Santa Rosa Creek
Watershed Management Plan

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Prepared for:

California Department of Fish and Game

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EXECUTIVE SUMMARY

The Santa Rosa Creek Watershed Management Plan was funded by California Department of Fish and Game's (CDFG) Fisheries Restoration Grant Program to develop a technically sound plan that addresses the strategic and scientific needs for watershed management, restoration planning, and south-central California coast steelhead (*Oncorhynchus mykiss*) recovery in the Santa Rosa Creek watershed, and that will be effective within current and foreseeable land use, water supply, and land ownership patterns in the watershed. Specifically, the objectives of the watershed management plan are to assess existing conditions, prioritize limiting factors for steelhead, and identify and prioritize restoration recommendations to address these limiting factors and improve physical functions and ecological conditions in the watershed. The watershed management plan was developed through the collaboration of a broad spectrum of participants. Stakeholders representing community sectors including agriculture, business, the community services district, planning advisory groups and fishing interests, and who work or live in the watershed, met periodically throughout the development of the watershed management plan to advise and inform the process, contribute historic and current information, assist in evaluating the accuracy of existing conditions and to review information and provide comments. In addition, a Technical Advisory Committee reviewed key watershed management plan elements, and input from the public was solicited at three public workshops.

Physical processes and ecological conditions in the Santa Rosa Creek watershed have been affected by historical clearing of land, groundwater pumping, urban development, bank revetment, historical mercury mining, land management practices, and road building. These activities have increased hillslope erosion and fine sediment supply to creek channels, resulted in channel incision, exacerbated low flows in the summer and fall, degraded riparian and aquatic habitat conditions, created barriers to fish migration, decreased water and sediment quality, and introduced non-native invasive species. Several of these effects limit the population of steelhead in the watershed by dramatically reducing instream flows in the summer and fall, decreasing pool habitat and large woody debris for summer and winter rearing, restricting their migration, and possibly limiting the potential for lagoon rearing.

The watershed management plan includes a suite of management, restoration, and study recommendations based on the synthesis of existing watershed conditions, steelhead limiting factors analysis, results of a geomorphic assessment and benthic macroinvertebrate sampling conducted specifically for the watershed management plan, and input from stakeholders and technical advisors. The recommendations present multiple ways to address steelhead limiting factors and conserve and improve physical processes and ecological conditions in the watershed, and are designed to be implemented individually, or in combination, on a voluntary basis, by or with the consent of willing landowners. Recommendations are presented by their ultimate objective and are listed in order of their relative importance to steelhead habitat restoration:

- Increase Summer and Fall Instream Flows
- Restore the Riparian Corridor
- Reduce Fine Sediment Delivery to the Creek
- Conserve and Protect Open Spaces and Existing Land Uses
- Increase Large Woody Debris Supply and Retention
- Remove Barriers to Fish Passage
- Fill Key Data Gaps
- Reduce Mercury Supply

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1 INTRODUCTION

1.1 Purpose of and Need for a Watershed Management Plan

Santa Rosa Creek in northern San Luis Obispo County once supported one of the largest populations of steelhead (*Oncorhynchus mykiss*) along the central California coast south of San Francisco (Titus et al. 2006). Perennial flow in most years, suitable instream habitat conditions (e.g., riparian cover and spawning substrate), and few physical barriers contributed to the success of this species in the watershed. However, recent fish studies have suggested that the population has dropped significantly below historic levels, driven by a number of probable factors including land uses and urbanization, road building, and groundwater and surface water management (e.g., Nelson 1994, D. W. Alley & Associates 2008, Nelson et al. 2009). In response to the concerns about existing habitat conditions for the threatened steelhead trout, several state and local advocacy groups began to identify limiting factors for steelhead trout habitat in the watershed (D. W. Alley & Associates 2008, TLCSLOC 2010) and implement stream habitat restoration projects (see Section 1.5).

Resource agency representatives responsible for recovering steelhead trout populations began to acknowledge the need to consolidate and unify these various efforts and provide a strategic and scientifically-based plan for improving steelhead habitat in Santa Rosa Creek. In 2008, California Department of Fish and Game (CDFG) awarded Greenspace – The Cambria Land Trust (Greenspace) grant funding to develop a comprehensive watershed management plan based on technical and local input that identifies limiting factors in the watershed and identifies and prioritizes restoration activities and can effectively restore creek function within current and foreseeable land use, water supply, and other constraints in the watershed. As the basis for these recommendations, the watershed management plan includes other recent information on watershed (e.g., climate, hydrology, and water quality) and steelhead population conditions. Acknowledging that there was a lack of understanding of physical factors that influence watershed conditions, the grant also included an investigation of the watershed's geomorphology —the scientific study of landforms and the processes that shape them (Section 2.5 and Appendix A). To better understand water quality conditions and their influence on aquatic biota, the grant included sampling of the benthic macroinvertebrate population as well (Section 2.8.4 and Appendix B). The purpose of this watershed management plan is to address the restoration needs for watershed management in the Santa Rosa Creek watershed by assessing existing conditions, identifying limiting factors for steelhead, and identifying and prioritizing restoration recommendations to improve physical and ecological conditions and facilitate the recovery of steelhead in the watershed.

What are your concerns about the creek and watershed?

"I would hope for a cooperative effort that results in a healthy watershed."
– Public Meeting Participant

1.2 Goals and Objectives

The objectives of this watershed management plan are to:

- Document historical watershed conditions.
- Assess physical and biological conditions in the watershed.
- Determine factors limiting the steelhead population.
- Identify and prioritize actions to address limiting factors for steelhead.
- Recommend additional actions that will improve overall fish and wildlife habitat.

The goals of the watershed managements planning process are to:

- Provide a thorough compilation of historical and current conditions in the Santa Rosa Creek watershed and assessment of steelhead limiting factors.
- Provide opportunities to educate the community on watershed conditions and ecological processes.
- Build local support for and participation in watershed conservation and restoration.
- Provide a supporting document so that willing participants can seek funds for recommended steelhead projects from CDFG's Fisheries Restoration Grant Program.

1.3 Overview of the Watershed

Looking up the Santa Rosa Creek watershed

Santa Rosa Creek watershed lies within the southern portion of the California Coast Range—a northwest-trending series of mountains and basins along the coast from Santa Barbara north to the Oregon border (Figure 1-1). The 48 mi^2 (123 km^2) watershed is bounded to the east by the Santa Lucia Mountain range and the west by the Pacific Ocean. Bordering the watershed are the similarly sized watersheds of San Simeon Creek to the north, Adelaida Creek to the northeast, Paso Robles Creek to the east, and Villa Creek to the south. Santa Rosa Creek and its tributaries flow mostly unobstructed down steep hillslopes mantled with shallow soils and sparse shrub vegetation and through agricultural areas and the small town of Cambria before reaching the Pacific Ocean. Santa Rosa Creek travels 16 mi (25 km) from its headwaters, following a sinuous course to the west through a confined canyon that opens up into a relatively long, broad valley floor. The town of Cambria sits near the mouth of Santa Rosa Creek, downstream of the confluence with Perry Creek—the largest tributary in the watershed. Only four creeks have been named on topographic maps of the U.S. Geological Survey (USGS)—Santa Rosa, Perry, Green Valley, and Fiscalini creeks (USGS 1979a, 1979b), while an additional six streams have been unofficially designated as derived from past or current property owner names (e.g., D. W. Alley & Associates 2008). These tributaries are referenced throughout this report, as summarized below in Table 1-1 and shown in Figure 1-2. The topographic relief is typical of the southern Coast Range terrain, with steep upland areas and low-gradient valley bottoms bordering the lower reaches of Santa Rosa, Green Valley, and Perry creeks (Figure 1-2). Relatively higher elevations are present in the Santa Rosa Creek sub-watershed, which peaks at Cypress Mountain with an elevation of 2,933 ft (894 m). In comparison, the highest point in the Perry Creek sub-watershed (NE corner of the Green Valley sub-watershed) reaches an elevation of 1,419 ft (433 m). At its lowest elevation, Santa Rosa Creek flows through a lagoon contained by an annually formed sandbar at Moonstone Beach that breaches when streamflow begins to rise and ocean wave action increases in late fall.

