estuaries that have thriving goby populations have good winter refuge habitat; those without refuge lack gobies or have only occasional population if nearby sources are available (J. Smith, pers. comm., 2008). In general, spawning tidewater goby are vulnerable to the effects of storms that occur after estuary closure. Storms, and associated elevated streamflow, may breach newly formed sandbars causing changes in estuary depth, salinity, and temperature that preclude embryo survival (Capelli 1997, Smith 1990). High flows may displace pelagic and benthic larvae, juveniles, and adults, and scour burrows, which are laid 1 in (2.5 cm) below the surface (Swenson 1997). Scour may also decrease the amount of sand substrate available for breeding.

On a population scale, presence of tidewater goby along the California coast follows the distribution of littoral cells that distribute sand and allow the development of closed estuaries (Capelli 1997). Geographic gaps in distribution correspond to steep coastlines with no embayments that are likely to form lagoons. Sandbars that separate lagoon habitat from the ocean can prevent tidal influence and reduce water velocity as well as the probability of tidewater goby displacement.

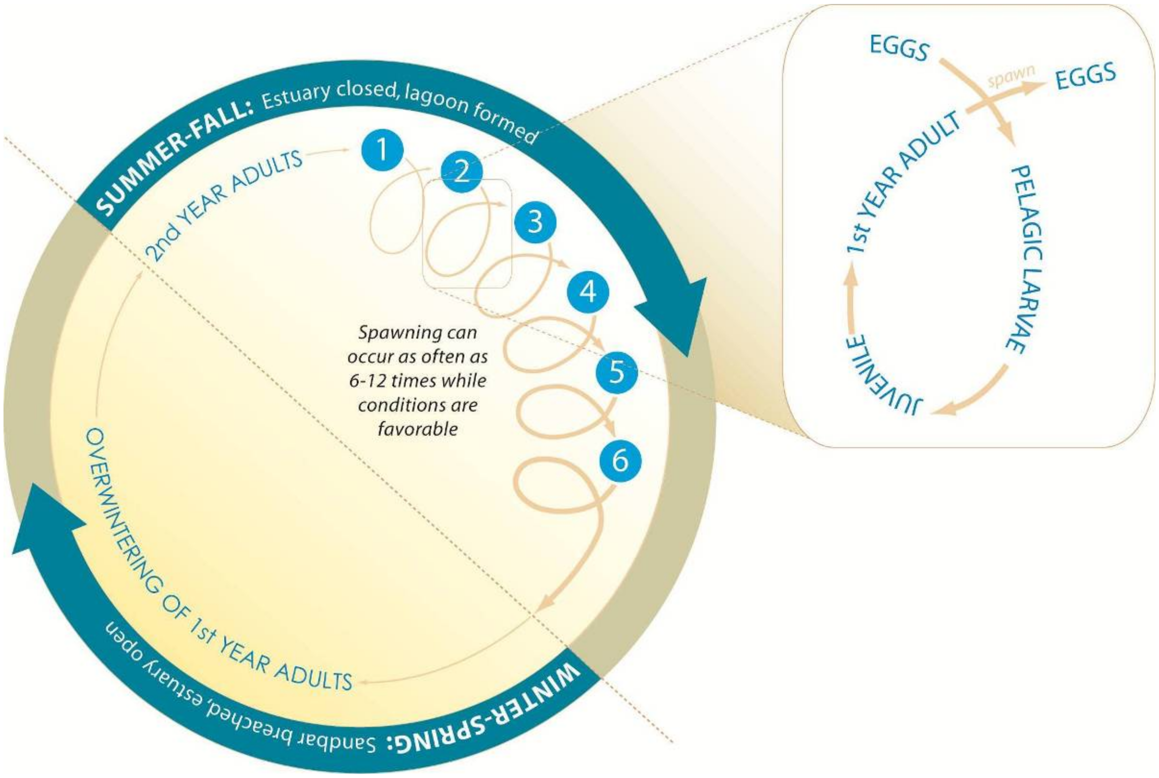

Figure 4-4. Tidewater goby life cycle.

Maintenance and restoration of the natural hydrologic regime is an important factor in preserving lagoon function, and the physical and chemical environment required by tidewater goby (Table 4-1) (Capelli 1997, Mitsch and Gosselink 1993, Smith 1990). Complete sandbar closure, availability of sand substrate, and availability of hydraulic refuge should support stable and sustainable populations of tidewater goby. Freshwater inflows after sandbar formation influence chemical (salinity, temperature, and dissolved oxygen) and physical conditions within the estuary, but tidewater gobies can do well in a variety of fresh to brackish conditions and even often with warm low oxygen water due to salinity stratification if shoreline water quality and substrate are suitable (Smith 1990). After sandbars breach and physical and chemical conditions become less than ideal for tidewater goby breeding and rearing, populations plummet, sometimes by several orders of magnitude, only to recover after bar closure (Moyle 2002, Smith 1990, Swift et al. 1989). Their high fecundity, frequent spawning, and territorial behavior allow populations to rebound, but alterations to the natural dynamics of lagoon formation can prevent this natural resiliency.

Table 4-1. Summary of tidewater goby life stage characteristics, habitat requirements, fecundity, and survival.

Stage	Size	Age	Habitat	Fecundity	Survival
Egg	--	--	• Coarse sand (0.5 mm [0.02 in] diameter) • Well oxygenated water	--	
Larvae	4–5 mm	9–11 days	• Water column	--	
Juvenile	16–18 mm	--	• Lagoon floor	--	
1st yr spawner	24–27 mm	<1 yr	• 8–15 ppt salinity • 17–22 °C (62–71 °F) • 20–100 cm (8–39 in) depth • Hydraulic refuge (channel margins, backwater habitat and vegetation	• Spawn every 1–3 weeks for several months, up to 6 times/yr • Female fecundity (# of eggs) = 37 * Standard Length (mm) - 692	
2nd yr spawner	>27 mm	>1 yr			0.001

Changes in flow regime affect bar closure timing, and physical and chemical conditions in the lagoon. Reduced freshwater inflows may delay the conversion from salt to brackish water (Table 4-2) (Capelli 1997). This delay will cause the estuary to remain stratified, with saltwater along the bottom and freshwater along the surface, longer into the late spring and early summer. The stratified water column, with salt water on the bottom, collects and stores heat because it cannot lose the heat to the surface like the overlying freshwater, causing sub-optimal to lethal temperatures (up to 30°C [86°F]) along the estuary bottom (Capelli 1997, USFWS 2005). Saltwater dominated bottoms can become anoxic, with low dissolved oxygen concentrations, creating a hostile condition for invertebrate and aquatic vegetation growth. Tidewater goby rely on chironimid larvae and invertebrate eggs, and amphipods and crustaceans as food sources (Swift et al. 1989). Lesser inflow can also reduce scour of aquatic vegetation that can occupy and stabilize sand substrate, precluding usage as spawning habitat. Greater input of freshwater causes the sandbar to form later in the spring or summer, and potentially increases the frequency of spring and summer sandbar breaching (Capelli 1997). Higher flows can displace pelagic larvae and scour burrows (Chamberlain 2006).

Table 4-2. Lagoon classification system for tidewater goby habitat.

Flow regime	Bar closure	Chemical conditions	Physical conditions
Normal	• Open in wet months • Closed in dry months	• Well mixed fresh or brackish water • Cool temperatures • High dissolved oxygen	• Low water velocity in dry months • Adequate backwater habitat for wet month hydraulic refuge • Available sand substrate for breeding
Reduced freshwater inflow	• Bar closure earlier in spring	• Delayed mixing • Longer periods of salt and freshwater stratification • Warm temperatures on bottom within saltwater lens • Low dissolved oxygen due to low mixing	• Low water velocity in dry months • Reduced aquatic habitat area • Less available sand substrate due to vegetation encroachment • Reduction in prey items
Increased freshwater inflow	• Incomplete or partial bar closure • Bar closure later in spring or summer • Increase in frequency of spring and summer breaching	• Dominated by freshwater • Cool temperatures • High dissolved oxygen	• High water velocity with fewer dry months • Shortened breeding season • Reduced backwater habitat • Displacement of pelagic larvae and scouring of burrows

4.3.4.4 Application of tidewater goby conceptual model to the San Gregorio Creek watershed

The Tidewater Goby Recovery Plan (Recovery Plan) (USFWS 2005) identified water quality (high coliform levels, sediment from non-point sources), anthropogenically initiated sandbar breaching, stream channelization, and natural predators as specific threats to the San Gregorio Creek population. Because of the strong association of sediments with the sorption of metals and organic compounds such as pesticides, estuary lagoons are the likely accumulation point for toxic compounds used within a watershed, where these pollutants may present a chronic, but undocumented cause of goby decline (Moyle 2002). Smith (1990) noted sediment deposition within the San Gregorio Creek lagoon, and that accelerated scour and fill processes potentially had serious effects on benthic invertebrates. While the San Gregorio Creek watershed is currently listed as impaired for both bacteria and sediment under Section 303(d) of the Clean Water Act (SFBRWQCB 2006), bacteria and turbidity in the watershed do not chronically exceed levels that would impact aquatic species (see Section 2.6). Lagoon water quality data collected by SGERC, San Mateo County, and CDFG indicate generally high water quality in the lagoon. San Gregorio Creek lagoon and beach rarely exceed bacterial levels that result in beach closures or public warnings based on San Mateo County and Surfrider Foundation monitoring. SGERC and CDFG data indicate that temperatures in the lagoon can exceed critical thresholds for coho salmon and steelhead in the later summer, particularly when the lagoon is stratified with high saline, lower DO, and high temperature water at the bottom (K. Atkinson, pers. comm., 2009). Slightly elevated temperatures, however, likely contribute to the productivity of the lagoon and its value as steelhead rearing habitat (K. Atkinson, pers. comm., 2009). Other water quality parameters monitored by SGERC in the lagoon do not suggest that water quality has limited tidewater goby over the monitoring period of record.

Anthropogenically initiated sandbar breaching was once a common practice intended to alleviate upstream flooding, to allow passage of anadromous fish, or to reduce stagnation and associated odors with algal growth and decay in the lagoon (Swenson 1997, USFWS 2005). Breaching by the public continues, presumably for recreation and to allow easier access to the beach from the parking lot. Artificial breaching causes lagoons to drain quickly and may strand individuals or dewater burrows (USFWS 2005). Swenson (1997) identified the lagoon, creek, and marsh as distinct tidewater goby habitat types. Lagoons are closest to the ocean, separated by a sandbar, and are the most commonly used habitat. Brackish marshes are completely or partially disconnected from the nearby lagoon or creek, and are potentially important refuges, providing stable physical conditions and prey availability (Swenson 1997). The lowered water surface elevation from breaching may disconnect creek and marsh habitats, preventing access to hydraulic refuge (Swenson 1997). Salinity levels also increase as saltwater enters the open lagoon. Breaching has occurred historically (Smith 1990) and regularly occurs at San Gregorio in most wet years. In 2005 and 2006 breaching by the public took place throughout the summer, so that the sandbar was rarely in place for more than two weeks (K. Atkinson, pers. comm., 2009). Observations in the 1980s (Smith 1990) and occasional observations since have found that the gobies do well in summer in years when the sandbar remains in place and have much lower early summer numbers following years of severe winter storms (J. Smith, pers. comm., 2008). The same patterns have generally held for sampling in other lagoons in San Mateo and Santa Cruz counties (J. Smith, pers. comm., 2008). Lagoons with good winter refuge habitat have relatively large numbers of gobies in spring and those without refuge have few or no gobies. In summer gobies in closed lagoons have high populations compared to those with tidal action.

In the recent past along the California coast, lagoons and waterways have been channelized and straightened to accommodate infrastructure, prevent flooding, and to reclaim farmland (USFWS 2005). Highway 1 crosses San Gregorio Creek upstream of the mouth, and during roadway construction the marsh and lagoon were partially filled and the creek displaced to the south under a bridge. The marsh now connects with the creek through a culvert, but downstream channel incision causes the marsh to drain during periods of low flow (Swenson 1997). Most lagoon volume is now contained in the stream channel upstream of the Highway 1 Bridge, adjacent to the marsh (Smith 1990). Stream channelization has potentially disconnected marsh habitat from the main channel, eliminating growth and refuge habitat, and increased water velocity in the lagoon during winter. Without hydraulic refuge, an isolated population is vulnerable to severe reduction or extirpation during stochastic events, such as flooding. Channel incision, followed by floods possibly eliminated the tidewater goby population in Waddell Creek (Smith 1990, Swenson 1997, Swift et al. 1989, USFWS 2005). Swenson (1997) observed larger tidewater goby in marshes of Pescadero Creek than in creeks or lagoons, possibly related to stable physical conditions and prey availability, suggesting that marshes provide opportunities to improve or restock lagoon and creek populations.

Tidewater goby populations are likely controlled by environmental conditions, not by interactions with natural predators (Moyle 2002). Tidewater goby are poor swimmers and lagoon habitats have relatively little escape cover, and predation by native species is noted in studies, but rarely mentioned as a major source of mortality (Capelli 1997, Swift et al. 1989). Still, non-native predators are a potential threat (Lafferty and Page 1997, as cited in Moyle 2002; Lafferty et al. 1999; Swift et al. 1997; C. Swift, pers. comm., 2006). Introduced yellowfin goby (*Acanthogobius flavimanus)* and shimofuri goby *(Tridentiger bifasciatus)* may also compete with or prey on tidewater goby (Swenson 1999, Swenson and McCray 1996), although these species have not been observed in San Gregorio Creek. Potential restoration projects for tidewater gobies should be evaluated for their potential impacts on habitat conditions for introduced exotic predatory species.

4.3.4.5 Limiting factors hypotheses

The Recovery Plan (USFWS 2005) notes that there is an abundant regular presence of tidewater goby within the San Gregorio Creek lagoon, and that no habitat restoration is needed. Still, there has been little long-term monitoring of tidewater goby, within San Gregorio Creek or across the entire geographic range, and population dynamics are poorly documented (USFWS 2005). In addition, recognizing the habitat elements that support tidewater goby populations is key to protecting them over the long term. Initial hypotheses of factors limiting the population of tidewater goby in the San Gregorio Creek watershed are:

1. The dynamics of sandbar formation caused by anthropogenically induced breaching affect the amount of calm water suitable for breeding and larval growth, limiting tidewater goby populations.
2. Channelization and associated channel incision, especially the reduced connection between the lagoon and marsh habitat, have reduced the area of critical habitat (e.g., winter refuge habitat) and is limiting tidewater goby populations.

4.4 Synthesis

Based on historical evidence, the San Gregorio Creek watershed likely supported robust populations of all the focal species analyzed. There are many ecological characteristics of the San Gregorio Creek watershed that continue to be very healthy relative to other streams in the region. These characteristics, including the protection of over a third of the basin from development and disturbance, a relatively health riparian zone, low-gradient stream reaches, coastal fog influence, low levels of urbanization, and an intact lagoon system highlight the regional significance and immense potential of this watershed to protect and recover these populations. Tidewater goby, steelhead, and California red-legged frog continue to occur in sustainable levels in at least some portions of the watershed, while coho salmon are rare. The limiting factor analysis identified key watershed-specific threats to the long-term persistence of tidewater goby, steelhead and California red-legged frogs, and to the recovery of coho salmon. Potential threats limiting the California red-legged frog population throughout the watershed are a lack of available slow-water/breeding habitat along San Gregorio Creek and on un-surveyed properties, non-native predators in some stock ponds, and improper stock pond management. For coho salmon and steelhead, the most critical threats to freshwater life stages are the lack of winter habitat from LWD and unembedded substrate, critically low flows and reduced pool volume in the summer and fall of some years, and for steelhead the frequency of artificial lagoon breaching. Tidewater goby are also threatened by a lack of winter refuge habitat and the frequency and timing of artificial and natural lagoon breaching as well. Protection and recovery of the focal species analyzed depends on management actions to both ensure that key ecosystem components (e.g., suitable lagoon habitat) remain intact, and to restore or enhance ecosystem components that threaten the integrity of the watershed ecosystem (e.g., artificial lagoon breaching and critically low instream flows).

5 MANAGEMENT, RESTORATION, AND RESEARCH PRIORITIES

There are many ecological characteristics of the San Gregorio Creek watershed that are very healthy relative to other streams in the region, and these characteristics are what allows the watershed to support populations of tidewater goby, steelhead, and other rare and endangered species. Further, a large portion of the watershed is owned by the MROSD, California Department of Parks and Recreations, and San Mateo County, helping to ensure that these characteristics are conserved. However, based on the local reports compiled in the San Gregorio Creek WIS, field surveys by CDFG, Stillwater Sciences, and others, in addition to the findings of both the Watershed Characterization and Limiting Factors Analysis sections, some watershed conditions have been degraded and will require restoration or enhancement to achieve protection and recovery of aquatic species populations.

The management, restoration, and research priorities provided in this section are recommended with the ultimate objectives of: (1) providing for the long-term protection of key ecosystem components, and (2) restoring or enhancing ecosystem components that require it. Many of the recommended actions discussed below are included because they directly address and/or test a factor potentially limiting a focal species population, as identified in the Limiting Factors Analysis section. Several actions are recommended based on local reports compiled in the San Gregorio Creek WIS and recent field survey results, as summarized and discussed in the Watershed Characterization section. Other actions are recommended based on previous comments from the TAC, or to maintain and/or enhance the local community's capacity to manage the watershed in the future. All of the recommendations are considered high-priority for implementation and are simply organized alphabetically in the following sections.

It should be noted that these recommendations are not intended to constrain or prevent other watershed assessment, restoration, or management actions that contribute to watershed understanding or ecological benefits but are undertaken outside of this watershed management planning effort.

5.1 Monitor Water Quality & Address Identified Sources of Impairment

SGERC and SWAMP monitoring has demonstrated that, with only a few exceptions, water quality conditions in the watershed are currently very good. This data was critical in evaluating potential limiting factors for steelhead and coho salmon, and identified several water quality parameters and locations of concern. For these reasons, and in an effort to preserve current water quality conditions, we recommend that water quality monitoring for a variety of parameters, such as that currently implemented by SGERC, continue to be conducted throughout the watershed. Monitoring should be conducted to identify seasonal and long-term trends in water quality parameters and specific sources of any measured impairment. Sources of impairment should be addressed as quickly as possible.

For example, while the San Gregorio Creek is a forested watershed influenced by marine fog, summer water temperatures in some locations occasionally exceed Basin Plan (SFBRWQCB 2007b) criteria and/or optimal conditions for coho salmon growth. At this time the causes of these occasional high-temperature events are not understood, although some combination of low instream flows and inadequate stream shading are two potential mechanisms for elevated stream temperatures. Water temperature monitoring should be compared with water-year type, instream flows, riparian canopy conditions, and other potential independent variables so that the source(s) of occasional high-water temperatures can be identified and addressed accordingly.

The Watershed Characterization also described occasional bacteria levels that exceed Basin Plan (SFBRWQCB 2007b) criteria. While the SFBRWQCB currently lists San Gregorio Creek as impaired by bacteria, there is some potential that the watershed will be delisted based on relatively low bacteria levels documented by San Mateo County and the Surfrider Foundation at San Gregorio State Beach and in the seasonal lagoon (J. Marshall, pers. comm., 2009). At this time the causes of these occasionally high bacteria levels are not understood, although leaking septic systems, livestock lot management, and livestock in the stream channels, or some combination of the three, are potential mechanisms for elevated bacteria levels. Existing and continued SWAMP, SGERC, San Mateo County, and Surfrider water quality data should be synthesized to better define potential point and non-point sources of bacteria. Land use analysis may be needed to identify the sources of coliform bacteria and *E. coli* that periodically exceed Basin Plan criteria.

5.2 Analyze Coho Salmon Spawning Conditions

In depressed coho salmon populations, such as in San Gregorio Creek, production from spawning may not be adequate to seed summer rearing habitat. When this occurs, every constructed redd is critical to produce enough progeny to seed available habitat, and the population can be effectively limited by density-independent sources of mortality, such as migration barriers for adults and egg mortality from redd scour. While a lack of suitable spawning habitat is not necessarily the critical limiting factor for coho salmon in the watershed, it could be important in the recovery of the species in the watershed. Focused studies on density independent factors that potentially limit production (e.g., redd scour, fry abundance estimates) are recommended to test the hypotheses of factors limiting coho salmon in the watershed.

5.3 Analyze Limiting Factors for an Expanded Set of Focal Species

In general, LFA is an effective way of assessing the health of an ecosystem by identifying the critical issues limiting the populations of focal species and, subsequently developing focused actions that can then be taken to improve populations and overall ecosystem health. The LFA conducted for this Management Plan was critical to identifying many of the priority recommendations described in this section, but was limited to primarily freshwater aquatic species. In response to TAC comments on the limitations of the LFA conducted for this Management Plan, we recommend that an LFA be conducted for an expanded set of focal species to assess the health of terrestrial and coastal ecosystems in the watershed. The San Gregorio Creek watershed supports a number of special-status terrestrial and coastal wildlife species that would make appropriate focal species for an LFA and provide an indication of the health of these ecosystems in the watershed.

5.4 Construct Off-stream Water Storage

Off-stream storage (OSS) of riparian water diversions, which would divert water during higher winter instream flow conditions and store it for use in the summer and fall, is one way of achieving additional instream flows for coho salmon and steelhead rearing and fall migration during dry water years. Hydrologic modeling of the watershed (see Section 3.4) suggests that OSS can be an effective means of decreasing demand for instream flows and achieving a target minimum bypass flow of 2 cfs in all water-year types. While there are potentially significant environmental benefits for anadromous fish and other aquatic and terrestrial species, there are also potentially significant environmental impacts, as well as technical and logistical constraints associated with off-stream water storage projects and programs. WEAP hydrologic modeling of the watershed indicates that opportunities exist for maximizing the effectiveness of OSS systems by focusing on areas of higher water demand (e.g., the lower San Gregorio watershed), and/or operating the systems to allow for active management of streamflows (e.g., returning stored water to augment dry season flows). Therefore off-stream storage options, such as ponds or tanks, must be planned and constructed according to site-specific conditions, engineering designs, and thorough analysis of potential effects on environmental and other watershed resources.

5.5 Measure Stream Flow

Minimum instream flows in San Gregorio Creek have been identified as a limiting factor for juvenile coho salmon and steelhead abundance, and for adult coho salmon and steelhead fall migration in dry water years. Stream flow measurement for the entire San Gregorio watershed has, and still is, dependent on flow measurements taken at the USGS stream gauge near the town of San Gregorio (#11162570). However, this USGS gauge is not consistently or permanently funded. The lack of funding for gauge operation has the potential to severely constrain the management of water diversions under the adjudication decree, the understanding of historical flow conditions (see Section 3: Hydrologic Assessment), the identification of critical instream flow requirements for various salmonid life stages (Section 5.19 below) and lagoon habitat functions (Section 5.10 below), and many other restoration, management, and research recommendations. Various funding mechanisms have been used over the past several years to continue operating the gauge. It is recommended that a consistent and ideally permanent source of funding be secured to continue the operation of the gauge. Alternatively, efforts should be made to secure a memorandum of understanding with the USGS that they will fund and continue to operate the gauge. Meanwhile, it is recommended that an adequate portion of any restoration or research funding for the watershed be applied to the operation of the gauge.

In addition to continuing the USGS stream gauge at Stage Rd, it is recommended that additional stream flow gauges be installed and/or continually monitored to better understand flow variability in the watershed, with a focus on the major tributaries to, and junctions with, San Gregorio Creek.

MROSD and SGERC each operate a gauge on upper El Corte de Madera Creek and lower La Honda Creek, respectively, and Trout Unlimited recently installed three gauges on mainstem San Gregorio Creek. These gauges should continue to be monitored and calibrated and additional continuously-recording gauges should be installed in strategic locations.

5.6 Continue to Support Watershed Groups

The San Gregorio Creek WWG and TAC are both critical to maintaining and improving local community capacity for watershed management. These groups provide forums for: stakeholders, landowners, and other parties to inquire about watershed activities; technical oversight to study and restoration action implementation; continued development and implementation of project evaluation and adaptive management; public outreach and education related to the watershed; and increased coordination with and between regulatory agencies. We recommend that continued efforts be made to identify and acquire adequate funding for continued coordination and facilitation of the SGERC, WWG, and TAC.

5.7 Control Non-native Invasive Species

As described in the Watershed Characterization, the number and extent of non-native invasive species is not well documented in the watershed, even though these species have the potential to degrade native habitats and impact the populations of native species. For example, non-native predators were identified as a potential factor limiting the population of California red-legged frogs in the watershed. Further, several non-native invasive plants are believed to have only small or recently established populations, making them easier to control and/or eradicate.

These non-native predators and invasive plants, among others, should be the target of control and ideally eradication measures. Non-native invasive species control methods must be implemented strategically, to increase the effectiveness of treatment measures and reduce the potential for later or downstream reinfestations. Therefore, the locations and populations of non-native, invasive species in the natural areas of the watershed (i.e., areas that are not of concern in terms of habitat quality or ecosystem conditions, such as towns and neighborhoods, do not necessarily need to be surveyed) should be mapped and described. Each mapped location should specify the species and some description of the population (e.g., number of individuals, percent cover, or qualitative description of infestation, such as sparse, widespread, etc.). In upland areas, since non-native invasive species are frequently introduced via human activities and tend to occur in and around disturbed areas, the inventory should focus on existing roads and trails, transmission line corridors, and cattle ponds to reduce the level of effort. In the riparian corridor, non-native species could be identified and mapped coincident with other surveys. Surveys for non-native predators of California red-legged frog should focus on stock ponds in the watershed. The inventory should conclude with a summary of identified species (in terms of their potential detriment to the ecosystem, rate of infestation, and methods of control) and priorities and designs for control measures.

Based on the non-native invasive species identified in the watershed, and the severity of their infestation, site-specific treatment methods should be developed. Treatment methods should be selected that are appropriate for the site, minimize disturbance to adjacent natural areas, and do not result in unintended effects on non-target species. When appropriate, treatment methods should be implemented by trained and/or licensed crews. In some cases, non-native species can be discouraged and/or controlled by properly managed, targeted maintenance activities. For example, grazing practices can be managed to encourage and restore native species over non-native grasses and forbs. Further, since California red-legged frogs breed in winter and late spring, and bullfrogs breed in summer, ponds repeatedly drained in late summer can aid in reducing bullfrog production by eliminating tadpoles (though it is important to consider that adults may tend to survive and recolonize). Timely draining of ponds may also aid in removal non-native predatory fish. This tactic is beneficial assuming appropriate non-breeding habitat for red-legged frogs is nearby for retreat after breeding ponds dry. However, poorly managed pond maintenance may encourage invasion of non-native predators by providing migration pathways for non-natives (Seymour et al. 2007), so it is important that management activities take this into consideration.

5.8 Identify Critical Instream Flow Requirements

Summer habitat for coho salmon and steelhead may be degraded by a lack of instream flows in the summer and fall of some years. A lack of instream flow has been identified as a factor potentially limiting the abundance of juvenile coho salmon, the abundance of age 0+ and age 1+ steelhead, and the fall migration of adult steelhead and coho salmon during dry years in San Gregorio Creek. CDFG stream surveys, other local literature, and a field survey by Stillwater Sciences conducted specifically for this effort, have all noted dry stream reaches in the late summer and fall in some years. Dry reaches restrict steelhead access to riffle and deep-pool rearing habitats. We recommend an analysis of how much flow is required to maintain adequate summer rearing habitat for age 0+ coho salmon and steelhead, and 1+ steelhead, juvenile salmonid migration, and summer invertebrate production. The results of this assessment, particularly when integrated with the Hydrologic Assessment of historical flow patterns in the watershed, can be used to help inform strategies to increase instream flow and improve summer rearing conditions, and possibly fall migration conditions as well.

5.9 Identify Opportunities to Improve Off-channel Habitat

A lack of available winter refuge habitat, in part from lack of access to inundated floodplain or off-channel habitats, has been identified as a limiting factor for coho salmon in the watershed. The lower mainstem San Gregorio Creek historically may have been a relatively un-confined, low gradient channel, with low terraces and floodplains providing refuge habitat for juvenile coho salmon during high flows. We recommend that the mainstem channel be assessed for opportunities to restore connectivity to the floodplain. Areas downstream of Stage Road, where the majority of the floodplain is owned and/or managed by the state, may be of particular focus.

Highway 1 crosses San Gregorio Creek upstream of the mouth, and during roadway construction the marsh and seasonal lagoon were partially filled and the creek forced to the south under a bridge. The marsh is now connected to the creek through a culvert, but downstream channel incision causes the marsh to drain during periods of low flow, disconnecting marsh habitat from the main channel and seasonal lagoon. This channelization and associated channel incision, especially the reduced connection between the seasonal lagoon and marsh habitat, have reduced the area of critical winter refuge habitat for coho salmon and steelhead, and is potentially limiting the tidewater goby population. The marsh may also provide suitable habitat for California red-legged frogs, although no frog surveys have been conducted in this area.

Restoring optimal lagoon and/or marsh habitat for one focal species may conflict with the habitat requirements of another. Further, lagoon/marsh restoration has the potential to disrupt sandbar formation at the beach. Therefore, it is critical that any lagoon/marsh restoration begin with an assessment of lagoon and marsh connectivity, and the value or potential value of the lagoon in providing habitat for each of the focal species. An analysis of historical lagoon/marsh extent and condition would help elucidate the potential effects of habitat change on focal species populations and provide a potential reference for restored conditions.

5.10 Implement a Large Woody Debris Enhancement Program

Based on previous CDFG stream surveys, a review of local and regional literature, and a field survey by Stillwater Sciences conducted specifically for this effort, a lack of available winter and summer habitat was identified as a factor limiting the population of steelhead and a likely factor limiting coho salmon recovery in the San Gregorio Creek watershed. Winter habitat has been degraded for both species in part from a lack of LWD, which provides important slower-water refuge areas during high flow events. Summer habitat for steelhead has been degraded in two primary ways, one of which is a lack of LWD, which helps to form pools where steelhead can over-summer and provides cover and protection from predators.

Winter habitat LWD enhancement projects should be implemented and designed to provide continuous velocity refuges for juvenile salmonids from winter baseflows and floods, while summer habitat LWD projects should be implemented and designed to provide cover, and facilitate scour during high flows to increase pool volume and frequency. Both single log and multiple log configurations can be used depending on site-specific conditions. In some cases it may be appropriate simply to leave naturally occurring LWD where it is found or to manipulate its orientation in its current location.

Prior to implementation, an inventory of LWD and winter and summer rearing habitat (for both age classes of steelhead and coho salmon) will be necessary to determine more accurately the current abundance of LWD in winter and summer rearing locations and identify suitable locations for LWD enhancement. Any inventory should include differentiation of hard woods and conifers, which can have implications for the value of LWD in streams. Suitable locations will support appropriate rearing water temperatures throughout the year and will not conflict with adjacent land uses or threaten private property or human safety should an LWD enhancement move. In addition to identifying suitable locations for LWD enhancement projects, this spatially-explicit inventory can be used to identify property access issues, site-specific design constraints and opportunities, and an appropriate implementation schedule.

Also prior to implementation, an education and outreach campaign aimed at local landowners should be initiated. Education efforts should focus on helping landowners develop a complete understanding of the roles LWD play in the riparian ecosystem, and the measures that can be taken to avoid conflicts between LWD enhancement projects and adjacent land uses. This could include a review of LWD enhancement projects and/or programs in other coastal California watersheds. Outreach can be used to identify landowners who may be interested in hosting LWD enhancement projects, and further assure landowners that LWD enhancement projects will be conducted to minimize any negative affect on their property.

Initial LWD enhancement projects should be implemented as an adaptive management experiment, with monitoring of the abundance and survival of juvenile salmonids, to further test the hypotheses that winter and summer habitat is limiting coho salmon and steelhead in the watershed and to assess the effectiveness of the enhancements. Based on the monitoring results of initial efforts, it can be determined whether to expand and/or revise the design of LWD enhancement projects in the future.

5.11 Implement Water Conservation Strategies

A lack of instream flow has been identified as a factor potentially limiting the abundance of juvenile coho salmon, the abundance of age 0+ and age 1+ steelhead, and the fall migration of adult steelhead and coho salmon during dry years in San Gregorio Creek. To reduce the amount of water diverted from the stream and pumped from the alluvial groundwater basin, and potentially maintain summer and fall instream flows, domestic, agricultural, and recreational water conservation strategies should be implemented. The San Mateo County RCD, Natural Resources Conservation Service, and San Mateo County Farm Bureau work extensively with farmers and ranchers in the watershed to implement water conservation strategies. Although agricultural producers in San Mateo County are among the most efficient irrigators on the Central Coast, this work must be sustained, continued, and expanded.

5.12 Increase Cobble/Boulder Winter Refuge Habitat

In addition to remediating sources of fine sediment, winter refuge habitat for steelhead that is provided by unembedded cobble/boulder substrates may be enhanced by increasing the amount and/or configuration of cobbles and boulders in the channel. Cobble/boulder substrates are not lacking in the watershed, but their ability to provide optimal winter refuge habitat conditions may be limited by their location in the creek (e.g., they may occur in reaches that are not accessible to steelhead or coho or that are not otherwise suitable for overwintering) or orientation in the channel. Cobble/boulder enhancement projects should be implemented in areas of low fine-sediment production or downstream of fine sediment treatment sites (see Section 5.19 below). Cobble/boulder habitat can be enhanced in two potential ways, depending upon the existing amount of cobbles and boulders at a project site. In existing cobble/boulder-dominated sites, existing cobbles and boulders can be rearranged into configurations that salmonids can better utilize. Where cobble/boulder substrates are lacking, but could persist at a site, cobbles and boulders obtained from local quarries or other reaches of the creek can be strategically placed in the channel. Site-specific designs prepared by a geomorphologist and fisheries biologist familiar with each site would be required to determine the best location to encourage fish use while avoiding the primary path of winter bedload transport, and to ensure that cobble/boulder placement would not reduce available summer habitat.