Table 1-1. Santa Rosa Creek watershed and sub-watershed areas and stream lengths.

Sub-watershed [a,b]		Tributary location [c]		Area [d]		Stream length [e]	
USGS-designated stream name	**Unofficial stream name**	**mi**	**km**	**mi^2**	**km^2**	**mi**	**km**
Santa Rosa Creek [f]		n/a	n/a	24.6	63.6	15.8	25.4
Unnamed	*Taylor Creek*	3.5	5.6	2.4	3.8	2.4	3.8
Unnamed	*Curti Creek*	7.5	12.1	2.1	5.5	2.2	3.5
Unnamed	*Lehman Creek*	9.7	15.6	2.5	6.5	2.6	4.1
Unnamed	*East Fork Santa Rosa Creek* [g]	12.1	19.5	1.9	4.9	2.9	4.7
Unnamed	*North Fork Santa Rosa Creek* [h]	12.5	20.1	2.2	5.6	2.6	4.2
Unnamed	*Mora Creek*	12.5	20.1	2.6	6.8	3.0	4.8
Perry Creek		3.0	4.8	22.9	59.3	9.7	15.6
Fiscalini Creek		5.2	8.4	2.6	6.7	1.4	2.3
Green Valley Creek		6.0	9.7	12.2	31.5	7.9	12.8
Total Santa Rosa Creek Watershed				**47.5**	**123**	**15.8**	**25.4**

[a] Tributaries are indicated by the degree of text indentation (e.g., Taylor Creek is a tributary to Santa Rosa Creek, Green Valley Creek is a tributary to Perry Creek which is a tributary to Santa Rosa Creek).
[b] To help identify unnamed tributaries on USGS topographic maps (USGS 1979a, 1979b) that are referred to later in this document unofficial tributary names from D.W. Alley & Associates (2008) are also presented.
[c] Locations of Taylor, Curti, Lehman, East Fork Santa Rosa, North Fork Santa Rosa, and Perry creeks are based on the longitudinal station at which they enter mainstem Santa Rosa Creek, starting at the Santa Rosa Creek mouth. The location of Mora Creek is based on the longitudinal station at which it enters North Fork Santa Rosa Creek upstream from mainstem Santa Rosa Creek. Locations of Fiscalini and Green Valley creeks are based on longitudinal stations along Perry Creek upstream from mainstem Santa Rosa Creek.
[d] Sub-watershed area derived in a GIS using a USGS 10m Digital Elevation Model (DEM).
[e] Stream length derived in a GIS using a USGS 10m DEM-generated stream network with a contributing area threshold of 0.04 km^2.
[f] Santa Rosa Creek mainstem continues along the unofficially named "East Fork Santa Rosa Creek" per the USGS stream designation (USGS 1979b).
[g] This creek is also commonly known as Soto Creek (D. Dunlap, pers. comm., 2009).
[h] This creek is also commonly known as Macacci Creek (D. Dunlap, pers. comm., 2009).

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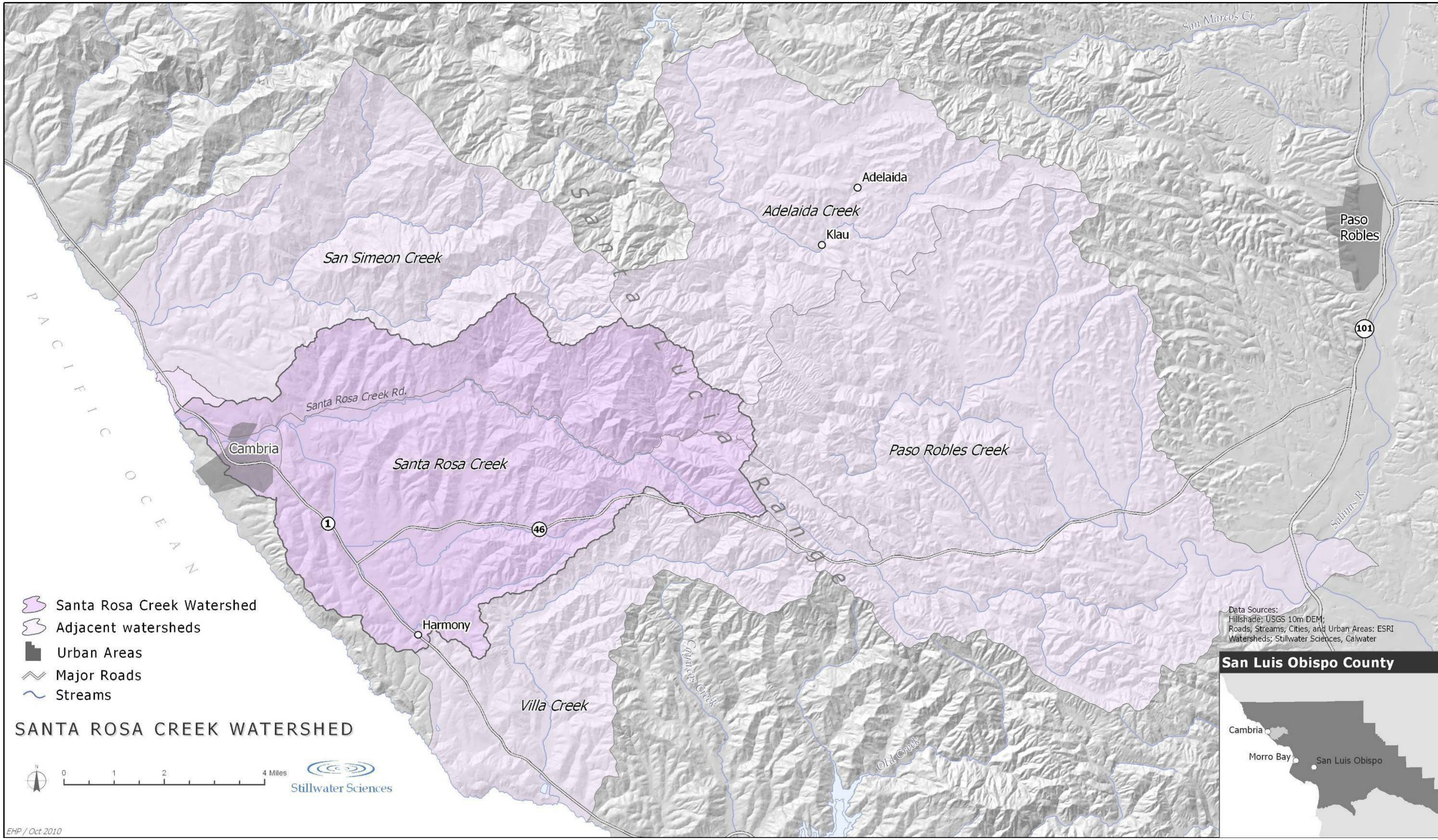

Figure 1-1. Santa Rosa Creek watershed and vicinity map.