Initial cobble/boulder placement projects should be implemented as an adaptive management experiment, with monitoring of the abundance and survival of juvenile salmonids, to further test the hypothesis that winter habitat is limiting steelhead production in the watershed, and to assess the effectiveness of the cobble/boulder projects. Based on the monitoring results of initial efforts, it can be determined whether to expand and/or revise the design of cobble/boulder placement projects in the future.

5.13 Maintain the San Gregorio Watershed Information System

The San Gregorio WIS represents a significant and unique investment of time and effort to compile existing information for a watershed. The WIS is a resource for the entire community, as well as to outside agencies and researchers. However, the utility of the WIS will decrease if it is not maintained or updated with new information sources. Therefore, we recommend that continued effort be made to identify and acquire adequate funding for maintenance of the San Gregorio WIS, including making corrections to the existing database, adding additional documents and data to the database, and advertising the existence and contents of the WIS to interested parties. In many cases, maintenance of the WIS could be a part of funding acquired for other actions in the watershed.

This recommendation would continue to provide a publically accessible source of information on the San Gregorio Creek watershed; provide a clearinghouse for information developed through the implementation of prioritized actions in the WMP; and address the SWRCB recommendation to establish watershed data management capacity.

5.14 Manage and Maintain Habitat for California Red-Legged Frog

The artificial stock ponds on MROSD land holdings in the watershed support an apparently successful, or at least stable, population of California red-legged frogs. Improper pond management was identified in the LFA as a factor that could potentially limit the distribution and abundance of California red-legged frog in other portions of the watershed. Therefore, it is important that existing suitable pond habitats be maintained and that potential pond habitats be identified and managed correctly.

Recommended management tasks on MROSD lands already include prescribed grazing, physical inspection and maintenance of ponds, and biological monitoring (e.g., Vollmar Consulting 2009). Continuing these management tasks is critical to maintaining existing high-quality California red-legged frog habitat.

These same management actions should be applied to non-MROSD lands, in cooperation with willing landowners, to better understand and restore California red-legged frog habitat in other portions of the watershed. Focused habitat assessments and frog-presence surveys on lands with the potential to support California red-legged frogs should be conducted to determine their habitat availability, distribution, and abundance across the watershed. Safe Harbor Agreements (SHA) under the ESA could be used as a tool to encourage private landowners to preserve habitat and support recovery of California red-legged frogs without fear of new restrictions being enforced on their property. A SHA is a voluntary agreement between a landowner and the USFWS, where the landowner receives formal assurances from the USFWS that they will not be required to conduct any additional or different management activities on their property as long as they fulfill the conditions of the SHA (e.g., permanently protecting or restoring habitat for the species). USFWS's special rule under 4(d) of the ESA, which under specific circumstances allows the USFWS to establish special regulations for threatened species that replace the normal protections of the ESA, may be another strategy to make private landowners at ease with having special-status surveys conducted on their lands. If surveys identify suitable California red-legged frog habitat on private properties, best management practices for prescribed grazing and/or pond maintenance should be developed and implemented in collaboration with USFWS, NRCS, San Mateo County RCD, and the landowners.

5.15 Monitor Alluvial Groundwater Wells

There is some potential that groundwater pumping in the watershed, particularly from the alluvial groundwater basin, reduces the amount of water available for instream flows and exacerbates this limiting factor for rearing and migrating salmonids in some dry years (Zatkin and Hecht 2009 [Appendix A]; A. Richards, pers. comm., 2009). Therefore, it is recommended that groundwater wells begin and/or continue to be monitored by San Mateo County (which requires meters on all approved wells). Well monitoring should be targeted at assessing potential impacts on both short and longer-term time scales. If impacts are determined to be significant, mitigation strategies should be developed to minimize or eliminate negative instream flow impacts due to ground water extraction.

Potential short-term monitoring studies may include working with willing well owners to measure short-term effects of pumping on instream flows using flow dataloggers upstream and downstream of the study wells. Alternatively, test wells of different construction and distance from the streams could be installed to demonstrate how varying pumping and irrigation strategies affect streamflows.

Potential longer-term monitoring studies may include an evaluation of groundwater conditions in relation to groundwater use. Working with willing well owners, records of long-term changes in water levels and salinity (measured as specific conductance or TDS) may be collected with either conventional quarterly or semi-annual monitoring with sounding (measuring water depths) and sampling (for salinity), or it may be based on water levels that are continuously recorded and transmitted to a central data repository. This information would then be compared to records of groundwater extraction to evaluate the potential for groundwater pumping to influence instream flow levels.

5.16 Monitor Coho Salmon and Steelhead Populations

Monitoring coho salmon and steelhead populations in the San Gregorio Creek watershed is recommended to accurately assess the population status of both coho salmon and steelhead, identify weak or strong year classes, continue to test and refine the hypotheses generated in the LFA, and to measure population response to restoration actions. This monitoring would also support NMFS recovery plans for coho salmon and steelhead, which should identify adult abundance targets for San Gregorio Creek. The current draft recovery target for coho is 1,363 adults (NMFS 2010). CDFG has been monitoring some salmonid life stages (e.g., fall juvenile abundance) in portions of the watershed in some years. In addition, CDFG has conducted steelhead abundance, growth, and habitat use surveys in the lagoon in some years. It is recommended that these efforts be continued and expanded to include spawning surveys, downstream migrant production, size at outmigration, estimates of marine survival, and scale analysis of both lagoon and stream life histories.

5.17 Protect the Sandbar and Lagoon

The tidewater goby population in San Gregorio Creek is dependent on the availability of suitable habitat in the lagoon, and rearing steelhead growth rates have been shown to be greatly enhanced under appropriate lagoon conditions. A lack of seasonal lagoon habitat in both space and time was identified as a limiting factor for tidewater goby and steelhead. The amount and quality of lagoon habitat can be degraded and/or limited when the sandbar is breached artificially or there is a lack of freshwater inflow. We recommend that the sandbar be protected from unpermitted anthropogenic breaching, which often is conducted by the public to maintain access to the beach. Actions may include constructing a berm to guide the lagoon away from the pathway down to the beach, interpretive signs to educate the public, and increased monitoring and/or enforcement by California Department of Parks and Recreation or other relevant agency staff.

In addition, long-term monitoring of sandbar formation, steelhead and tidewater goby use of the lagoon, and lagoon water quality (e.g., water temperature, dissolved oxygen, and salinity profile) in relation to lagoon inflows are recommended to inform minimum instream flow requirements for the watershed and to maintain and protect lagoon habitat.

5.18 Remediate Sources of Fine Sediment

For both coho salmon and age 0+ and 1+ steelhead, a lack of winter habitat was identified as a limiting factor. In addition to a lack of LWD (discussed above) winter habitat for age 0+ and age 1+ steelhead has been degraded by fine sediment filling the interstitial spaces between streambed cobbles and boulders that are used by age 0+ and age 1+ fish to avoid high flows. The refuge area provided by unembedded cobble/boulder substrates is critical to the over-winter survival of juvenile steelhead in streams that experience episodic storm-driven high flow events. CDFG stream surveys, other local reports, and a field survey by Stillwater Sciences conducted specifically for this effort (Stillwater Sciences 2008, unpubl. data) all suggest that fine sediment is embedding cobble/boulder interstitial spaces and reducing suitable winter refuge habitat in some portions of the watershed. The San Gregorio Creek WIS includes over six detailed and relatively recent inventories of bank erosion, landslide, and road-related fine sediment supply areas, primarily on MROSD and San Mateo County properties. In addition, the San Mateo County Resource Conservation District (RCD) is conducting additional assessments and geospatial analysis of roads in the watershed as part of its Rural Roads Program. Implementing the high-priority recommendations for treatment in these detailed inventories is a logical and cost-effective way, since the inventory has already been conducted, of beginning to remediate known sources of fine sediment.

The various sediment source inventories suggest that similar sediment sources exist in other portions of the watershed as well. Therefore, while these fine sediment sources are being addressed, additional focused inventories of fine sediment sources on properties throughout the watershed, with a focus on County-maintained roads, should be conducted throughout the watershed in collaboration with the landowners. These inventories can be used to further prioritize the treatment of fine sediment sources in the watershed as a whole, and as the basis of collaborating with and assisting willing landowners to implement stormwater and sediment retention best management practices on their properties.

Initial treatment of fine sediment should be implemented as an adaptive management experiment, with monitoring to determine if treatments are effective at reducing embeddedness. In addition, treatments should be conducted in coordination with those described below to increase cobble/boulder refuge habitat to further test the hypotheses that winter habitat is limiting steelhead production in the watershed and to assess the effectiveness of the enhancements. Based on the monitoring results of initial efforts, it can be determined whether to expand and/or revise treatment of fine sediment in the future.

5.19 Remove Critical Fish Passage Barriers

Previous surveys of the San Mateo County coast that were reviewed for the LFA documented several fish passage barriers in the San Gregorio Creek watershed that limit the distribution and likely populations of steelhead and coho salmon. These barriers, which are identified and described by Ross Taylor and Associates (2004) and Cox and Robins (2006), restrict steelhead and coho salmon from accessing over three miles of potential spawning and rearing habitat in tributary streams. These barriers should be removed or modified to allow fish passage and migration under the full range of flow conditions. Appendix F includes identified fish passage barriers in the watershed.

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Appendices

Appendix A

Zatkin and Hecht (2009): Groundwater Influences Affecting Aquatic Habitat Potential, San Gregorio Creek Watershed

Groundwater Influences Affecting Aquatic Habitat Potential, San Gregorio Creek Watershed

By Robert Zatkin and Barry Hecht

Introduction

No known unified discussion of groundwater conditions, and the effects of such conditions on aquatic habitat, exists for the San Gregorio Creek watershed (hereafter SGCW). This section presents an initial framework for discussion of groundwater conditions.

What is known about groundwater in the SGCW

- The San Mateo County Department of Environmental Health (hereafter DEH) maintains a database of permitted wells in the SGCW.
- Based on first principles the SGCW can be divided into groundwater terrains. The terrains vary in their capacity to yield water to ground water wells, and the quality of the water that they produce. The distribution of wells according to the DEH appears to reflect groundwater abundance.
- The State of California Department of Water Resources maintains some records of groundwater conditions and use from the 1960s (California Department of Water Resources, 1965).
- High naturally-occurring salinities exist in the groundwater of the SGCW, probably associated with the original waters of deposition (‘connate waters’) of several distinguishable formations.

Issues

- Groundwater well location data have been recently assembled by the DEH, and are now available for the first time. As with well records in all other counties in California, these records are likely not quite complete and may need validation if they are to be used for watershed-wide assessment in the SCGW.
- A large proportion of land owners – private and public – are likely to have limited success in developing groundwater to supplement surface diversions, or as an alternative to surface diversions. With relatively little groundwater of suitable quality available, water re-use, conservation, and possibly high-flow diversions to surface storage are particularly important means of making land use and aquatic habitat protection as compatible as possible.
- Because the SGCW was formally adjudicated in 1990, groundwater may be the only new source of water available to owners who do not hold a 1990 adjudicated right, making groundwater more vulnerable to overdevelopment than in most other coastal San Mateo County watersheds.

- Summer baseflow in the SGCW originates from groundwater outflow to the channels. Baseflow is comparable to Pescadero Creek but low relative to other nearby coastal watersheds (see below). The low baseflow is a direct result of low groundwater recharge, storage, and flow in the geologic units underlying the SGCW. Because little groundwater enters the streams during summer or dry years, habitat management must operate within tighter constraints than in most other Santa Cruz Mountains channels.

- Groundwater in the SGCW tends to have higher salinities than is typical of the Santa Cruz Mountains streams. Pockets of groundwater naturally too salty for agricultural and most habitat uses are distributed throughout the watershed, most noticeably beneath the northern ridges in the western part of the watershed.

- Continual diminishment in base flows may result in an increase in surface water salinity which is a potential limitation to salmonid and California red-legged frog use of some tributaries.

- Recharge areas with surface-groundwater exchange relationships are hydrologically important and measures to augment recharge in such areas are likely to benefit habitat. Practices or projects that diminish recharge in such areas should be discouraged, for example paving roads, compacting sites, and installing denser drainage.

Geological Overview and Groundwater Occurrence

Prior investigations

While a wealth of important geological studies exists for the San Gregorio watershed[26], relatively little is known about the occurrence, recharge, quality, or use of groundwater. The earliest systematic compilation of groundwater in the SGCW was by the California Department of Water Resources in (1965), which collected scattered information on well yield and water quality as part of a regional study of water resources in western San Mateo County. Most subsequent reports discuss individual wells or sites of relatively limited extent. At the subwatershed scale, a number of groundwater studies have been conducted in the La Honda area, summarized in Owens and others (2008). Hecht and others (2003) analyzed the hydrogeology of Fandango Ranch, which includes much of the Coyote and Bear Creek subwatersheds, and helping to establish a framework for considering groundwater in the western portion of the watershed.

San Mateo County's Department of Environmental Health (2006, updated 2008) has recently compiled 40+ years of information from well permits and drillers' logs into GIS database; Greg Smith, of DEH, kindly provided a listing of wells in and near the SGCW for this study. Currently, no watershed-wide groundwater summary or inventory of seeps and springs is known to exist.

Terrains

Absent a prior groundwater framework for the watershed, it may be useful to draw upon a regional classification developed for the San Mateo County Resource Conservation District (RCD), which considered a regional program of diverting high flows to off-stream storage as a means of providing a reliable supply of agricultural water supplies. This approach is most effective if off-stream storage is augmented with a small but steady rate of groundwater inflow.

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[26] Summarized in Brabb and others, 2000

Hecht (2004) divided the RCD's area of interest into six terrains based on hydrogeologic conditions[27] which might allow production of low, reliable groundwater yields. The following three of these terrains occur within the SGCW.

Skyline Terrain – The Skyline Terrain is the eastern portion of the watershed delineated on the west by the La Honda Fault which trends northwest – southeast approximately mid-point between Redwood Terrace and La Honda. An area of complex geology, the Skyline Terrain contains a relatively broad recharge area along the crest and upper slopes of the watershed. Hydrogeologic characteristics of the rocks of the Skyline Terrain, coupled with the highest rainfall rates in the SGCW, are conducive to groundwater recharge. Most recharge in the SGCW seems to occur within the Skyline Terrain, which also supports the highest baseflow rates in the SGCW. Late September near-unimpaired baseflows at the watershed scale may be on the order of 0.015 to 0.06 cfs/sq. mi. (Owens and others, 2008; Pescadero nr Pescadero gage; Gartner and others, 2009)

Purisima Terrain – The Purisima Terrain encompasses that portion of the SGCW that is underlain primarily by the Purisima Formation, from the La Honda Fault to the western boundary. The composition of the Purisima Formation is not conducive to the storage and transmission of groundwater, although locally portions of the Purisima Formation may produce groundwater in sufficient quantities to meet domestic, and possibly agricultural and live-stock, requirements. Late-September near-unimpaired baseflows at the watershed scale may be on the order of 0 to 0.05 cfs/sq. mi. (Pilarcitos at HMB gage; Owens and others, 2001; Tunitas Creek typically dry)

Alluvial Terrain – The Alluvial Terrain consists of relatively coarse-grained, water yielding alluvial deposits of varying ages, principally along San Gregorio Creek, and to a lesser extent along the larger tributaries such as Clear Creek and Alpine Creek. The alluvial deposits are usually relatively thin, narrow and bounded by bedrock – they are not nearly as deep as the alluvium along Pescadero, Butano, Pilarcitos, and other larger coastal San Mateo County creeks where the alluvial aquifers are large, and are often hydrologically connected to terrace deposits.[28] The alluvial deposits are notably shallow upstream of Old Stage Road.[29] Water in the alluvium of the SGCW is closely connected with the adjoining channel, such that wells drawing from alluvium are likely to affect flow in the stream. Conversely, water discharged to alluvium, such as through leachfields, percolation from offstream reservoirs, or from agricultural or hard-surface runoff, can serve to recharge the channels. While not much is known about the alluvial aquifer downstream from Old Stage Road the alluvium is likely linked to San Gregorio Creek, the lagoon at San Gregorio Beach, and the ocean.

In comparison, late-September near-unimpaired baseflows at the watershed scale for the Montara Mountain granitic terrain seem to be approximately 0.08 to 0.20 cfs/sq. mi. per Owens and others, 2001 and unpublished data), and for the Chalks terrain may be about 0.08 to 0.12 cfs/sq. mi. based on 2002 to current data from Balance Hydrologics' Gazos Creek gage; on Whitehouse Creek (unpublished Balance Hydrologics field observations), and on Waddell Creek (Hecht and Rusmore, eds.,1973)

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[27] Based primarily on – (a) geological continuity, (b) inferred groundwater abundance, (c) water quality, and (d) degree of direct hydrological connection with streams supporting steelhead and coho.