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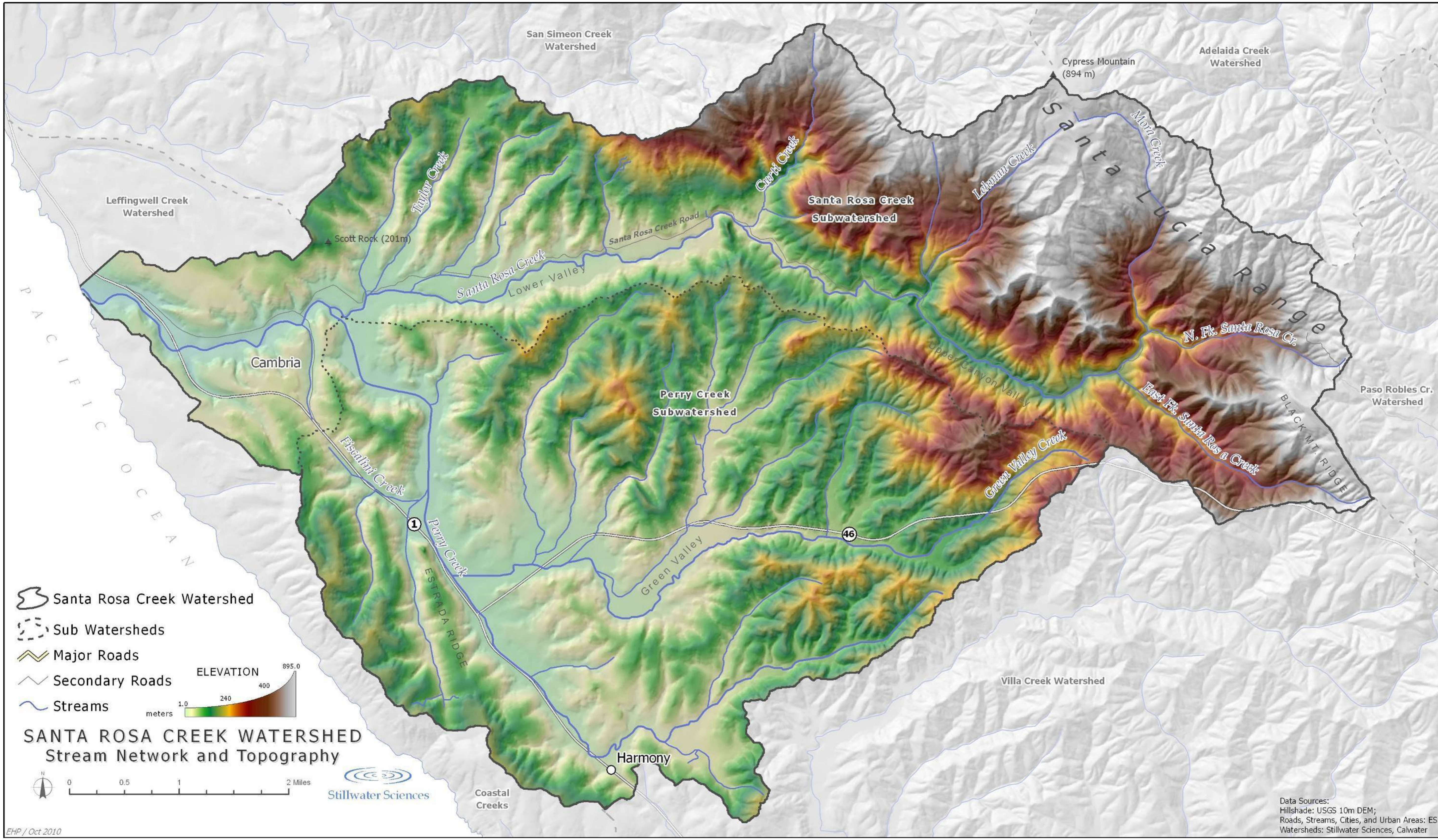

Figure 1-2. Santa Rosa Creek watershed stream network and topography.

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1.4 Stakeholder Involvement in the Watershed Management Plan

Recognizing that the development of a watershed management plan requires understanding and embracing the needs and concerns of local landowners, water users, and industry, the watershed management plan included the establishment of a stakeholders group. The role of stakeholders in formulating the watershed management plan is central to the success of its development and implementation, and their willingness to share information to shape the context of issues, marks a plan that will live beyond its written pages.

Stakeholders representing the various sectors that exist in the watershed, including agriculture, business, the community service district, planning advisory groups and fishing interests, were recruited to participate in the development of the watershed management plan. All stakeholders either work or live in the watershed. Stakeholders met periodically to contribute historic and current information, assist in reviewing the accuracy of existing conditions and other information, and provide comments. In addition, each stakeholder meeting included educational opportunities to offer background on a variety of topics related to steelhead ecology and watershed restoration, and increase awareness of and appreciation for the way in which watershed residents and businesses could voluntarily engage in restoration activities. Stakeholders' time and effort are recognized as being the cornerstone of continuing efforts to address factors limiting steelhead in the Santa Rosa Creek watershed, and are acknowledged throughout this document, as well as in the acknowledgements section at the end of this document (Section 5). Stakeholders met eight times between September 2009 and March 2011, representing a total of 240 person-hours, not including the time spent reviewing documents.

What are your concerns about the creek and watershed?

"Sustainable management of water for environment and people; enhance the productivity of ecosystem services of the watershed."

– *Stakeholder*

A Technical Advisory Committee (TAC) was convened to review and provide input to the watershed management plan to ensure that the data, analyses, and recommendations in the watershed management plan are correct, appropriate, and in keeping with local, regional, state, and federal efforts. TAC members are listed in the acknowledgements section at the end of this document.

In addition to stakeholders, the public was invited to attend three meetings during the course of the watershed management plan's development to facilitate information feedback between the TAC and the larger community and to provide a forum for education. The first meeting, held in January 2010, introduced the project to the public and sought input through a written questionnaire (Appendix C). The second meeting in August 2010 provided the public with a summary of watershed conditions. The third meeting in March 2011 unveiled the final watershed management plan and formally expressed gratitude to the community and stakeholders for their contributed time and effort.

1.5 Related Studies and Management Actions in the Watershed

A number of watershed management and restoration studies and/or actions have and are being conducted in the Santa Rosa Creek watershed. Several of these provided the impetus for this watershed management plan, while others support it by improving watershed conditions and incorporating a broad range of community members in the conservation and restoration of the watershed.

The Land Conservancy of San Luis Obispo County (TLCSLOC) recently completed the *Santa Rosa Creek Watershed Conservation Plan* (TLCSLOC 2010). The conservation plan compiled an extensive set of existing data for the watershed, collected additional data on upland erosion, and presents conservation strategies based on Natural Resources Conservation Service and California Rangelands resources. The synthesis of existing watershed conditions in this watershed management plan relied in part on the data compiled and collected by TLCSLOC (2010).

Rathbun et al. (1991) documented the status of four special-status declining reptiles, amphibians, and fishes in lower Santa Rosa Creek, which provided much of the basis for the *Lower Santa Rosa Creek Enhancement Plan* (Prunuske Chatham Inc. 1993). The lower creek plan, which was completed in 1993, described the ecological conditions and presented a plan for enhancing the reach of the creek from the Main Street Bridge to the ocean (Prunuske Chatham Inc. 1993). This watershed management plan updates and geographically expands upon the lower creek plan, and incorporates several of its enhancement measures.

Riparian buffer between Santa Rosa Creek and adjacent farmland

Many property owners in the watershed are already protecting watershed resources by implementing best management practices, and several local organizations, including Greenspace, the Cambria Community Services District (CCSD), Friends of Fiscalini Ranch Preserve, Cambria Forest Committee, and others, have completed enhancement, monitoring, and educational projects and events in the watershed. These have included:

- Water quality monitoring snap shot days (ongoing, approximately annually)
- Beach and creek cleanups (ongoing, annually)
- Ferrasci Road barrier removal (2011)
- Non-native eucalyptus tree removal downstream of Highway 1 (2010)
- Steelhead habitat enhancement, bank stabilization, and educational signs downstream of the Highway 1 Bridge (2007/2008)
- Burton Street Bridge barrier removal (2006)
- Fiscalini streambank stabilization (2005)
- San Luis Obispo County stream crossing inventory and fish passage evaluation (2005)
- Cambria forest management plan (2002)
- Santa Rosa Creek is Your Watershed educational program (2002)
- Watershed and Cambria forest conferences (2002 and 1991)

2 SYNTHESIS OF WATERSHED CONDITIONS

2.1 Historical Watershed Conditions and Watershed Impacts

Looking at a watershed's past provides insight into natural physical and ecological trends in addition to the identification of human-induced changes over time. An informed forecast of future watershed conditions can therefore be made based on synthesizing the understanding of past and present conditions. The information presented in this section summarizes general historical conditions in the watershed dating back to pre-European settlement in an attempt to illuminate the historical (both natural and human-induced) events that may have had an effect on physical processes and ecological conditions in the watershed (Figure 2-1).