[28] We were unable to unambiguously distinguish wells drawing from the alluvial aquifer using data in San Mateo County Department of Environmental Health's database, and combined them with the underlying bedrock terrain. The term 'shoestring aquifer', with its roots in California water law, is perhaps more appropriate to the bedrock-bounded thin alluvial bodies of the SGCW; 'terrain' is used simply for consistency with the nearby watersheds.

[29] The USGS stream gage is sited immediately downstream of Old Stage Road, where a bedrock constriction minimizes flow in the adjoining alluvium.

Landslide Deposits

An unusual number of large, deep-seated landslides are mapped throughout the SGCW (c.f., Brabb and others, 2000; Wiezcorek, 1982). These substantial masses of unconsolidated material can hold considerable volumes of groundwater. Some of these landslides may serve as supplemental sources of water to support habitat and land uses at a small scale. In portions of SGCW with adverse bedrock water quality, landslides may provide the only usable water source. Landslide 'aquifers', by their nature, are one-of-a-kind systems, with varying properties, and hydrologic connections to streams, springs, or both, with appreciable habitat values, so their effects on baseflows may require case-by-case assessment.

Faults, Fractures, Dikes and Sills

The hydrogeologic framework of the SGCW reflects the affects of movement on large faults within and adjacent to the watershed.[30] Movement along the faults have juxtaposed a diverse array of rock types, of different hydrogeologic properties, in the watershed and likely influence the occurrence and transmission of groundwater. Principal influences of faults include the following.

- Conduits for groundwater flow.

- Barriers to groundwater flow.

- Control the occurrence of seeps and springs.

- Fault movement imparted fracture systems in geologic formations and associated tectonic stress. Such fractures can collect groundwater and act as conduits for groundwater flow.

The occurrence of dikes and sills[31] is likely constrained to the single volcanic rock in the watershed – the Mindego Basalt. Dikes and sills can influence the flow of groundwater by acting as impermeable barriers that alter the flow direction. Alteration may result in effective recharge to streams and generation of seeps and springs. The occurrence of fault, dike or sill controlled emergent groundwater from the Mindego Basalt to adjacent streams, is in particular, potentially significant. The Mindego Basalt outcrops in the Bogess Creek, Harrington Creek, La Honda Creek, Mindego Creek and Alpine Creek. Fracture systems in the Mindego Basalt may also provide conduits for groundwater recharge to streams. It is noteworthy that a spring system flowing from the Mindego Basalt has been the long-term domestic water supply for the approximately 400 residences and businesses at La Honda as well as the La Honda School.

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[30] San Andreas Fault approximately 1.5 miles east of the eastern boundary. Pilarcitos Fault approximately .75 miles east of the eastern boundary. San Gregorio Fault at the western boundary. La Honda Fault at mid-point of the watershed. The predominant trend of these faults is northwest-southeast.

[31] A dike is a tabular body of igneous or sedimentary rock that cuts across the structure or beds into which it was intruded. A sill is a tabular body of igneous rock that is concordant with the beds or structure of rock mass into which it was intruded. Both occur widely in the eastern half of the San Gregorio watershed, where the dikes and sill are composed of basaltic Mindego volcanics. The sandstone dikes prevalent further south in the Santa Cruz Mountains have not been recorded in the SGCW.

Hydrogeologic Overview

Aquifer Properties

Insufficient information is available to bracket the properties of the SGCW aquifers.

Groundwater Level Fluctuations

Static groundwater levels fluctuate seasonally about 5 to 10 feet in ridgetop wells in the northwestern portion of the SGCW (Hecht and others, 2003). Anecdotal information is that water levels vary up to about 10 feet in domestic wells linked to the alluvial aquifer. A wide range of seasonal water-level fluctuations are reported from other wells, especially those on slopes or in landslides. Little information is available about how water levels vary over wet-year/drought cycles.

Water Quality

Groundwater quality in the SGCW varies widely. The concentrations of total dissolved solids, as well as the major ions contributing to 'salinity', usually reflect the composition and history of the geologic units from which the water emanates. Waters within several distinct geologic formations – among them, the Lambert Shale/Vaqueros sandstone, the San Lorenzo formation, and the Tahana and San Gregorio members (see Cummings and others, 1962) of the Purisima formation – can, but not always do, all exhibit very high salinities in the SGCW and immediately adjoining watersheds.[32] Total dissolved solids can vary from 400 to 500 mg/L, near La Honda and along the ridgelines, particularly along the southern watershed boundary in areas of Pomponio soils, to more than 13,000 mg/L in springs and wells near the intersection of Old Stage Road and Highway 1. Generally, the mineral concentrations in groundwater of the SGCW are amongst the highest in San Mateo County.

In common with other central California aquifers, calcium and bicarbonate tend to be the dominant ions in most local waters, although springs in which magnesium and sulfate predominate are found in parts of the Bear Creek sub-basin. Sodium-chloride waters are found locally, mainly throughout the northern half of the watershed, and particularly in the northwestern portion. Portions of the basin are underlain by the compressed anticlinal structures of the former La Honda oil field, from which high-salinity waters may be migrating into adjacent formations and to the surface, as they do in the same formations in the upper Pescadero Creek watershed of San Mateo County and San Lorenzo Creek watershed of Santa Cruz County (Hecht, 1975).[33]

While most wells and springs provide water of suitable or usable quality, the mineral content in much of the watershed exceeds levels suited for domestic use or for agriculture. Testing required by San Mateo County as part of a well permit will identify most constraining salts or other constituents, and is recommended for all springs or wells drawing upon groundwater. A number of homes depending upon wells use water conditioners or bottled water to varying degrees. Some

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[32] Useful discussions of the water qualities associated with individual formations, and how these affect overall baseflow chemistry in the adjoining Pescadero watershed (Steele, 1972;; Phillips, 1994; Phillips and Rojstaczer, 2001; Woyshner and others, 2003) and the San Lorenzo River catchment (Sylvester and Covay, 1978).

[33] To our knowledge, there has been no assessment of whether the wells from this field, active in the 1920s through 1950s, may be leaking to the surface in the SGCW, as they do in near Boulder Creek, Santa Cruz County. A watershed-wide canvass of springs and seeps might help shed light on this question and provide other useful information.

of the springs sampled throughout the northwestern portion of the watershed have salinities exceeding the reported tolerance for California red legged frogs (c.f., Hecht and others, 2003).

The County has required testing for chloride, nitrate, bacteria and one or more measures of salinity, among other constituents. Such data have not yet been compiled, which could serve as useful tool in watershed-scale planning.

Recharge and Groundwater Movement

Recharge of groundwater occurs throughout the SGCW, even in the driest areas near the coast. Most recharge in the watershed is in the eastern half, where rainfall averages nearly twice the 18 to 20 inches per year observed at the coast. Groundwater generally moves from ridges and slopes to adjoining drainages. In the steeper portions of the SGCW, geology and topography can divert groundwater, such that the groundwatershed does not necessarily correspond to the topographic watershed. As one example, Carol Prentice, a geologist living in La Honda, has noted that much of flow in Woodhams Creek probably originates in the adjoining Langley and possibly Woodruff sub-basins (San Mateo County Department of Planning and Building, 2006, oral testimony).

Ridgelines are particularly important areas for recharge in the SGCW. Springs occur just below the ridgelines in many places in the watershed. Along Gordon Ridge, a number of such springs which flow nearly all year originate from catchments of 20 to 40 acres. The total dissolved solids concentrations of these springs are quite low (typically 300 to 500 mg/L), strongly suggesting percolating rainfall as their origin. These ridgeline springs are critical in maintaining low salinity baseflows in Coyote and Bear Creeks. Similar observations have been made along the ridgeline between the SGCW and the Pomponio watershed.

Wells

The distribution of wells in a watershed provides inferential insight into potential dewatering of streams due to groundwater extraction. In addition, groundwater wells can be utilized to perform a variety of pumping tests that provide data sets which can be interpreted to determine physical properties of a groundwater system, including how a groundwater system and surface water system may respond to different extraction scenarios.

Groundwater pumping tests conducted in the SGCW to assess groundwater conditions and affects on stream flow are not known to exist. Whereas the DEH requires a minimum rate of water be produced from a groundwater well before it is permitted for domestic use, such data provide no insight into potential couples between groundwater and surface water.

The DEH is the single source for information on the location of groundwater wells in the SGCW. Two databases of wells permitted[34] in the SGCW were obtained from the DEH. The years of data are 2004 to 2006; the second set includes most, but not all wells from 2006 through part of 2008. The total number of groundwater wells is 311. The concatenated data sets indicate the distribution of wells in the SGCW occurs in the following general areas.

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[34] Permitting wells include new wells, deepened wells, or wells that have been structurally altered or renovated.

Area	Number of Wells	Terrain
La Honda	169	Skyline
San Gregorio	66	Purisima[35]
Woodside	76	Skyline

It is important to note the following.

1. DEH records are likely incomplete. Typical of county health files statewide, more operational wells may exist in the SGCW than indicated by the DEH record.

2. The areas in which wells are clustered are expansive owing to the rural nature of the SGCW. For example, wells in Woodside area located east and west of Skyline Boulevard and from the north boundary of the SGCW to the south boundary.

Unique Attributes of SGCW Groundwater

The groundwater system in the SGCW differs from groundwater in most other coastal Santa Cruz Mountains watersheds in several respects:

1. The alluvial aquifer is generally shallower and narrower than in most other watersheds, and is not hydrologically connected to extensive marine terrace aquifers as it is in the Pilarcitos, Pescadero, and valleys of the midcoast. As a result, groundwater in the alluvium is usually more closely connected to flow in the adjoining streams. Pumping of wells can more directly deplete low flows in these channels; conversely, recharging the alluvial aquifer can sustain flow in the streams.

2. SGCW is one of the three watersheds in the Santa Cruz Mountains for which water rights have been adjudicated. In such basins, all non-storm flow in streams and springs has already been allocated to specific users. New users have a limited number of possible water supplies, among which is groundwater. Pragmatically, existence of an adjudication means that there is potentially additional incentive for individual landowners to develop groundwater resources.

3. Small amounts of groundwater within many of the deep-seated landslides may be developed to support land uses or to sustain habitat. The numbers and sizes of such slides in the SGCW are large relative to other watersheds nearby.

4. Local bedrock aquifers contain among the highest natural concentrations of total dissolved solids ('salinity') in the region. Some portions of the SGCW are underlain almost exclusively by aquifers containing water too mineralized to sustain agriculture or domestic use.

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[35] Includes wells located in the Alluvial Terrain, which are difficult to distinguish hydrogeologically in SGCW.

Summary and Conclusions

1. Most groundwater is recharged in the wetter eastern and southern portions of the watershed primarily in the Skyline Terrain, with less recharge occurring in the drier, generally less permeable western part of the catchment, which is primarily underlain by Purisima formation.

2. Data from the DEH indicate 79% of the known groundwater wells in the SGCW are located in the Skyline Terrain, and 21% are located in the Purisima Terrain. These data indicate that groundwater extractions are occurring in the broad groundwater recharge zone that is the Skyline Terrain (San Mateo County, Department of Environmental Health, ?? to 2004). Rates, and therefore volumes, of groundwater extractions are not known. These data, however, are likely incomplete and do not fully account for all wells in the SGCW.

3. Most of the SGCW is not in the coastal San Mateo County terrains that will likely yield additional habitat-appropriate developable water with careful planning (Hecht, 2004). Furthermore, baseflow originates from groundwater outflow to channels, which is low relative to nearby watersheds and much lower than most other central coast streams. This low baseflow is due to low groundwater recharge, storage and flow in geologic formations underlying the SGCW. Of importance is that low summer baseflow dictates that habitat management must operate with tighter constraints than most other Santa Cruz Mountain channels. As such, options may be severely constrained for managing the water resource in an aquatic biota-centric manner.

4. The adjudication of the SGCW may influence the preferential use of groundwater, however such use may prove constrained by relatively little available groundwater. Water conservation and high-flow diversions to storage are important measures for making land use and aquatic habitat protection as compatible as possible. In addition practices in groundwater recharge areas that diminish recharge should be discouraged.

5. High groundwater salinities in the SGCW contributed to salinities that are at the high end of the typical range for Santa Cruz Mountain streams. Occurrences of groundwater naturally too saline for agriculture and most habitat uses exist throughout he watershed, in particular beneath the northern ridges in the western part of the watershed. Future reduction in baseflow may increase surface water salinity which may prove to be a potential limitation in some tributaries to use by salmonids and California red-legged frogs.

Recommendations

1. Given that the adjudication can drive water users toward preferential use of groundwater, understanding existing groundwater conditions is particularly important. Efforts to establish baselines for groundwater levels and quality should be encouraged, funded and implemented.

2. Endorse DEH's initiative in recently compiling a database describing permitted wells in and near SGCW, and encourage compilation of data on well construction, re-working, and abandonment, together with results of required water-quality testing on wells.

3. Map springs and seeps throughout the SGCW linking these to reaches with persistent baseflow. Linkage can be established by measuring stream flows and salinity of the spring or seep, and in the stream. In the process, assess whether high-salinity seeps may be originate in part from abandoned oil and gas wells from the La Honda oil field, active primarily about 60 to 80 years ago; if so, seek funding from the state to properly abandon these wells.

4. Identify areas of and preserve existing rates of infiltration into loamy and sandy soils that are important areas of groundwater recharge along the northern, eastern and southern ridges bounding the SGCW.

5. Encourage groundwater recharge of domestic wastewater through appropriately designed on-site wastewater treatment systems. As much as possible, recharge should be into the same catchment from which homes obtain their water supply.

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Appendix B

Beneficial Uses and Water Quality Criteria for the San Gregorio Creek Watershed

The 2007 San Francisco Bay Region Water Quality Control Plan (Basin Plan) (SFBRWQCB 2007b) is the master policy document for the San Francisco Bay Region, including the San Gregorio Creek watershed. This plan identifies beneficial use designations for most water bodies, water quality objectives to protect those beneficial uses, and a strategy to achieve designated water quality objectives. Designated beneficial water uses of San Gregorio Creek watershed (abbreviations in parentheses) are described in Table B-1 and range from agricultural production (AGR), recreation (REC-1, REC-2), and support of the fish (COLD, MIGR, RARE, SPWN, WARM) and wildlife (WILD) resources that inhabit the project study area (SFBRWQCB 2007b).

Table B-1. Designated beneficial uses in the San Gregorio Creek watershed.

Designated beneficial use	Description
Agricultural (AGR) Supply	Uses of water for farming, horticulture, or ranching including, but not limited to, irrigation (including leaching of salts), stock watering, or support of vegetation for range grazing.
Water Contact Recreation (REC-1)	Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water skiing, skin and scuba diving, surfing, white water activities, fishing, or use of natural hot springs.
Non-Contact Water Recreation (REC-2)	Uses of water for recreational activities involving proximity to water, but where there is generally no body contact with water, nor any likelihood of ingestion of water. These uses include, but are not limited to, picnicking, sunbathing, hiking, beach-combing, camping, boating, tide-pool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.
Cold Freshwater Habitat (COLD)	Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
Warm Freshwater Habitat (WARM)	Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
Migration of Aquatic Organisms (MIGR)	Uses of water that supports habitats necessary for migration of other temporary activities by aquatic organisms, such as anadromous fish.
Rare, Threatened, or Endangered Species (RARE)	Uses of water that support habitats necessary at least in part for the survival and successful maintenance of plant or animal species established under state or federal laws as rare, threatened, or endangered.
Spawning (SPWN)	Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.
Wildlife Habitat (WILD)	Uses of water that support terrestrial or wetland ecosystems including, but not limited to, preservation or enhancement of terrestrial habitats or wetlands, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources.

The Regional Water Quality Control Boards (RWQCBs) are required to consider a number of items when establishing water quality standards, including: (1) past, present and probable future beneficial uses; (2) environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto; (3) water quality conditions that could reasonably be achieved through the coordinated control of all factors that affect water quality in the area; and

(4) economic considerations. Water quality objectives (i.e., criteria) to protect designated beneficial uses are shown in Table B-2.

Table B-2. Narrative water quality criteria to support designated beneficial uses.

Water quality objective	Description
Bacteria	See Table A-3.
Biostimulatory Substances	Water shall not contain biostimulatory substances that promote aquatic growth in concentrations that cause nuisance or adversely affect beneficial uses.
Chemical constituents	Waters shall not contain chemical constituents in concentrations that adversely affect beneficial uses. Although certain trace element levels have been applied to particular water bodies, no portion of the Project affected area is cited within the Basin Plan (RWQCB 1995). In addition, waters designated for municipal or domestic use must comply with portions of Title 22 of the California Code of Regulations.
Dissolved oxygen	Monthly median of the average daily dissolved oxygen concentration shall not fall below 85% of saturation in the main water mass, and the 95% concentration shall not fall below 75%of saturation. Minimum level of 7 mg/L. When natural conditions lower dissolved oxygen below this level, the concentrations shall be maintained at or above 95% of saturation.
pH	The pH of surface waters will remain between 6.5 to 8.5, and cause changes of less than 0.5 in receiving water bodies.
Sediment	The suspended sediment load and suspended-sediment discharge rate of surface waters shall not be altered in such a manner as to cause a nuisance or adversely affect beneficial uses.
Settleable material	Waters shall not contain substances in concentrations that result in the deposition of material that causes a nuisance or adversely affects beneficial uses.
Suspended material	Waters shall not contain suspended material in concentrations that cause a nuisance or adversely affect beneficial uses.
Water temperature	The natural receiving water temperature of interstate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Quality Control Board that such alteration in water temperature does not adversely affect beneficial uses. Increases in water temperatures must be less than 2.8°C above natural receiving-water temperature.
Toxicity	All waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life. Compliance with this objective will be determined by analysis indicator organisms, species diversity, population density, growth anomalies, and biotoxicity tests as specified by the Regional Water Quality Control Board.
Turbidity	In terms of changes in turbidity (Nephelometic Turbidity Units [NTU]) in the receiving water body: where natural turbidity is 0 to 5 NTUs, increases shall not exceed 1 NTU; where 5 to 50 NTUs, increases shall not exceed 20%; where 50 to 100 NTUs, increases shall not exceed 10 NTUs; and where natural turbidity is greater than 100 NTUs, increase shall not exceed 10%.

To determine compliance with Basin Plan water quality standards, affected waters must meet both the test for non-exceedance of numerically defined objectives as well as to ensure adequate protection of the designated beneficial uses. Additional numeric water quality criteria are listed in the Basin Plan (SFBRWQCB 2007b), the California Toxics Rule (CTR) (USEPA 2000), drinking water standards under Title 22 of the California Code of Regulations, as well as regional reference levels of biostimulatory substances from the USEPA (2000).

Table B-3. Basin Plan (SFBREQCB 2007b) criteria for bacterial concentrations in fresh water designated for water contact recreation.

Bacteria type	Frequency of recreational use	Criteria	Units	Specified sampling regime	Source
Fecal Coliform	Any	Geometric mean <200	MPN/100 mL	A minimum of five consecutive samples equally spaces over a 30-day period.	SFBRWQCB 2007a
		90th percentile <400			
Total Coliform	Any	Geometric mean <240	MPN/100 mL	A minimum of five consecutive samples equally spaces over a 30-day period.	SFBRWQCB 2007a
		No sample >10,000			
E. coli	Any	Steady state 126	Colonies/ 100 mL	Not specified	USEPA 1986 as cited in SFBRWQCB 2007a
	Designated beach	Maximum 235			
	Moderately used area	Maximum 298			
	Lightly used area	Maximum 406			
	Infrequently used area	Maximum 576			
Enterococci	Any	Steady state 33	Colonies/ 100 mL	Not specified	USEPA 1986 as cited in SFBRWQCB 2007a
	Designated beach	Maximum 61			
	Moderately used area	Maximum 89			
	Lightly used area	Maximum 108			
	Infrequently used area	Maximum 151			

Appendix C

Vegetation Series and Types in the San Gregorio Creek Watershed

Table C-1. Vegetation series and compiled vegetation types in the San Gregorio Creek watershed.

Compiled vegetation type	Vegetation series/association*	Area	
		Ha	Ac
Agriculture	9200 - Agriculture	134	332
Blue blossom	3104 - Blue Blossom-Jimbrush Mapping Unit	4	9
Box elder	2340 - Box Elder Series	4	11
Broom	3210 - (Br) - Broom Series	7	16
California bay - tanoak	1101 - (Mh-L) - Lower Elevation Mixed Broadleaf Hardwoods (California Bay - Tanoak)	371	916
	1102 - (Mh-H) - Higher Elevation Mixed Broadleaf Hardwoods (California Bay - Tanoak)	234	579
	1140 - Tanoak - (California Bay) Multiple Series Mapping Unit	115	284
California buckeye woodland	2220 - California Buckeye Series	165	408
Coast live oak	2110 - Coast Live Oak Series	962	2,376
Coyote brush	3201 - Coastal Bluff Scrub Habitat (sparsely vegetated coastal bluffs: Coyote Brush)	3	7
	3220 - (BaPi) - Coyote Brush Series	145	358
	3221 - Coyote Brush Mesic Stands (Coyote Brush - Ocean Spray - Rubus spp.)	1,176	2,906
	3222 - Coyote Brush Xeric Stands (Coyote Brush - California Sagebrush - Mimulus)	244	603
	3223 - Coyote Brush Open Stands (Coyote Brush / California Annual Grasslands)	532	1,314
	3224 - Coyote Brush Coastal Fringe (Coyote Brush - Lizardtail - Yellow Bush Lupine)	6	14
	3225 - Dwarf Coyote Brush Prairie (BaPi dominates with native bunch grasses)	1	4
Developed	9300 - Built-up / Urban Disturbance	465	1,149
Douglas-fir	1220 - Douglas-fir Series	68	167
	1221 - Douglas-fir - / Mixed Hardwoods Mapping Unit	1,660	4,101
	1223 - Douglas-fir - Coast Redwood Association	651	1,607
Eucalyptus	1150 - Eucalyptus Series	52	128
Grassland	4300 - Tall Temperate Annual Graminoids	6	15
	4310 - California Annual Grasslands Series	3,280	8,106
	4330 - Yellow Star-thistle Series	44	109
	4401 - (Wr) - Weedy Ruderal (Harding Grass - Velvet Grass - Thistle spp.)	353	871
	4410 - Harding Grass Series	16	40
Hazelnut - dogwood	3430 - Mesic Deciduous Shrubs (Hazelnut - Dogwood - Holodiscus - Poison Oak)	21	53
Landslide - outcropping	9410 - Landslides, Cliffs, Rock Outcrops	7	18
Manzanita - blue blossom	3101 - Chaparral - Coastal Scrub Transition (Manzanita spp. - Blue-blossom - Coffeeberry)	103	254
Mixed willow	1310 - Mixed Willow Series Mapping Unit (contains Arroyo Willow, Red Willow)	3	7
	1330 - Arroyo Willow (Arroyo willow identified as dominant component)	178	439
Monterey pine	1201 - Planted Stands of Pine (Monterey Pine - Monterey Cypress - other spp.)	68	168
Poison oak	3410 - Poison Oak Series	69	171
Pond	9820 - Small Ephemeral Ponds	21	53

Compiled vegetation type	Vegetation series/association*	Area	
		Ha	Ac
Red alder	1340 - Red Alder Series (mixed willow)	159	393
Redwood	1210 - Redwood Series	665	1,644
	1211 - Redwood / Tanoak Association	1,289	3,184
Reservoir	9810 - Reservoirs	1	2
Unvegetated	9000 - Land Use / Unvegetated	176	434
Water	9800 - Water	5	12
Wetland	4101 - Undifferentiated Marsh (cattail, bullrush)	4	10
	4110 - Cattail Series	1	1
	4120 - Bullrush Series	0.04	0.10
	4210 - (CaJu) - Sedge - Juncus Meadow Mapping Unit	2	6

*Vegetation series/associations were classified and mapped by Aerial Information Systems (2001, 2006) using the Sawyer and Keeler-Wolf (1995) *A Manual of California Vegetation* classification system.

Appendix D

Special-status Species in the San Gregorio Creek Watershed

Table D-1. Special-status species documented to occur in the vicinity of the San Gregorio watershed.

Common name ***Scientific name***	**Status[1]** **Federal**	 **State**	 **Other**	**Habitat associations**	**Notes**	**Source[2]**
Plants						
San Mateo thorn-mint *Acanthomintha duttonii*	FE	SE	1B.1	Chaparral, Valley and foothill grassland/serpentinite. The blooming period for this species is Apr-Jun. This species occurs at an elevation of 50–300 m. Extant populations only known from very uncommon serpentinite vertisol clays; in relatively open areas.	Known from only two extant natural occurrences and one introduced population; three historical occurrences have been extirpated. Seriously threatened by development, vehicles, and vandalism. USFWS uses the name *Acanthomintha obovata ssp. duttonii.*	CDFG (2008) CNPS (2008) USFWS (2008)
Franciscan onion *Allium peninsulare var. Franciscanum*			1B.2	Cismontane woodland, Valley and foothill grassland/clay, volcanic, often serpentinite. Clay soils; often on serpentine. Dry hillsides. The blooming period for this species is May-Jun. This species occurs at an elevation of 52–300 m.	Threatened by foot traffic and non-native plants.	CDFG (2008) CNPS (2008)
Santa Cruz Mountains manzanita *Arctostaphylos andersonii*			1B.2	Broad-leafed upland forest, Chaparral, North Coast coniferous forest/openings, edges. The blooming period for this species is Nov-Apr. This species occurs at an elevation of 60–730 m.	Confused with other species merged with it as varieties. Threatened by development and road maintenance. Documented along La Honda Creek in 1924, but has not been observed since.	CDFG (2008) CNPS (2008) DCE (2007)
Kings Mountain manzanita *Arctostaphylos regismontana*			1B.2	Broad-leafed upland forest, Chaparral, North Coast coniferous forest/granitic or sandstone outcrops. The blooming period for this species is Jan-Apr. This species occurs at an elevation of 305–730 m.	Threatened by urbanization. Not regenerating well. Documented along La Honda Creek in 1934, 2001, and 2002.	CDFG (2008) CNPS (2008) DCE (2007) Kan (2002)
Coastal marsh milk-vetch *Astragalus pycnostachyus var. Pycnostachyus*			1B.2	Coastal dunes (mesic), Coastal scrub, Marshes and swamps (coastal salt, streamsides). The blooming period for this species is Apr-Oct. This species occurs at an elevation of 0–30 m.	Possibly threatened by cattle trampling, erosion, and competition.	CDFG (2008) CNPS (2008)

Common name ***Scientific name***	**Status[1]**			**Habitat associations**	**Notes**	**Source[2]**
	Federal	**State**	**Other**			
Round-leaved filaree *California macrophylla*			1B.1	Cismontane woodland, Valley and foothill grassland/clay. Clay soils. The blooming period for this species is Mar-May. This species occurs at an elevation of 15–1200 m.	Threatened by urbanization, habitat alteration, vehicles, pipeline construction, feral pigs, and non-native plants. Potentially threatened by grazing.	CDFG (2008) CNPS (2008)
San Francisco Bay spineflower *Chorizanthe cuspidata var. Cuspidata*			1B.2	Coastal bluff scrub, Coastal dunes, Coastal prairie, Coastal scrub/sandy. The blooming period for this species is Apr-Jul (Aug). This species occurs at an elevation of 3–215 m.		CDFG (2008) CNPS (2008)
Crystal Springs fountain thistle *Cirsium fontinale var. Fontinale*	FE	SE	1B.1	Chaparral (openings), Cismontane woodland, Valley and foothill grassland/serpentinite seeps. The blooming period for this species is May-Oct. This species occurs at an elevation of 46–175 m.	Known from only five occurrences in the vicinity of Crystal Springs Reservoir. Seriously threatened by urbanization, dumping, road maintenance, non-native plants, and hydrological alterations.	CDFG (2008) CNPS (2008) USFWS (2008)
Santa Clara red ribbons *Clarkia concinna ssp. Automixa*			4.3	Cismontane woodland, chaparral. This species occurs at an elevation of 90–970 m.	On slopes and near drainages.	CDFG (2008)
San Francisco collinsia *Collinsia multicolor*			1B.2	Closed-cone coniferous forest, Coastal scrub/sometimes serpentinite. On decomposed shale (mudstone) mixed with humus. The blooming period for this species is Mar-May. This species occurs at an elevation of 30–250 m.	Threatened by non-native plants and urbanization.	CDFG (2008) CNPS (2008)
Western leatherwood *Dirca occidentalis*			1B.2	Broad-leafed upland forest, Closed-cone coniferous forest, Chaparral, Cismontane woodland, North Coast coniferous forest, Riparian forest, Riparian woodland/mesic. On brushy slopes, mesic sites; mostly in mixed evergreen and foothill woodland communities. The blooming period for this species is Jan-Mar(Apr). This species occurs at an elevation of 50–395 m.	Possibly threatened by road maintenance. Populations declining; not reproducing well. Has been documented along La Honda Creek and in the redwood forest in La Honda Creek OSP.	CDFG (2008) CNPS (2008) DCE (2007) Kan (2002)

Common name ***Scientific name***	**Status[1]**			**Habitat associations**	**Notes**	**Source[2]**
	Federal	**State**	**Other**			
Ben Lomond buckwheat *Eriogonum nudum var. decurrens*			1B.1	Chaparral, cismontane woodland, lower montane coniferous forest (maritime ponderosa pine sandhills)/sandy. Ponderosa pine sandhills in Santa Cruz County. The blooming period for this species is Jun-Oct. This species occurs at an elevation of 50–800 m.	Threatened by development and sand mining.	CDFG (2008) CNPS (2008)
San Mateo woolly sunflower *Eriophyllum latilobum*	FE	SE	1B.1	Cismontane woodland (often serpentinite, on road cuts). Often on road cuts; found on and off of serpentine. The blooming period for this species is May-Jun. This species occurs at an elevation of 45–150 m.	Threatened by development, erosion, and road maintenance.	CDFG (2008) CNPS (2008) USFWS (2008)
Marin western (=dwarf) flax *Hesperolinon congestum*	FT	ST	1B.1	Chaparral, Valley and foothill grassland/serpentinite. In serpentine barrens and in serpentine grassland and chaparral. The blooming period for this species is Apr-Jul. This species occurs at an elevation of 5–370 m.	Threatened by development, non-native plants, and foot traffic.	CDFG (2008) CNPS (2008) USFWS (2008)
Legenere *Legenere limosa*			1B.1	In beds of vernal pools. The blooming period for this species is Apr-Jun. This species occurs at an elevation of 1–880 m.	Threatened by grazing, road widening, non-native plants, and development.	CNPS (2008) CDFG (2008)
Rose leptosiphon *Leptosiphon rosaceus*			1B.1	Coastal bluff scrub. The blooming period for this species is Apr–Jul. This species occurs at an elevation of 0–100 m.	Possibly threatened by competition and non-native plants.	CNPS (2008) CDFG (2008)
Crystal Springs lessingia *Lessingia arachnoidea*			1B.2	Cismontane woodland, coastal scrub, valley and foothill grassland/serpentinite, often roadsides. Grassy slopes on serpentine; sometimes on roadsides. The blooming period for this species is Jul–Oct. This species occurs at an elevation of 60–200 m.	Threatened by non-native plants and pipeline maintenance.	CNPS (2008) CDFG (2008)

Common name ***Scientific name***	**Status[1]**			**Habitat associations**	**Notes**	**Source[2]**
	Federal	**State**	**Other**			
Arcuate bush-mallow *Malacothamnus arcuatus*			1B.2	Chaparral, cismontane woodland. Gravelly alluvium. The blooming period for this species is Apr-Sep. This species occurs at an elevation of 15–355 m.	Threatened by alteration of fire regimes.	CNPS (2008) CDFG (2008)
Hall's bush-mallow *Malacothamnus hallii*			1B.2	Chaparral, coastal scrub. Some populations on serpentine. The blooming period for this species is May-Sep (Oct). This species occurs at an elevation of 10–760 m.	Threatened by development. Possibly threatened by non-native plants.	CNPS (2008) CDFG (2008)
Marsh microseris *Microseris paludosa*			1B.2	Closed-cone coniferous forest, cismontane woodland, coastal scrub, valley and foothill grassland. This species occurs at an elevation of 5–300 m.		CDFG (2008)
Robust monardella *Monardella villosa ssp. Globosa*			1B.2	Broad-leafed upland forest, chaparral, cismontane woodland, valley and foothill grassland. Openings. This species occurs at an elevation of 30–300 m.		CDFG (2008)
Dudley's lousewort *Pedicularis dudleyi*		Rare	1B.2	Chaparral, north coast coniferous forest, valley and foothill grassland. Deep shady woods of older coast redwood forests; also in maritime chaparral. This species occurs at an elevation of 100–490 m.		CDFG (2008)
White-rayed pentachaeta *Pentachaeta bellidiflora*	FE	SE	1B.1	Valley and foothill grassland. Open dry rocky slopes and grassy areas, often on soils derived from serpentine bedrock. This species occurs at an elevation of 35–620 m.		CDFG (2008) USFWS (2008)
White-flowered rein orchid *Piperia candida*			1B.2	North coast coniferous forest, lower montane coniferous forest, broad-leafed upland forest. Coast ranges from Santa Cruz County north; on serpentine. Forest duff, mossy banks, rock outcrops and muskeg. This species occurs at an elevation of 0–1,200 m.		CDFG (2008)