Prior to European settlement along the California coast, the watershed is assumed to have been in a relatively undisturbed condition, responding only to fluctuating flood, drought, earthquake, and fire sequences, and with relatively minor impacts associated with the hunting and gathering practices of the local indigenous peoples. The first recorded accounts of Santa Rosa Creek valley are those made during the Portola Expedition where, in September 1769, the party encountered a "canyon… and arroyo[1] surrounded with hills of pine" (Hamilton 1974). On numerous instances, the expedition party noted flowing streams, both along what is now known as the mainstem Santa Rosa Creek and from many of its "springs", or tributaries (Hamilton 1974). Few other records of this area's natural resources were made for several decades despite the establishment of Mission San Miguel (1779) near present-day Paso Robles and the growing use of the Santa Rosa and San Simeon watershed areas for timber and wild game to support the Spanish population throughout the southern Coast Range region.

In 1840, Don Julian Estrada was granted possession of Rancho Santa Rosa—a 13,200-ac (53-km^2) land holding encompassing a portion of the western half of the watershed (Angel 1883, Hamilton 1974). Estrada drafted an illustration of his land in that year that depicts several notable features of the historical landscape, including Santa Rosa and San Simeon creeks draining to the ocean from steep upland areas, continuous pine forests upon hillsides surrounding lower Santa Rosa Creek near the area of present-day Cambria, a coastal trail parallel to the coastline, and, perhaps most interestingly, a "laguna", or lake along the narrow valley of lower Perry Creek (Figure 2-2). This lake is further described in Hamilton (1974) as a "shallow, broad lake… clogged with tules" fed by both Perry and Green Valley creeks, and bordered along its eastern shore by a coastal trail linking San Luis Obispo with San Simeon. The exact location of this lake is not precisely known, but it has been estimated to have formerly extended from the Perry and Green Valley creeks confluence north towards Santa Rosa Creek (Hamilton 1974; D. Dunlap, pers. comm., 2009). The lake was eventually drained by "Walker Ditch" in the early 1870s under the direction of the second owner of this portion of Rancho Santa Rosa, George Hearst, for the purpose of converting the wetland area to agricultural land (Hamilton 1974; D. Dunlap, pers. comm., 2009). The first official survey map of San Luis Obispo County published in 1874 does not depict the lake, indicating that it had already been drained when the survey was conducted, and instead shows a stream channel that generally follows the present-day stream course of lower Perry Creek (Harris 1874) (see Appendix A). Today, this artificial stream course of lower Perry Creek stands out from all other stream courses in the watershed as it follows long, straight segments connected by right-angle turns along the valley floor and north towards its confluence with Santa Rosa Creek.

[1] The Spanish word of "arroyo", as used in this account, translates to mean a small creek and not one that is necessarily incised, which is unlike the contemporary use of the word in the English language to mean an incised creek, typically those found in the American southwest.

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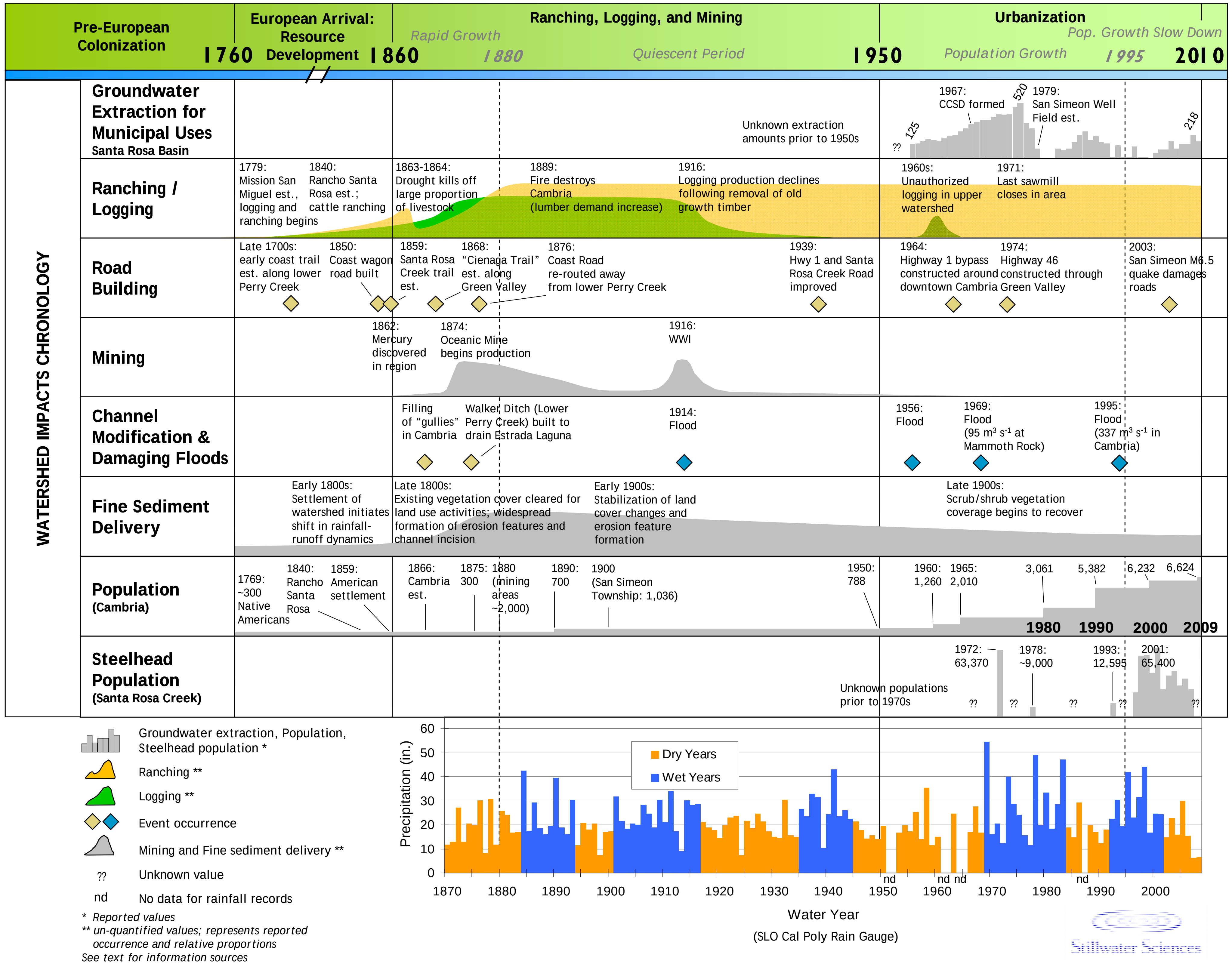

Figure 2-1. Chronology of watershed impacts and events. Precipitation records indicate periods of cumulatively wetter (blue) and drier (orange) periods in the watershed.

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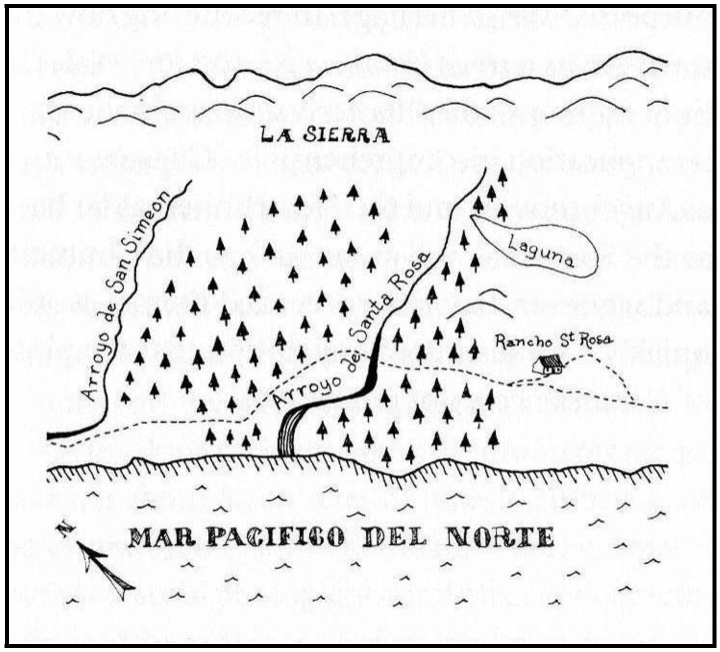
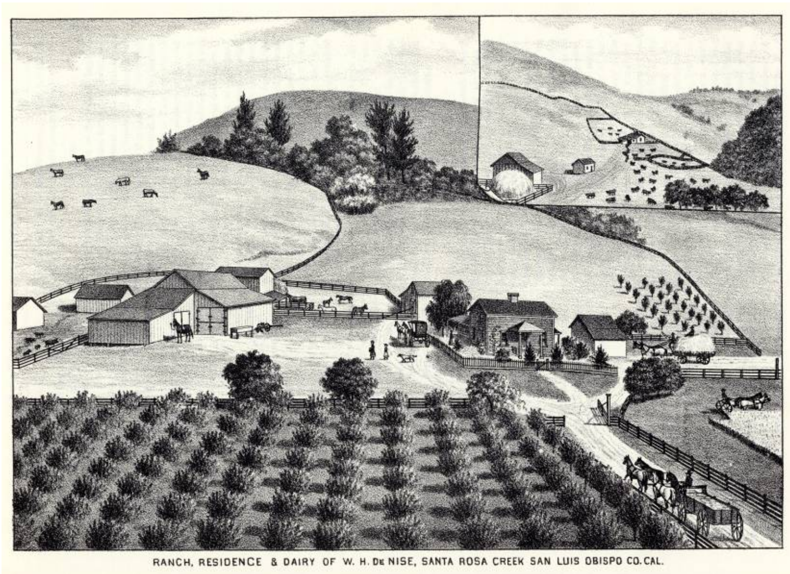


Figure 2-2. Illustration of Rancho Santa Rosa by Don Julian Estrada as part of his 1841 land grant application. Source: Coffman 1995.

The lagoon likely functioned as a settling basin for sediment delivered by tributaries of Perry Creek, and effectively served historically to separate the Perry Creek sub-watershed from the Santa Rosa Creek sub-watershed in terms of sediment delivery, especially of coarse sediments.

In the early 1800s, clearing of the land in support of agricultural activities—cattle ranching, crop cultivation, and logging—likely caused significant changes to rainfall-runoff relationships as trees, shrubs, and deep-rooted native perennial grasses in the valleys and upon hillslopes were degraded and replaced by shallow-rooted, non-native annual grass species that less effectively protect soil against erosion. Initially, cattle herds from Mission San Miguel were occasionally moved into the Santa Rosa Creek watershed because of ample sources of water and foraging vegetation even during the dry seasons (Hamilton 1974). Starting in the late 1850's, Americans and European immigrants began settling the watershed and greatly increased the pace of land clearing, which was reportedly achieved by cutting and/or burning the native vegetation (Coffman 1995; D. Dunlap, pers. comm., 2009). Historical accounts from across the coastal region tell of coordinated efforts by land owners to clear valley-bottom forests along major rivers (Boughton et al. 2006), which was likely practiced along Santa Rosa, Perry, and Green Valley creek valleys as very little forest cover remains but for some riparian stands closely bordering the stream channels (see Appendix A). Overall, these land uses coupled with episodic storm events resulted in several significant changes in the watershed, namely: (1) greater volumes of hillslope runoff generated per unit rainfall, with far greater volumes of fine sediment production throughout the watershed and increased gullying and shallow landslide potential on the steeper hillslopes; and (2) incision of the mainstem stream channels due to decreased stream bank stability and increased stream power allowing high flows to entrench the channel. Prior to incision, the Santa Rosa, Perry, and Green Valley creek channels would have supported higher groundwater elevations and more frequent inundation under lower flows, which supported the valley forests.

Between 1865 and 1885, a period of population growth and land development occurred in the watershed. Despite a die-off of beef cattle during the intense 1863–1864 drought, a shift to dairy farming, continued logging, and mining of cinnabar for mercury in the region maintained a steady rate of landscape alteration over the next two decades. Urban development and road building began the process of filling in small stream channels, especially those situated near Cambria (Hamilton 1974). By 1880, the landscape had been radically changed from its pre-European settlement condition and appeared very similar to present-day conditions, as represented in several illuminating sketches made during the 1870s (Angel 1883) that show grass-covered hillslopes and valley floors used for pasture with some relict patches of native riparian vegetation remaining near stream channels (Appendix A). Another notable feature depicted in two of these



DeNise ranch, residence, and dairy in the Santa Rosa Creek watershed, circa 1880 (Angel 1883)

illustrations is active hillslope erosion in the form of gullies, which remains a ubiquitous feature of the present-day landscape.

Beginning in 1874, cinnabar, the common ore of mercury, began to be mined at the Oceanic Mine in the Curti Creek sub-watershed. During peak production, ore was milled and processed into pure forms of mercury in a furnace located approximately ½-mile downhill from the mine (Eckel et al. 1941, as cited in CCRWQCB 1999). Mining production continued on and off through the 1900s, with a second peak around 1916 in support of World War I efforts (Hamilton 1974, Baker 2003). While land clearing, road building, and excavation associated with the mine likely resulted in increased fine sediment supply to Curti Creek and downstream, the mine's most deleterious impact has been to water quality. Iron-rich, red seepage from the mine and erosion of mercury-rich waste rock at the former mill site continue to pollute and discolor Curti Creek for most of the downstream distance to Santa Rosa Creek (CCRWQCB 1999, CDPH 2009).

Between 1920 and 1940, the rate of new land development leveled off as mining and logging operations declined, along with the transient population that supported those industries. These trends were driven, respectively, by falling mercury prices and by the near-depleted stock of old growth pine trees (Hamilton 1974). Through this period, dairy farming and crop cultivation continued, but likely did not increase in extent. In general, the landscape condition present during this period appeared very similar to the present-day condition (Appendix A). However, despite these seemingly unchanged conditions in many areas of the watershed, significant changes to specific areas did occur after this relatively quiescent period in the watershed's post-settlement history. The only available records of fish stocking in the watershed occurred during this time. Titus et al. (2006) cite a 1933 record of approximately 4,000 brown trout and a 1951 record of approximately 3,000 rainbow trout being planted in the watershed.

Starting in 1960 and extending through to the mid-1990s, the town of Cambria experienced a steady increase in population and, correspondingly, an increase in urban development in the form of new housing, commercial, and some industrial developments as driven by their tourism industry. According to County and U.S. Census data, Cambria's population (excluding the remainder of the watershed) increased from 788 to 5,382 between 1950 and 1990, representing 6.8-fold increase, while California as a whole experienced only a 2.8-fold increase. Recent population growth in Cambria since 2000, however, dropped considerably to only a 1.1-fold increase, which is below the state growth rate during the past decade (A. Ochs, pers. comm., 2009; U.S. Census Bureau 2003, 2009). This population growth slowdown period signifies stabilization not only of the Cambria population but also of development that would expand the town's urban footprint in the watershed.