Common name ***Scientific name***	**Status[1]**			**Habitat associations**	**Notes**	**Source[2]**
	Federal	**State**	**Other**			
Choris' popcorn-flower *Plagiobothrys chorisianus* var. *chorisianus*			1B.2	Chaparral, coastal scrub, coastal prairie. Mesic sites. This species occurs at an elevation of 15–100 m.		CDFG (2008)
San Francisco campion *Silene verecunda ssp. Verecunda*			1B.2	Coastal scrub, valley and foothill grassland, coastal bluff scrub, chaparral, coastal prairie. Often on mudstone or shale; one site on serpentine. This species occurs at an elevation of 30–645 m.		CDFG (2008)
Invertebrates						
San Bruno elfin butterfly *Incisalia (=Callophrys) mossii bayensis*	FE			Coastal, mountainous areas with grassy ground cover, mainly in the vicinity of San Bruno Mountain, San Mateo County. Colonies are located on steep, north-facing slopes within the fog belt. Larval host plant is *Sedum spathulifolium.*		USFWS (2008)
Bay checkerspot butterfly *Euphydryas editha bayensis*	FT			Restricted to native grasslands on outcrops of serpentine soil in the vicinity of San Francisco bay. *Plantago erecta* is the primary host plant; *Orthocarpus densiflorus* and *O. purpurscens* are the secondary host plants.		CDFG (2008) USFWS (2008)

Common name ***Scientific name***	**Status[1]**			**Habitat associations**	**Notes**	**Source[2]**
	Federal	**State**	**Other**			
				Amphibians		
California tiger salamander *Ambystoma californiense*	FT		SSC	Need underground refuges, especially ground squirrel burrows and vernal pools or other seasonal water sources for breeding	Central valley DPS listed as threatened. Santa Barbara and Sonoma counties DPS listed as endangered. Only known occurrence in the Santa Cruz mountains is at Stanford University.	CDFG (2008) USFWS (2008) CDFG (2003), as cited in DCE (2007)
California red-legged frog *Rana draytonii*	FT		SSC	Lowlands and foothills in or near permanent sources of deep water with dense, shrubby or emergent riparian vegetation. Requires 11–20 weeks of permanent water for larval development. Must have access to estivation habitat.	Critical habitat has been proposed for this species within the San Gregorio watershed. Known to occur at fifteen locations in the La Honda Creek OSP, and elsewhere in the watershed.	CDFG (2008) USFWS (2008) Seymour & Westphal (2000) Seymour et al. (2006), as cited in DCE (2007) Seymour et al. (2007)
Foothill yellow-legged frog *Rana boylii*			SSC	Shallow tributaries and mainstems of perennial streams and rivers, and adjacent upland habitats		CDFG (2008) USFWS (2008)

Common name ***Scientific name***	**Status[1]** **Federal**	 **State**	 **Other**	**Habitat associations**	**Notes**	**Source[2]**
Reptiles						
Western pond turtle *Actinemys marmorata*			SSC	Inhabits permanent or nearly permanent bodies of water (ponds, marshes, rivers, streams and irrigation ditches) with aquatic vegetation in many habitat types. Requires basking sites such as partially submerged logs, vegetation mats, or open mud banks. Needs suitable upland nesting sites.		CDFG (2008) Seymour et al. (2007)
San Francisco garter snake *Thamnophis sirtalis tetrataenia*	FE	SE		Vicinity of freshwater marshes, ponds and slow moving streams in San Mateo County and extreme northern Santa Cruz County. Prefers dense cover and water depths of at least one foot. Upland areas near water are also very important.	While rare, there have been a number of documented occurrences in the watershed.	CDFG (2003), as cited in DCE (2007) CDFG (2008) USFWS (2008)
Fish						
Tidewater goby *Eucyclogobius newberryi*	FE		SSC	Brackish water habitats along the California coast from Agua Hedionda Lagoon, San Diego County to the mouth of the Smith River. Found in shallow lagoons and lower stream reaches, they need fairly still but not stagnant water and high oxygen levels.	Critical habitat has been identified for this species within the San Gregorio watershed. Occurs in the seasonal lagoon at the mouth of San Gregorio Creek.	CDFG (2008) USFWS (2008) CDFG, pers. comm. (2008)
Coho salmon (central California coast ESU) *Oncorhynchus kisutch*	FE	SE		Federal listing includes populations between Punta Gorda and San Lorenzo River. State listing includes populations south of Punta Gorda. Require beds of loose, silt-free, coarse gravel for spawning. Also need cover, cool water and sufficient dissolved oxygen.	Critical habitat has been identified for this species within the watershed; although rare, it has recently been observed in the watershed.	USFWS (2008) CDFG, pers. comm. (2008)
Steelhead (Central California Coast ESU) *Oncorhynchus mykiss irideus*	FT			Streams; spawns in gravel riffles from Russian River, south to Soquel Creek and to, but not including, Pajaro River. Also San Francisco and San Pablo bay basins.	Documented to occur in the watershed; critical habitat has been designated within the watershed.	CDFG (2008) USFWS (2008) CDFG, pers. comm. (2008)

Common name *Scientific name*	Status[1] Federal	Status[1] State	Status[1] Other	Habitat associations	Notes	Source[2]
Birds						
Short-eared owl *Asio flammeus*			SSC	Found in swamp lands, both fresh and salt; lowland meadows; irrigated alfalfa fields. Tule patches/tall grass needed for nesting/daytime seclusion. Nests on dry ground in depression concealed in vegetation.		CDFG (2008)
Long-eared owl *Asio otus*			SSC	Riparian bottomlands grown to tall willows and cottonwoods; also, belts of live oak paralleling stream courses. Require adjacent open land productive of mice and the presence of old nests of crows, hawks, or magpies for breeding.		CDFG (2008)
Burrowing owl *Athene cunicularia*			SSC	Open, dry annual or perennial grasslands, deserts and scrublands characterized by low-growing vegetation. Subterranean nester, dependent upon burrowing mammals, most notably, the California ground squirrel.		CDFG (2008)
Marbled murrelet *Brachyramphus marmoratus*	FT	SE	CDF	Feeds near-shore; nests inland along coast from eureka to Oregon border and from Half Moon Bay to Santa Cruz. Nests in old-growth redwood-dominated forests, up to six miles inland, often in Douglas fir.	Critical habitat has been identified for this species within the San Gregorio watershed.	USFWS (2008)
Western snowy plover *Charadrius alexandrinus nivosus*	FT		SSC	Sandy beaches, salt pond levees and shores of large alkali lakes. Needs sandy, gravelly or friable soils for nesting.		CDFG (2008) USFWS (2008)
Northern harrier *Circus cyaneus*			SSC	Coastal salt and fresh-water marsh. Forages over grasslands. Nests on ground in shrubby vegetation, usually at marsh edge.		CDFG (2008)
Black swift *Cypseloides niger*			SSC	Breeds on cliffs behind or adjacent to waterfalls in deep canyons and sea-bluffs above the surf. Forages widely over various habitats.		CDFG (2008)

Common name ***Scientific name***	**Status[1]**			**Habitat associations**	**Notes**	**Source[2]**
	Federal	**State**	**Other**			
White-tailed kite *Elanus leucurus*			FP	Rolling foothills and valley margins with scattered oaks and river bottomlands or marshes next to deciduous woodland. Open grasslands, meadows, or marshes for foraging close to isolated, dense-topped trees for nesting and perching.		CDFG (2008)
American peregrine falcon *Falco peregrinus anatum*	D	SE	FP CDF	Near wetlands, lakes, rivers, or other water; on cliffs, banks, dunes, mounds; also, human-made structures. Nest consists of a scrape on a depression or ledge in an open site.		CDFG (2008)
Saltmarsh common yellowthroat *Geothlypis trichas sinuosa*			SSC	Resident of the San Francisco bay region, in fresh and salt water marshes. Requires thick, continuous cover down to water surface for foraging; tall grasses, tule patches, willows for nesting.		CDFG (2008)
Osprey *Pandion haliaetus*			CDF	Ocean shore, bays, fresh-water lakes, and larger streams. Large nests built in tree-tops within 15 miles of a good fish-producing body of water.		CDFG (2008)
California brown pelican *Pelecanus occidnetalis californicus*	FE	SE	FP	Breeds on the Channel Islands and disperses along the entire California coast where it inhabits estuarine, marine, subtidal and marine pelagic waters.		USFWS (2008)
Mammals						
Pallid bat *Antrozous pallidus*			SSC	Deserts, grasslands, shrublands, woodlands and forests. Most common in open, dry habitats with rocky areas for roosting. Roosts must protect bats from high temperatures. Very sensitive to disturbance of roosting sites.	Documented in the La Honda Creek OSP. This locale appears to be the last remaining maternity roost in the region.	CDFG (2008) Heady and Frick (2000), as cited in DCE (2007)
Townsend's big-eared bat *Corynorhinus townsendii*			SSC	Throughout California in a wide variety of habitats. Most common in mesic sites. Roosts in the open, hanging from walls and ceilings. Roosting sites limiting. Extremely sensitive to human disturbance.	Documented in the La Honda Creek OSP.	CDFG (2008) Heady and Frick (2000), as cited in DCE (2007)

Common name ***Scientific name***	**Status[1]**			**Habitat associations**	**Notes**	**Source[2]**
	Federal	**State**	**Other**			
San Francisco dusky-footed woodrat *Neotoma fuscipes annectens*			SSC	Forest habitats of moderate canopy and moderate to dense understory. May prefer chaparral and redwood habitats. Constructs nests of shredded grass, leaves and other material. May be limited by availability of nest-building materials.		CDFG (2008)

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[1] Status codes:

Federal
FE = Endangered under the federal ESA
FT = Threatened under the federal ESA
D = Delisted under the federal ESA

State
SE = Endangered under the California ESA
ST = Threatened under the California ESA

Other
CDF = Considered a sensitive species by the California Department of Forestry and Fire Protection
FP = Fully protected by CDFG
SSC = Considered a species of special concern by CDFG

<u>CNPS</u>
1B.1 = Considered rare, threatened, or endangered in California, and elsewhere by CNPS; Seriously threatened
1B.2 = Considered rare, threatened, or endangered in California by CNPS, and elsewhere; Fairly threatened
4.3 = Considered of limited distribution, a watch list by CNPS; Not very threatened

[2] Sources:

- CDFG (2003) = California Natural Diversity Database (CNDDB) (searched in 2003)
- CDFG (2008) = California Natural Diversity Database (CNDDB) (version 3.1.0, searched on May 21, 2008)
- CNPS (2008) = California Native Plant Society online inventory of rare plants.
- USFWS (2008) = Lists of special-status species generated by the USFWS on 4 June 2008.
- DCE (Design, Community, and Environment). 2007. La Honda Creek Open Space Preserve Master Plan, existing conditions report. Prepared for the Midpeninsula Regional Open Space District, Los Altos, California.
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Appendix E

Focal Species Selection Process for the San Gregorio Creek Watershed Limiting Factors Analysis

1 FOCAL SPECIES SELECTION PROCESS

Stillwater Sciences has developed a set of criteria and a vetting process for selecting focal species, as illustrated in Figure E-1**.** The application of these criteria to a pool of candidate species facilitates a comparison of the species, which clarifies and simplifies the process of selecting a suite of focal species. One of the functions of the focal species approach is to facilitate the synthesis, analysis, and organization of information by engaging a manageable number of species; however, this process can be undermined by the selection of too many focal species.

1.1 Step 1: The Species Currently Exists, or Existed Historically, Within the Target System

The first step of the vetting process involves determining if a candidate focal species currently exists, or existed historically, within the watershed. Species that currently occur in the system demonstrate an adaptation to current habitat conditions, so that the conservation and enhancement of existing habitat would likely not pose a threat to an existing population. This step also allows for the re-introduction of an extirpated species, which can be a goal of a restoration program.

Because many ecosystems currently support non-native species, the first step of the vetting process does not eliminate non-native species from consideration as a focal species. Non-native species can serve as valuable focal species, especially if they are strong interactors in the system, by clarifying or increasing our knowledge of the environmental changes that have conferred a competitive advantage to them. Such knowledge can assist the design of management actions that reduce that competitive advantage. Though it is often infeasible to eradicate a non-native species once it has become widely established, management actions may help to control the abundance or distribution of targeted non-native species so that their ecological effects are reduced.

1.2 Step 2: Is the Species Listed as Endangered or Threatened?

The second step of the vetting process acknowledges that the recovery of listed species constitutes a high social priority, both economically and ecologically. It also recognizes that listed species are often at the center of resource management conflicts, so that recovery of the species can be an important management goal as a means of reducing conflict with, and restrictions on, human activities.

1.3 Step 3: Additional Criteria for Non-listed Species

The third step of the selection process provides much of the information used to compare candidate focal species by applying a series of criteria to non-listed species. It is often important to include non-listed species in the group of focal species in order to capture potential ecosystem changes that are reducing their populations, which could necessitate future protection that would exacerbate resource conflicts.

- **Other special-status designation**. The first criterion queries whether an unlisted species has some other special-status designation (e.g., species of concern). For example, tidewater goby (*Eucyclogobius newberryi*) is a federal endangered species and California species of special concern.

- **High economic or public interest value**. The second criterion recognizes the economic or social importance of certain species, such as species that are sportfish and the focus of recreational angling (e.g., steelhead).
- **Narrow habitat requirements**. The third criterion tests whether a species has narrow habitat requirements such that loss of that habitat type would pose a significant threat to the health of the population. For example, California red-legged frogs breed in ephemeral or permanent ponds, and slow-moving, pond-like parts of streams, marshes, and lagoons (Lannoo 2005). These habitats are threatened by urban encroachment, construction of reservoirs and water diversions, introduction of exotic predators and competitors, and livestock grazing.
- **Weak disperser**. The fourth criterion identifies species that have difficulty dispersing to new areas, which prevents a species from establishing new sub-populations that can help mitigate the loss of an existing breeding/spawning population from a catastrophic event. For example, tidewater goby are found in lagoons, estuaries, and stream mouths separated by intolerable marine environments, and are absent from steep coastline areas and streams without lagoons or estuaries (USFWS 2005). The fish’s current distribution is entirely within its observed historical range, but 17% (23/134) of once populated sites are now extirpated and 40-50% (55-70/134) maintain such small populations that long-term persistence is uncertain (USFWS 2005). As a consequence, a natural or anthropogenic event that eliminates habitat in one of these original localities could reduce the species’ range.
- **Strong Interactor**. The fifth criterion indicates that particular species can significantly influence natural communities through ecological interactions with other species. For example, a species may serve as an important prey species for a number of other species, such that a decline in its population can reduce the food base for other species and depress the abundance of an entire community, such as the California red-legged serving as a main prey item of the San Francisco garter snake (*Thamnophis sirtalis tetrataenia*).
- **Loss of habitat**. The sixth criterion addresses a key factor contributing to reductions in abundance or distribution of a species: habitat loss and degradation from system-wide anthropogenic changes. For example, all salmonids along the California coast have experienced losses of spawning and rearing habitat as a function of land use and water diversion. This criterion highlights that changes in current resource management (e.g., flow, LWD, available floodplain) have the potential to improve ecosystem conditions that support species, despite habitat loss and degradation.
- **Local and/or regional population declines**. The final criterion applied in step three of the vetting process acknowledges that population abundance and distribution are two key metrics for assessing a species’ health. Local and regional population declines are an indicator of system-wide change, and give further motivation to identify factors affecting local and regional populations. Continued population declines may require future federal or state protection, which often intensifies conflicts over natural resources.

1.4 Step 4: Availability of Information

If a species satisfies one Step 3 criterion, then it passes to Step 4, which assesses available information about that species. At a minimum, the general habitat requirements and life history stages of a species must be known for it to qualify as a focal species. Ideally, quantitative data on a species' habitat preferences will exist, and although it is preferable for these data to be specific to the San Gregorio Creek basin, knowledge from a similar system is also valuable. For example, there is little information about the abundance and distribution of the western pond turtle in the San Gregorio Creek basin, but data from other river systems (e.g., Waddell Creek) about general habitat preferences is useful and applicable to San Gregorio Creek.

1.5 Step 5: Ranking of Species

The information produced for each candidate species in Steps 2, 3 and 4 provides the foundation to rank species in Step 5 of the vetting process. Rankings can be either nominal (e.g., high, medium, low priority) or ordinal (e.g., first, second, third, etc.). To select focal species, we used nominal rankings. Species receiving high rankings needed to have adequate information available (Step 4) and had to be officially listed (Step 2) or meet two or more criteria listed under Step 3.

1.6 Step 6: Select Focal Species

The rankings from Step 5 are used to inform the final selection process in Step 6. Selection of focal species also emphasizes using species that represent different assemblages or guilds and species utilizing a broad range of habitat types within the study reach, so that the synthesis and analysis of information are relevant to a broad range of local species.

Selecting too many focal species can undermine the purpose of a focal species approach, which is to focus and organize the discussion and analysis in a manner that is still relevant to a broad array of species. We estimate that a total of three or four species could allow us to engage and organize much of the information available for San Gregorio Creek and cover a broad range of habitat types that occur within the basin. If two or more candidate species used similar habitat types, the one with the highest ranking in Step 5 was selected.

2 CANDIDATE AND SELECTED FOCAL SPECIES

For the San Gregorio Creek Watershed Management Plan, we adapted the vetting process by selecting a pool of ten candidate focal species. We also identified species that are at the center of resource management conflicts or the object of significant study in the basin. The pool of candidate species included:

- Coho salmon (*Oncorhynchus kisutch*)
- Steelhead (*Oncorhynchus mykiss*)
- Pacific lamprey (*Lampetra tridentata*)
- Tidewater goby (*Eucyclogobius newberryi*)
- California red-legged frog (*Rana draytonii*)
- Santa Cruz black salamander (*Aneides flavipunctatus niger*)
- Western pond turtle (*Actinemys marmorata*)
- San Francisco garter snake (*Thamnophis sirtalis tetrataenia*)
- Marbled murrelet (*Brachyramphus marmoratus marmoratus*)

The following sections describe the vetting process used for each candidate species to explain its inclusion or exclusion from the final group of focal species. Table E-1 summarizes the results of the vetting process and the final selected focal species.

2.1 Coho Salmon (*Oncorhynchus kisutch*)

Coho salmon historically existed in the San Gregorio basin, but populations were severely reduced in the late 1970s to early 1980s after a severe drought in 1976-1977 (Step 1) (CDFG 1995). Coho salmon found in the San Gregorio Creek basin watershed belong to the Central California Coast evolutionarily significant unit (ESU) (NMFS 1997), which is listed as endangered under the federal Endangered Species Act (ESA) (Step 2) (NMFS 1996, 2005). Coho salmon generate high public interest because it appeals to the broader public as a charismatic megafauna associated with wild places and California history (Step 3). Eggs and alevins require high oxygen levels and gravel permeability to result in normal development. Fry tend to aggregate in backwaters, side channels, stream margins, and other low velocity locations, especially areas with low light intensity and overhead cover (Step 3) (Nickelson et al. 1992). As they grow, juvenile coho salmon move to deeper habitats, although they continue to prefer low-velocity habitat throughout the rearing period. Numerous studies have shown that deep pools with substantial cover in the form of LWD are the most important habitat elements used by juvenile coho salmon in the winter (Hartman 1965, Bustard and Narver 1975a, 1975b, Tschaplinski and Hartman 1983, Murphy et al. 1984, Bisson et al. 1985, 1988, Everest et al. 1986). In general, coho salmon have undergone substantial population declines and no longer occupy many of the streams in California where they used to occur (Step 3) (Hassler et al. 1991, Brown et al. 1994). In the Central California Coast ESU, historical populations are estimated to have numbered between 50,000 and 125,000 naturally spawning fish, but current abundance is estimated to be less than 5,000 fish, most of which are considered of hatchery origin (Step 3) (Brown and Moyle 1991, Bryant 1994, CDFG 1994). Although little is known about the current coho salmon population in the basin, sufficient regional information is available (Step 4) (CDFG 1995, 2002, 2004), leading to a high priority ranking (Step 5) and their selection as a focal species (Step 6).

2.2 Steelhead (*Oncorhynchus mykiss*)

Steelhead are currently found within the San Gregorio Creek basin (Step 1), belonging to the Central California Coast Distinct Population Segment (DPS) (NMFS 2006, Smith 1990). This DPS is threatened under the federal ESA (Step 2) (NMFS 2006). Steelhead, like coho salmon, generate high public interest because of their appeal to the broader public as a charismatic megafauna, associated with wild places and California history, and it is prized by recreational anglers (Step 3). The current distribution of anadromous steelhead in the San Gregorio basin is influenced by water diversion affecting sandbar and seasonal lagoon formation and increased fine sediment loads from surrounding land use practices that potentially degrade spawning and rearing habitat (Step 3) (Smith 1990, SWRCB 2003). In general, steelhead stocks throughout California have declined substantially. The most current estimate of the population of steelhead in California is approximately 250,000 adults, which is roughly half the adult population that existed in the mid-1960s (Step 3) (McEwan and Jackson 1996). Though steelhead stocks throughout the Pacific Northwest have been the object of much study, we know relatively little about the specific habitat preferences of the steelhead population that spawns in the San Gregorio Creek basin. Nevertheless, we can use information derived from other sub-populations to understand the general habitat requirements of steelhead in the San Gregorio Creek basin (Step 4).

Table E-1. Focal species vetting process results for the San Gregorio Creek Watershed Management Plan.

Step		Coho salmon (Central CA ESU)	Steelhead	Tidewater goby	California red-legged frog	San Francisco garter snake	Marbled murrelet	Southwestern pond turtle	Pacific lamprey	Santa Cruz black salamander
1	**The species currently exists in the watershed.**	N	Y	Y	Y	Y	N	N	N	N
	The species historically existed in the watershed.	Y	Y	Y	Y	Y	Y	Y	Y	–
2	**The species listed as endangered or threatened.**	Y	Y	Y	Y	Y	Y	N	N	N
3 (for non-listed species)	**Other special-status designation?**	N	N	Y	Y	Y	Y	Y	N	N
	High economic or public interest value?	Y	Y	N	Y	Y	Y	N	N	N
	Narrow habitat requirements?	Y	Y	Y	Y	–	Y	N	Y	N
	Weak disperser?	–	–	Y	–	–	–	Y	–	–
	Strong interactor?	–	–	Y	–	Y	N	N	–	–
	Documented loss of habitat?	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Documented local and/or regional population declines?	Y	Y	Y	Y	Y	Y	Y	–	N
4	**Sufficient information available**	Y	Y	Y	Y	N	Y	Y	Y	N
5	**Priority ranking**	H	H	H	H	M	M	M	L	L
6	**Selected focal species**	Y	Y	Y	Y	N	N	N	N	N

Steelhead received a high priority ranking because they are a listed species, they satisfied multiple criteria in the third step of the vetting process, and we know enough about their general life history stages and habitat requirements to understand how changes in the system may affect them. Steelhead were selected as a focal species (Step 6).

2.3 Pacific Lamprey (*Lampetra tridentata*)

Historically, the range of Pacific lamprey extended along the entire California Coast (Moyle 2002), but there has been no recent documentation of their presence in the San Gregorio Creek basin (Step 1). They are not listed as federal or state endangered (Step 2), nor do they have any other special designation (Step 3). The United States Fish and Wildlife Service (USFWS) rejected a petition to list them under the ESA in December 2004 due to lack of information regarding current populations (USFWS 2004). Their habitat is degraded through the same impacts as salmonid habitat: water diversions affect stream flow and increase water temperatures, barriers, such as dams, limit migration and distribution (Step 3) (USDE 1995). Fish ladders designed for salmonids are still impassable to Pacific lamprey and limit their distribution even further (USDE 1995, USFWS 2005). They were once distributed along the California coast, but current populations are severely reduced, with some extirpated populations in southern California (Step 3) (USFWS 2004). Population trends are not well-documented, and there is little local or regional information regarding the life history and habitat requirements of Pacific lamprey to provide information for assessing current habitat (Step 4) (Moyle 2002, CDWR 2004, USDE 1995, USFWS 2004). The Pacific lamprey received a low ranking (Step 5) because there was not adequate information and it is not a listed species. Therefore, it was not selected as a focal species (Step 6).

2.4 Tidewater Goby (*Eucyclogobius newberryi*)

Tidewater goby has been observed historically and are currently found in the San Gregorio Creek Estuary (Step 1) (Smith 1990, CDFG 2009). The goby is a federal endangered species (Step 2), and a state species of special concern (Step 3). The fish are an estuarine species that disperse infrequently through marine habitat, but have no dependency on marine habitat for its life cycle (Step 3) (Swift et al. 1989, Lafferty et al. 1999). Floods and estuary breaching events can disperse tidewater gobies to nearby suitable habitat, but survival is likely low and dispersal is limited. They are an important part of estuarine food webs, as they provide prey for larger fish and piscivorous birds (Step 3) (Swenson and McCray 1996). Current distribution is within the original observed range of the species, but 20% of these populations are extirpated and 50% are likely too small or too degraded to persist long-term (Step 3) (USFWS 2005). Their main threats are changes in water quality, degradation and loss of habitat due to urbanization, and predation from invasive species such as the African clawed frog (*Xenopus laevis*). It is estimated that tidewater goby has disappeared from 74 % of the coastal lagoons south of Morro Bay (Step 3). In 1999 populations of tidewater goby north of Orange County were proposed to be removed from the federal endangered species list, and the United States Fish and Wildlife Service (USFWS) completed a recovery plan for the fish in 2005 (USFWS 2005), providing a good source for understanding habitat needs of the species (Step 4). The tidewater goby received a high ranking (Step 5) because there is extensive information about life history requirements, it is a listed species, and met multiple criteria under Step 3. It was, therefore, selected as a focal species (Step 6).

2.5 California Red-legged Frog (*Rana draytonii*)

The California red-legged frog is currently found within the San Gregorio Creek basin (Step 1) (CDFG 2009, USFWS 2002). It is a threatened species under the federal ESA (Step 2) (USFWS 1996) and a California species of special concern (Step 3). The frogs are associated with dense riparian vegetation closely associated with deep (>2 ft [0.6 m]) still or slow moving water, and may aestivate within 300 ft (91 m) of a riparian area. They breed primarily in ponds with water depths >1.6 ft (0.5 m) with some emergent vegetation, usually cattails, rushes, or willows (Step 3) (Lannoo 2005). The ponds can be ephemeral or permanent bodies of water, though individuals also breed in slow-moving, pond-like parts of streams, marshes, and lagoons (Lannoo 2005). Little is known about the frog's terrestrial activities or associations with terrestrial vegetation or land cover (Bulger et al. 2003). Along the coast of California, the frogs occur south of Elk Creek in Mendocino County to Southern California and are threatened within this remaining range by a wide variety of human impacts, including urban encroachment, construction of reservoirs and water diversions, introduction of exotic predators and competitors, livestock grazing, and habitat fragmentation (Step 3) (USFWS 2002). The species has been extirpated from 70% of its natural range and is now largely restricted to coastal drainages from Marin County to Baja California (Step 3) (USFWS 2002). The red-legged frog met criteria under Steps 1 and 2, and multiple criteria under Step 3, and there is a wealth of regional information to provide an understanding of habitat needs (Step 4), leaving the frog with a high priority ranking (Step 5). California red-legged frog was, therefore, selected as a focal species (Step 6).

2.6 Santa Cruz Black Salamander (*Aneides flavipunctatus niger*)

The Santa Cruz black salamander is not currently found within the San Gregorio Creek basin, although historically it may have occurred within the basin (Step 1) (CDFG 2009). It is not listed under the federal ESA, nor does it appear in the list of California Species of Special Concern (Step 2). The only federal or state listed salamander occurring in the Santa Cruz region is the Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*), which is fully protected by the state of California and is listed as Endangered under the federal ESA(USFWS 1967). Although black salamander populations are disjunct, and the southernmost populations (Santa Cruz Mountains) have been shown to exhibit a high level of genetic differentiation compared with the northern Shasta populations, the black salamander is not recognized as a subspecies by CDFG, USFWS, Lannoo (2005) or Petranka (1998). Black salamanders occur in a wide variety of habitats, including seeps in talus slopes, wet soil beneath logs and rocks in fields and old pastures, and beneath debris in recently burned areas (Petranka 1998). These salamanders are likely poor dispersers, although movements of plethodontids (*Aneides spp.*) have been poorly documented (Petranka 1998) (Step 3, Step 4). Recent black salamander population declines may be largely attributed to the proliferation of vineyards in northern California (Lannoo 2005) (Step 3). Santa Cruz black salamanders are not currently documented within the San Gregorio Creek basin, little regional information about the species is available (Step 4), they are not federally or state listed, nor do they have another special designation, and they met only one criterion under Step 3, leaving the species with a low priority ranking (Step 5). The Santa Cruz black salamander was not selected as a focal species (Step 6).

2.7 Western Pond Turtle (*Actinemys marmorata*)

Western pond turtle is found within the San Gregorio Creek basin (Step 1) (Seymour et al. 2006, as cited in DCE 2007), although its current distribution in the basin has likely been reduced from its historical distribution. Though the western pond turtle is not currently listed as an endangered or threatened species (Step 2), it has been designated as a federal and state species of concern (Step 3). Western pond turtle populations have experienced extensive population declines as conversion of wetland and riparian habitats to urban and agricultural use has accelerated (Step 3) (Jennings and Hayes 1994, Germano and Bury 2001). The general abundance and distribution of western pond turtle has also been shrinking throughout their range (Step 3), which has contributed to its designation as a species of special concern (USFWS 1992, Germano and Bury 2001).

There is information about their distribution within the San Gregorio Creek basin, and research conducted elsewhere provides a general understanding of their life history stages and habitat requirements (Step 4). The western pond turtle received a moderate ranking (Step 5), because it has special designation and met multiple criteria under Step 3. However, because of a limit on the number of species that could be included in the analysis, western pond turtle was not selected as a focal species (Step 6).

2.8 San Francisco Garter Snake (*Thamnophis sirtalis tetrataenia*)

The San Francisco garter snake currently exists within the San Gregorio Creek basin (CDFG 2009). The species is a federal and state listed endangered species (Step 2) and is a protected state species (Step 3). The snake has high public interest value in the San Francisco Bay Area as recent Bay Area Rapid Transit and San Francisco International Airport expansion projects were required to modify plans in order to protect and create habitat for the snake (Step 3). This sub-species of common garter snake prefers grasslands or wetlands near ponds, marshes, and sloughs, but can use a wide variety of habitats (Stebbins 2003). The species is a strong interactor as their preferred habitat is also the preferred habitat of their main prey, the California red-legged frog (Step 3) (USFWS 2002). Also, adult snakes estivate in rodent burrows during summer months when habitats dry. Populations of San Francisco garter snakes have declined due to urban development and agricultural land use, and due to declines in its preferred prey (California red-legged frog) and increase in non-native bullfrogs (*Rana catesbeiana*) that consume California red-legged frogs and San Francisco garter snakes (Step 3) (Stebbins 2003).

There is little information about populations within the San Gregorio Creek basin, and few recent studies or recovery plans (Step 4). The snake received a medium priority ranking due to the lack of information (Step 5); its habitat needs could also be satisfied with the selection of coho salmon and/or the California red-legged frog. Therefore, it was not selected as a focal species (Step 6).

2.9 Marbled Murrelet (*Brachyramphus marmoratus marmoratus*)

The marbled murrelet was historically found in the San Gregorio Creek basin (Step 1) and the basin supports critical habitat (Paton and Ralph 1990, USFWS 1997, Ralph and Miller 1995, USFWS 2006, CDFG 2009). The bird is a federally threatened and a state endangered species (Step 2), and is a California sensitive species (Step 3). Marbled murrelets nest inland in stands of old-growth conifers typically within 6.5 mi (10 km) of the coast and abundant near-shore food sources (Step 3) (Miller and Ralph 1995). The most commonly occupied stands are dominated by old-growth redwoods (>50%) characterized by dense, multi-layered, canopy cover and large trees (Miller et al. 1995 as cited in Cooperrider et al. 2000, USFWS 1995, Nelson 1997). These nesting preferences give the marbled murrelet a high economic and public interest value (Step 3). The birds have narrow habitat requirements (Step 3), foraging in coastal marine waters near kelp beds or stream outlets at surface and mid-water depths (approximately 160–330 ft [50–100 m]) within 2 mi (3.2 km) off the shore, and nesting in mossy depressions on limbs at heights of 100 ft

(30 m) that are concealed by high overhead and horizontal canopy cover (Hamer and Nelson 1995). Marbled murrelets exhibit extreme site fidelity and are known to return to the same stand and even the same tree from year to year (Step 3) (Miller et al. 1995). The loss of old-growth forest habitat is believed to be the primary reason for the marbled murrelet's decline (Step 3) , but they are also vulnerable to oil spill impacts and nest predation from Corvids (ravens, crows and jays). Up to 60,000 marbled murrelets historically may have been found along the California coast, while a 1995 estimate placed the population at 6,000 (Step 3) (Ralph and Miller 1995).

Although there is little information regarding local populations and critical habitat, there is recent information on population distribution and habitat preferences on a regional scale (Step 4) (McShane et al. 2004). The marbled murrelet occupies upland habitat that is unique among candidate species, and it received a medium priority ranking (Step 5). However, because it does not provide a strong linkage with the aquatic environment (which was the focus of this Watershed Management Plan), marbled murrelet was not selected as a focal species (Step 6).