The urbanization time period between 1960 and the 1990s also represented an expansion of groundwater pumping and stream diversions to irrigate crops and to provide drinking water to Cambria, which has reduced base flows in Santa Rosa Creek, and potentially within Perry and Green Valley creeks as well. A lowered groundwater table has led to subsidence in areas of the lower Santa Rosa Creek valley, which was observed in Cambria during 1976—the year with the highest municipal groundwater extraction (Yates and Van Konyenburg 1998). Groundwater lowering may have led to further degradation of mature riparian vegetation (in areas where riparian vegetation was not replaced by crops), which is reliant primarily on groundwater during the summer dry season. Large floodplain areas with extensive riparian vegetation may have attenuated floods within Santa Rosa Creek; the removal and degradation of large riparian stands would have therefore increased the "flashy" nature of flood events (i.e., higher flows over a shorter time period). Indeed, large floods in 1914, 1956, 1969, and 1995 have damaged properties situated upon floodplain areas (Hamilton 1974; D. Dunlap, pers. comm., 2009). As a result, bank revetments, or riprap, were subsequently installed along some reaches of Santa Rosa Creek near Cambria to protect floodplain developments from future flood-induced bank erosion. To date, however, no levees have been constructed along the creek or its tributaries, although Highway 1 serves as a low-lying berm to the west of downtown Cambria.

A very significant impact to the watershed from 1960 to the 1990s is the construction of roads; Highways 1 and 46, and Santa Rosa Creek Road. Each of these roads has altered runoff patterns as it traverses the landscape. The first trails and roads in the watershed closely followed the contours of the natural terrain. Their impact was likely limited only to vegetation removal and fine-sediment run-off. The present-day route of Santa Rosa Creek Road primarily follows the original wagon road from Cambria and east towards Paso Robles (Harris 1874, Hamilton 1974) and was paved in 1939. While paving may limit fine-sediment runoff from the road surface, it may also concentrate flow drainage near the stream channel and cause gullies to form on the out-board side of the road and into the creek. The route taken today by Highway 1 differs from that traced by the original "coast road" (Harris 1874, Hamilton 1974) and was cut into hillslopes and laid across small streams channels with culverts. Many of the culverts in the watershed have become partial if not complete barriers to fish migration and movement (see Section 2.7).

Completed in 1974, Highway 46 travels through Green Valley and is the most recent roadway constructed in the watershed, involving relatively large cut and fill sections that allow for a nearly straight path through the varied topography. The need for an extensive series of fill embankments and cuttings for Highway 46 greatly increased rates of fine sediment input to Green Valley Creek during and shortly after construction, and has led to on-going problems of embankment and culvert-related erosion, as well as accelerating runoff into Green Valley Creek. In addition, upper Green Valley Creek and numerous small streams have been virtually cut-off from lower Green Valley Creek, but for the presence of some culverts. Under normal circumstances, water may be conveyed completely through these culverts, but coarse sediment and large woody debris deposited at the culvert entrance during high flows causes blockages that deny the replenishment of gravel and cobble substrates and woody debris in the lower reaches. This adversely affects not only the channel morphology of Santa Rosa Creek but also the availability and complexity of steelhead trout habitat (D. W. Alley & Associates 2008, Nelson et al. 2009). An additional negative of all three major roadways in the watershed has been their effect on erosion associated with concentrating runoff towards the downslope side of the roads (see Section 2.7).

As stated above, the most recent time period between the mid-1990s and present day is generally characterized by a population growth slowdown and, accordingly, a reduction in additional urban development that would act to further alter the landscape, physical processes, and ecological conditions the watershed (see Section 2.2.4). This period also marks the initiation of several endeavors to restore ecologic and geomorphic function in Santa Rosa Creek, including the removal of fish passage barriers and bank-repair projects (see Section 1.5).

2.2 Land Use

2.2.1 Current land uses

The majority of the Santa Rosa Creek watershed is sparsely populated, with urban development concentrated downstream at the town of Cambria. As of 2009, the town supported a population of 6,624 (Cambria Chamber of Commerce, pers. comm., 2009). The remainder of the watershed is almost entirely under agriculture, with primary activities consisting of cattle ranching and limited crop cultivation, which require some level of water usage, primarily obtained via groundwater pumping. In Cambria, developments consist of a business district, which closely borders the lower 2.8 mi (4.5 km) of Santa Rosa Creek from Main Street Bridge to the lagoon area, and residential neighborhoods that extend to the north and south upon the adjacent hillsides. Tourism, primarily directed towards visitors traveling to Hearst Castle in nearby San Simeon, is the chief industry of Cambria. As of 2001, developed areas account for approximately 8% of the watershed area (Homer et al. 2004). Besides the town of Cambria, the only other significant elements of infrastructure in the watershed include three roadways: Highway 1, Highway 46, and Santa Rosa Creek Road. The roadways closely follow and occasionally cross, via bridge or culvert, portions of Santa Rosa, Perry, and Green Valley creeks.

Field ready for planting

2.2.2 Land use planning

The Santa Rosa Creek watershed is entirely within the unincorporated area of the County of San Luis Obispo, where current land use decisions and long range planning are governed by the County's General Plan Land Use Elements and Local Coastal Program. The overarching land use and resource management planning tools embedded in the Land Use Elements include the Resource Management System, the Framework For Planning (Inland) (2009), Coastal Zone Framework For Planning (1993), and Planning Areas. Two Planning Areas, separated by the Coastal Zone Boundary (Figure 2-3), cover the Santa Rosa Creek watershed: the North Coast Planning Area, which is governed by both the Coastal Act and County's General Plan Local Coastal Program, and the Adelaida Planning Area, governed by the General Plan.

The lower half of Santa Rosa Creek watershed is within the rural North Coast Planning Area (Figure 2-3, Coastal Zone Boundary), which covers 165,300 ac (668 km^2) along the San Luis Obispo County coastline, approximately 77,000 ac (311 km^2) of which are owned by the Hearst Corporation. Cambria is one of only two urban areas in the North Coast Planning Area (the other is San Simeon Acres in the San Simeon Creek watershed). Aside from two small commercial/retail parcels on Hearst Corporation property, the entire North Coast Planning Area is designated as agriculture, with two relatively small areas of rural land use north of Cambria and on the border of Monterey County. Table 2-1 summarizes the types of development projects completed between 2003 and 2008 in the North Coast Planning Area (outside the urban areas of Cambria and San Simeon Acres).

The upper half of the watershed is within the Adelaida Planning Area, which covers 208,008 ac (842 km^2) and borders the cities of Paso Robles, Atascadero and Morro Bay and the communities of Cayucos and Templeton. In 1990, the Adelaida Planning Area was extended over the ridge of the Santa Lucia range and onto the western coastal slope of the upper Santa Rosa Creek watershed. Table 2-1 summarizes the types of development projects completed between 2003 and 2008 in the Adelaida Planning Area.

As shown in Figure 2-3, the vast majority of land in the watershed is designated agriculture with small parts of the upper watershed designated as rural lands. A number of urban development types are allowed in these land use categories, including wineries and tasting rooms, bed and breakfasts, retail sales, restaurants, veterinary hospitals, residences, sale of farm equipment and supplies, camping, certain types of manufacturing, and communication facilities (San Luis Obispo County 1993).

Table 2-1. Completed development projects in the Adelaida and North Coast Planning Areas [a] of San Luis Obispo County between 2003 and 2008.

Type of development	Adelaida Planning Area [b]							North Coast Planning Area [b]						
	2003	2004	2005	2006	2007	2008	Total	2003	2004	2005	2006	2007	2008	Total
Winery facility	1	10	2	4	9	10	36	0	0	0	0	0	0	0
Misc. commercial	0	2	0	0	1	2	5	0	0	0	1	0	0	1
Commercial/ industrial addition/alteration	2	4	1	7	3	2	19	2	2	0	0	0	2	6
Farm support quarters	0	1	0	0	0	0	1	0	0	0	1	0	0	1
New single family dwelling	3	19	12	12	24	15	85	0	3	5	4	1	3	16
Guesthouse	1	2	3	1	4	2	13	0	0	0	2	0	0	2
Secondary dwelling	0	0	1	1	0	1	3	0	0	0	0	0	0	0
Mobile home	2	6	9	8	1	11	37	1	0	0	1	1	1	4
Swimming pool/spa; resident. & comm.	3	5	5	7	7	8	35	0	0	0	0	0	1	1
Radio/cell tower	0	0	2	1	2	1	6	0	1	1	0	0	0	2
Wind/solar system	0	5	4	14	11	18	52	0	1	1	0	1	3	6

[a] The Coastal Zone is the boundary between these two planning areas (Figure 2-3).
[b] Source: Permit Tracking Summaries 2003–2008, accessed at: www.slocounty.ca.gov/planning/Permits/

2.2.3 Growth trends in San Luis Obispo County

The 2008 Growth Assessment states that between 2000 and 2007, two of every five new homes built in the unincorporated County were built in rural areas outside of the urban communities. If this trend continues, the County estimates that population in the rural areas of the County will increase by 7,900 to 15,800 individuals by 2030. According to the County's 2006 General Plan Annual Progress Report, the Adelaida Planning Area is projected to see a population increase of 2,241 between 2010 and 2030. Table 2-1 of completed projects in the Adelaida Planning Area from 2003 through 2008 shows a trend toward water-intensive wineries and residential uses. To date, however, that development has occurred primarily on the eastern side of the Santa Lucia range on rural lands outside the urban areas of Paso Robles, Templeton, and Atascadero.

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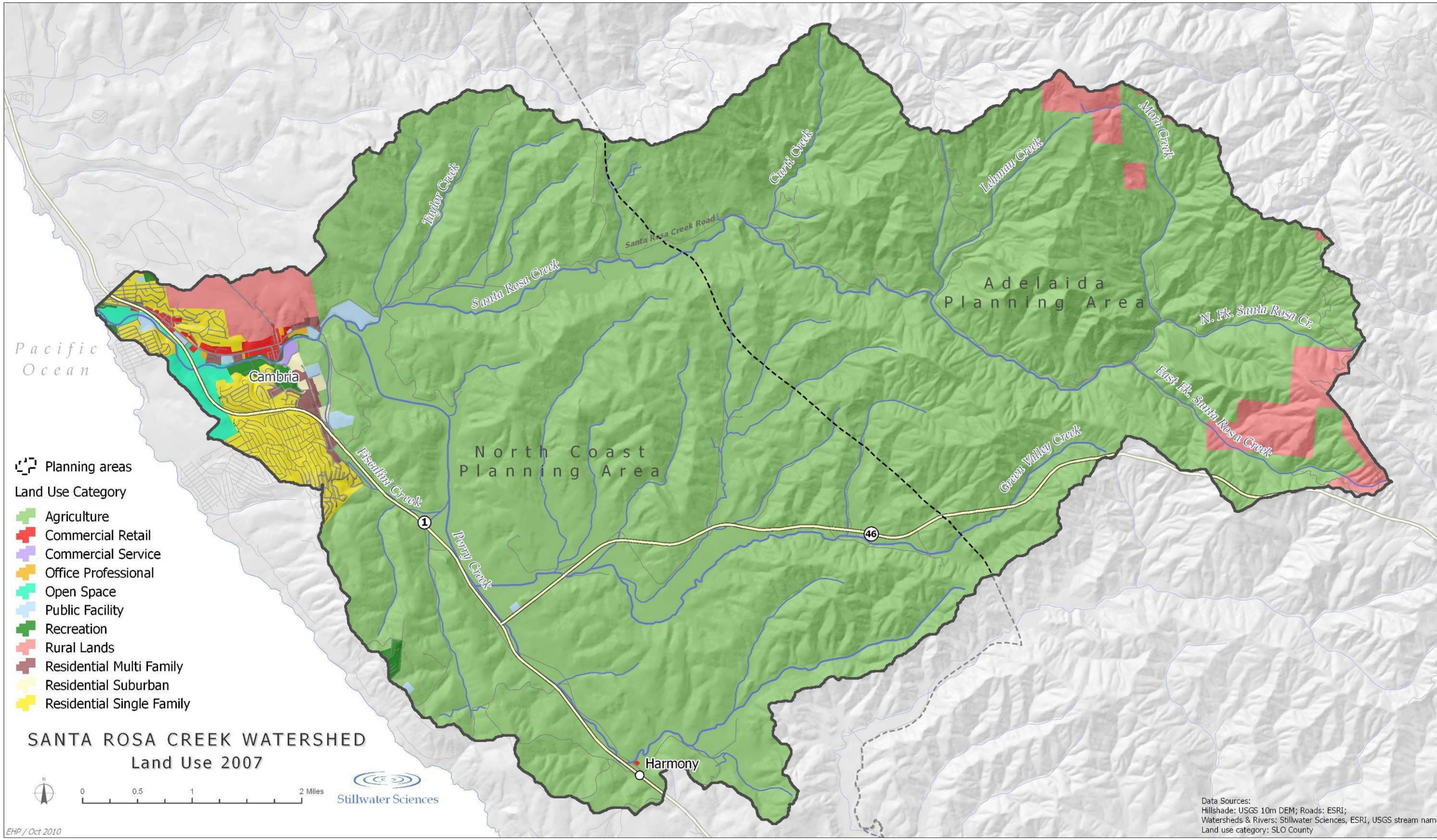

Figure 2-3. Land uses within the Santa Rosa Creek watershed.

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A steady increase in the numbers of people choosing to live in the rural areas of the County is fueled in part by the existence of underlying antiquated subdivisions[2], of which there are over 3,500 in the unincorporated County area. Many of these parcels are capable of being developed through the process of obtaining certificates of compliance (legal documents that certify compliance of an underlying parcel with the California Subdivision Map Act). And while in 1977 approximately 80% of these parcels were farmed or grazed with only a small fraction of the parcels developed at that time, since the year 2000 over 600 of these parcels have been developed with homes (San Luis Obispo County 2009).

2.2.4 Rural to urban conversion

City and Regional Planning research indicates that there is a typical sequence to land use changes over time as rural lands are converted to urban uses (Briassoulis 2000). Portions of the lower Santa Rosa Creek watershed exhibit this shift, as large ranches have been subdivided and converted to dairy and row crops and urban land uses. This conversion can degrade the quality of watershed resources and it is often the degree and balance of disturbance in urban land uses versus rural that is of consequence. Said differently, rural land use development may impact watershed health in a dispersed manner whereas urban influences are more concentrated.

As rural lands are developed, shifting from grazing to intensified agriculture and/or urban uses, water consumption generally increases, rainfall runoff volume and velocity increase as impervious surfaces increase, groundwater recharge/infiltration decreases, bank erosion and channel incision may increase, and tributary and mainstem peak flow volumes, and therefore flood risk, increase during the rainy season. In the dry season, base flow is reduced as groundwater is pumped year-round.