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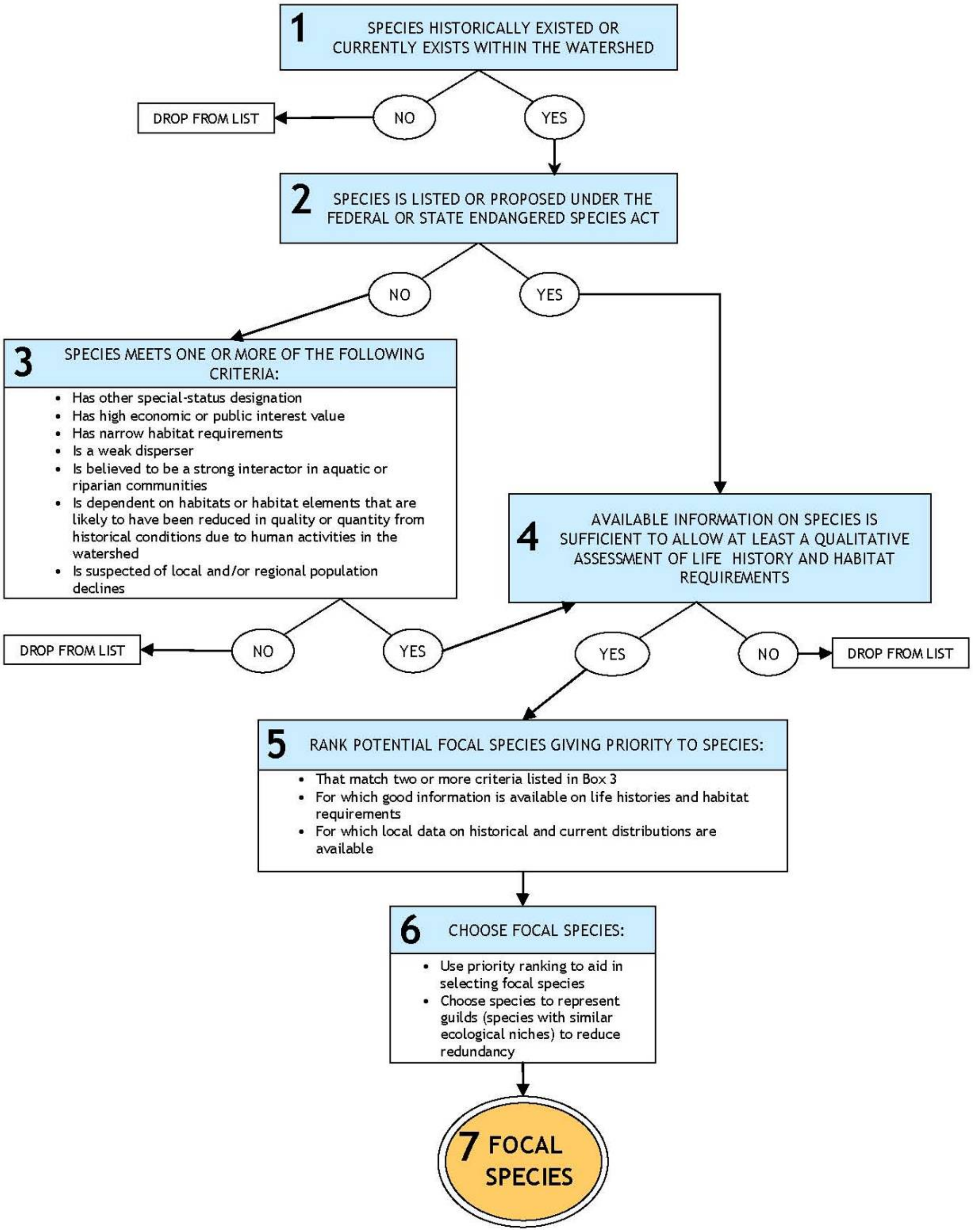

1 SPECIES HISTORICALLY EXISTED OR CURRENTLY EXISTS WITHIN THE WATERSHED

2 SPECIES IS LISTED OR PROPOSED UNDER THE FEDERAL OR STATE ENDANGERED SPECIES ACT

3 SPECIES MEETS ONE OR MORE OF THE FOLLOWING CRITERIA:

- Has other special-status designation
- Has high economic or public interest value
- Has narrow habitat requirements
- Is a weak disperser
- Is believed to be a strong interactor in aquatic or riparian communities
- Is dependent on habitats or habitat elements that are likely to have been reduced in quality or quantity from historical conditions due to human activities in the watershed
- Is suspected of local and/or regional population declines

4 AVAILABLE INFORMATION ON SPECIES IS SUFFICIENT TO ALLOW AT LEAST A QUALITATIVE ASSESSMENT OF LIFE HISTORY AND HABITAT REQUIREMENTS

5 RANK POTENTIAL FOCAL SPECIES GIVING PRIORITY TO SPECIES:

- That match two or more criteria listed in Box 3
- For which good information is available on life histories and habitat requirements
- For which local data on historical and current distributions are available

6 CHOOSE FOCAL SPECIES:

- Use priority ranking to aid in selecting focal species
- Choose species to represent guilds (species with similar ecological niches) to reduce redundancy

7 FOCAL SPECIES

Figure E-1. Focal species vetting process.

Appendix F

Barriers to Anadromous Fish Passage in the San Gregorio Creek Watershed

Table F-1. Barriers to fish passage in the San Gregorio Creek watershed from CDFG's Passage Assessment Database (PAD).

PAD ID No.	Barrier ID No.	Stream Name	Barrier Name	Barrier Type	Status
705300	5499	Alpine Creek	Concrete Dam	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Not a barrier
706673	8056	Alpine Creek	waterfall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Total
707061	8492	Alpine Creek	Denil Ladder at Alpine Rd. and Pescadero Rd.	Fish passage facility	Temporal
716940	27064	Alpine Creek	Log and Brush Jam	Log jam	Partial
716941	27065	Alpine Creek	Concrete Dam	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Total
716942	27066	Alpine Creek	Glenwood Boys Ranch Diversion	Diversion (screened/unscreened)	Unknown
716215	26287	Alpine Creek		Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Total
706675	8058	Bogess Creek	concrete box culvert hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Temporal
706676	8059	Bogess Creek	Private concrete road crossing	Road crossing (culvert, bridge, low-flow, etc.)	Temporal
706677	8060	Bogess Creek	channel type changes to A2	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Total
712418	14441	Clear Creek	Private crossing	Road crossing (culvert, bridge, low-flow, etc.)	Partial
712419	14442	Clear Creek	Hwy 84 crossing	Road crossing (culvert, bridge, low-flow, etc.)	Temporal & Partial
712420	14443	Clear Creek	Bear Gulch Road #1	Road crossing (culvert, bridge, low-flow, etc.)	Temporal & Partial
712421	14444	Clear Creek	Bear Gulch Road #2	Road crossing (culvert, bridge, low-flow, etc.)	Temporal & Partial
716966	27090	Clear Creek	Man-made Dam (Earth-filled Burlap Bags)	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Unknown
733747	29222	Clear Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733745	29220	Coyote Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
706678	8061	El Corte De Madera Creek	Dam with 2 foot step	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Temporal

PAD ID No.	Barrier ID No.	Stream Name	Barrier Name	Barrier Type	Status
733749	29225	El Corte de Madera Creek	Bridge	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
706679	8062	El Corte De Madera Creek	vertical bedrock sheet/waterfall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Total
716943	27067	El Corte De Madera Creek	10FT. Bedrock Fall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Unknown
716944	27068	El Corte De Madera Creek	10FT. Cement and Rock Dam	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Total
716945	27069	El Corte De Madera Creek	4FT. Bedrock Fall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Unknown
723633	9821	El Corte Madera Creek	Bear Gulch Road	Road crossing (culvert, bridge, low-flow, etc.)	Partial
716947	27071	Harrington Creek	Rock Fall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Total
716948	27072	Harrington Creek	Rock Fall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Unknown
716963	27087	Kingston Creek	5FT. Log Jam	Log jam	Partial
716964	27088	Kingston Creek	Bedrock Shoot with a 6FT. Drop	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Partial
716965	27089	Kingston Creek	Log Jam	Log jam	Total
706674	8057	La Honda Creek	steep gradient	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Temporal & Partial
716949	27073	La Honda Creek	Sack Dam	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Temporal
716950	27074	La Honda Creek	Bridge	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
716951	27075	La Honda Creek	Bridge	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
716952	27076	La Honda Creek	18FT. Log Jam	Log jam	Total
716953	27077	La Honda Creek	12FT. Log Jam	Log jam	Total
716954	27078	La Honda Creek	Log Jam	Log jam	Total
716955	27079	La Honda Creek	10FT. Large Log and Earth Blockage	Log jam	Total
733760	29239	La Honda Creek	Bridge	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733764	29244	La Honda Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown

PAD ID No.	Barrier ID No.	Stream Name	Barrier Name	Barrier Type	Status
706680	8063	Mindego Creek	dam	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Temporal
706681	8064	Mindego Creek	Waterfall on Mindego Creek	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Total
716956	27080	Mindego Creek	8FT. Concrete Dam	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Total
716957	27081	Mindego Creek	7FT. Bedrock Drop	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Unknown
716958	27082	Mindego Creek	Flow measurement weir	Flow measurement weir	Unknown
716959	27083	Mindego Creek	Unnamed fish passage facility	Fish passage facility	Unknown
716960	27084	Mindego Creek	4FT. Earth-fill Dam and Diversion	Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Unknown
716961	27085	Mindego Creek	12FT. Fall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Unknown
716962	27086	Mindego Creek	10FT. Fall	Non-structural (waterfall, grade, temperature, insufficient flow, landslide, velocity, etc.)	Unknown
733839	29350	Pacific Ocean	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733840	29351	Pacific Ocean	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733847	29358	Pacific Ocean	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
716229	26301	Reflection Lake		Dam (debris, earth, rock, flashboard, drop structure, arch, weir, gravity, wing, gabion, etc.)	Unknown
712347	14287	Rogers Gulch (tributary to Alpine Creek)	Heritage Road	Road crossing (culvert, bridge, low-flow, etc.)	Total
733741	29216	San Gregorio Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733746	29221	San Gregorio Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733751	29228	San Gregorio Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733753	29230	San Gregorio Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown

PAD ID No.	Barrier ID No.	Stream Name	Barrier Name	Barrier Type	Status
733755	29233	San Gregorio Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733756	29235	San Gregorio Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733757	29236	San Gregorio Creek	Bridge	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733758	29237	San Gregorio Creek	Bridge	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733759	29238	San Gregorio Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733838	29349	San Gregorio Creek	Bridge	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733842	29353	San Gregorio Creek	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733843	29354	San Gregorio Creek	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733743	29218	unknown	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733844	29355	unknown	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733845	29356	unknown	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733846	29357	unknown	Culvert Hwy 1	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733771	29253	Weeks Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown
733765	29246	Woodruff Creek	Culvert Hwy 84	Road crossing (culvert, bridge, low-flow, etc.)	Unknown

Source: California Department of Fish and Game Passage Assessment Database (PAD) http://nrm.dfg.ca.gov/PAD/default.aspx

Table F-2. Barriers to anadromous fish passage in the San Gregorio Creek watershed from Cox and Robin (2006)[1, 2].

Distance Upstream (ft)	Site Type	Site Description	Status	Comments	PAD ID
Clear Creek[3]					
232	Road crossing	Private crossing	Partial	No anadromous fishery. Steelhead listed as not present in NOAA CCC 2005 Distribution list. Habitat listed as unknown to poor. Not NOAA critical habitat for steelhead	14441
1,300	Road crossing	Hwy 84 crossing	Temporal & Partial	Same as above	14442
2,629	Road crossing	Bear Gulch Road #1. Not addressed in Taylor report	Temporal & Partial	Same as above	14443

Distance Upstream (ft)	Site Type	Site Description	Status	Comments	PAD ID
3,784	Dam	Man-made Dam (Earth-filled Burlap Bags)	Unknown	Same as above	27090
4,100	Road crossing	Bear Gulch Road #2. Not addressed in Taylor report	Temporal & Partial	Same as above	14444
El Corte De Madera Creek[3]					
12,416	Non-structural	10FT. Bedrock Fall	Unknown	Natural feature	27067
13,205	Dam	10FT. Cement and Rock Dam	Total	DFG files (1994 survey) indicate a two foot plunge off of cement dam at approx the same location. Is this the same ? Also, NOAA lists steelhead critical habitat above this supposedly total barrier. This may be a priority site.	27068
19,211	Dam	Dam	Temporal	Dam creating a 2 ft step with no pool below (from DFG files). If 27068 is prioritized, then this one should be site evaluated also. Steelhead listed as not present in NOAA CCC 2005 Distribution list above this site. This barrier is the end of NOAA critical habitat for steelhead.	8061
21,296	Non-structural	4FT. Bedrock Fall	Unknown	Natural barrier feature	27069
23,234	Non-structural	25FT. Bedrock Fall	Total	Natural limit to anadromy	27070
24,531	Non-structural	vertical bedrock sheet/waterfall	Total	Natural limit to anadromy/above natural limit to anadromy	8062
14,200	Road crossing	Bear Gulch Road		Based on a DFG 1985 survey the stream goes through a 12 ft wide crossing that is made up of two, 2 ft diameter diversions and an 18 inch corrugated culvert that is a barrier. However, 2 steelhead noted upstream of crossing.	Not listed in PAD
Bogess Creek[3]					
233	Road crossing	concrete box culvert	Temporal	Highway 84 crossing - High velocities in wet months may limit access. DFG recommends in 1996 habitat survey to install baffles.	8058
2,352	Road crossing	concrete road crossing	Temporal	Private crossing. According to DFG 1996 habitat evaluation, there is a 2 foot jump on downside with a 0.1 foot laminar flow through concrete crossing.	8059
24,661	Other	channel type changes to A2	Total	Natural limit to anadromy	8060

Distance Upstream (ft)	Site Type	Site Description	Status	Comments	PAD ID
Kingston Creek[3]					
128	Log jam	Log jam	Total	Steelhead presence listed as unknown in NOAA CCC 2005 Distribution list. DFG files indicate an impassable log jam in 1985. Suitable habitat is present but poor in creek.	27089
556	Non-structural	Bedrock Shoot with a 6FT. Drop	Partial	Natural feature	27088
3,072	Log jam	5FT. Log Jam	Partial	Log jam	27087
Harrington Creek[3]					
8,404	Non-structural	Rock Fall	Total	Natural limit to anadromy	27071
15,309	Non-structural	Rock Fall	Unknown	Natural feature/above natural limit to anadromy	27072
La Honda Creek[3]					
1,515	Dam	Sack Dam	Temporal	MROSD has a grant proposal submitted to take out La Honda barriers.	27073
11,989	Log jam	10FT. Large Log and Earth Blockage	Total	Log jam	27079
13,336	Road crossing	Bridge	Unknown	Does not appear to be a barrier based on stream survey information from DFG files.	27074
15,925	Road crossing	Bridge	Unknown	Does not appear to be a barrier based on stream survey information from DFG files.	27075
26,159	Non-structural	Steep gradient	Temporal & Partial	Natural feature	8057
27,527	Log jam	18FT. Log Jam	Total	Log jam	27076
32,398	Log jam	12FT. Log Jam	Total	Log jam	27077
32,753	Log jam	Log Jam	Total	Log jam	27078
Mindego Creek[3]					
3,223	Dam	dam	Temporal	Dam with Denil ladder. Is the ladder at approx 7,000 feet noted in 1973 survey gone?	8063
14,329	Non-structural	waterfall	Total	Natural limit to anadromy	8064
Alpine Creek[3]					
12,489	Dam	7FT. Concrete Dam	Total	Could not locate this barrier during site visit.	27065
15,890	Log jam	Log and Brush Jam	Partial	Log jam	27064
27,978	Non-structural	waterfall	Total	Natural limit to anadromy	8056
	Dam	200 ft downstream from Heritage road crossing at Rogers Gulch (PAD site # 14287)	Partial	During site visit we found a concrete sac dam approx 2-3 feet high, that appeared to have been cut down from a 4-5 foot dam. Located at approx stream distance of 10,900 feet from mouth.	Not listed in PAD

Distance Upstream (ft)	Site Type	Site Description	Status	Comments	PAD ID
Rogers Gulch (Tributary to Alpine Creek)[3]					
82	Road crossing	Heritage Road. Taylor site # SM-012: Roy Gulch/Pescadero Creek Road	Total	Taylor high priority site. San Mateo County is replacing the culvert to avoid a blowout. No know passage barriers upstream.	14287

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[1] Barrier location, status, anadromy, priority and other information was developed from a review of the California Fish Passage Assessment Database (PAD) and California Department of Fish and Game files.

[2] Color coding:

Green: No action necessary or appropriate (e.g., natural features, acceptable passage, completed projects). Although often anthropogenic in nature, log jams are included in this category.

Blue: Barriers that impede passage but do not meet prioritization criteria or are beyond the scope of this project (e.g., large reservoir dams, barriers that are planned for removal).

Yellow: Barriers about which more information is required.

Orange: Potential high priority sites.

[3] Watershed boundaries follow San Mateo County's Priority Watersheds for Restoration of Coho Salmon and Steelhead Trout Habitat map (http://www.co.sanmateo.ca.us/smc/department/home/0,,5562541_5562589_16567582,00.html).