Although urbanization in the Santa Rosa Creek watershed is limited to the relatively small community of Cambria and surrounding neighborhoods, several of the impacts associated with land use shift have been documented in the lower watershed. These include increased municipal water demand that can reduce instream flows (see Section 2.6), additional instream infrastructure that reduces habitat quality (see Section 2.7), and increased rainfall runoff and associated impacts to water quality and drainage (see Section 2.8). Urban development of the watershed has been limited by land use planning regulations and water supply (see Section 2.2.5 below), and is constrained to the downstream end of the watershed, where the ill effects associated with urbanization are limited to a small portion of the watershed. Changes in land use controls could, however, lift some of the current constraints to urbanization (see Section 2.2.5 below). It will be important to recognize and prevent or mitigate land use changes that could exacerbate the ill effects associated with urbanization or promote the expansion of such land use changes further up the watershed.

2.2.5 Land use controls

While a portion of the lower watershed has already been developed, outside of this area the pattern of rural to urban land use conversion is currently limited in the majority of the Santa Rosa Creek watershed. This is due to a variety of planning related factors, such as the Coastal Act, Local Coastal Program, Williamson Act, and agricultural and rural land use designations that limit development, and physical factors, such as the limited supply of water and road access to

[2] Underlying antiquated subdivisions are parcels created before modern land-use planning laws. These parcels underlay larger parcels created by the California Subdivision Map Act and they are antiquated because they were created before the Map Act was passed.

most of the watershed. Several of these land use control are, however, at risk of being lifted, which could increase the conversion of rural land uses to intensified agriculture and/or urban uses and, as described above, result in serious impacts to the ecological conditions of the watershed.

A major difference in land use controls within the two planning areas of the watershed is the resource protections provided by the California Coastal Act and the Local Coastal Program that apply only to the lower watershed in the North Coast Planning Area (see Figure 2-3). The Coastal Act requires protection of agricultural resources and environmentally sensitive habitat areas and provides an additional layer of development permit review by the California Coastal Commission. In addition, land use plans in the coastal zone must be consistent with the resource protection requirements of the Coastal Act and must be certified by the Coastal Commission. By contrast, the upper half of the watershed is not subjected to the same state agency scrutiny during the planning process or the development review process. Land uses are also tracked by the Coastal Commission during periodic reviews that provide additional data that are not available for inland portions of the upper Santa Rosa Creek watershed.

The geographic dividing line of the Santa Lucia Mountain ridge separates the development patterns in the upper Santa Rosa Creek watershed from other areas within the Adelaida Planning Area. While the majority of the planning area spreads east and south from the ridge to include land adjacent to the urban communities of Paso Robles, Templeton, Atascadero, Cayucos, and Morro Bay, the upper Santa Rosa Creek watershed is remote from urban communities other than Cambria and is connected to Cambria only by Santa Rosa Creek Road which at some points narrows to a single lane. Santa Rosa Creek Road is the only collector road in the watershed (Adelaida Planning area Circulation Map). Therefore, data representing the overall Adelaida Planning Area do not reflect the coastal influences, geographic conditions and development patterns that have occurred in the upper Santa Rosa Creek watershed and cannot be relied upon to show development trends in that area. The development projects completed between 2003 and 2008 in the Adelaida Planning Area (Table 2-1) do not represent the development that has occurred on the upper slopes of the Santa Rosa Creek watershed. For example, there are only two wineries in the Santa Rosa Creek watershed, while data for the Adelaida Planning Area show 36 new wineries completed between 2003 and 2008 (Table 2-1).

Development on the majority of privately-owned currently undeveloped parcels in the watershed is limited under Williamson Act contracts (Figure 2-4). The Williamson Act, the common name for the California Land Conservation Act of 1965, enables local governments to enter into contracts with private landowners for the purpose of restricting specific parcels of land to agricultural or related open space use. In return, landowners receive property tax assessments which are much lower than normal because they are based upon farming and open space uses as opposed to full market value. If Williamson Act contracts are allowed to expire one of the primary land use controls in the watershed will be lifted, and large parcels, particularly in the Adelaida Planning Area where California Coastal Act and Local Coastal Program protections do not apply, may be at risk of subdivision and development.

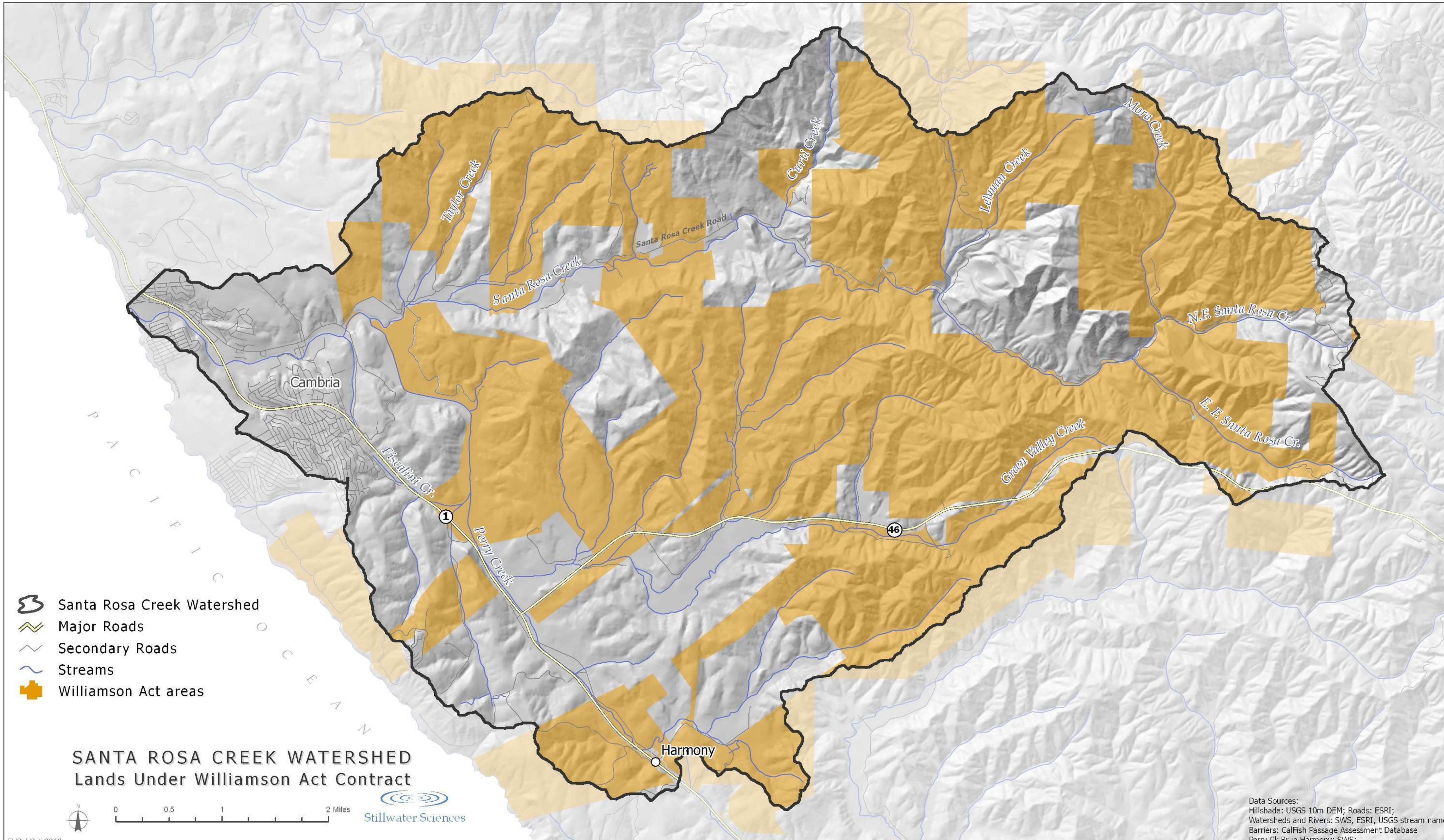

Figure 2-4. Land under Williamson Act contract within the Santa Rosa Creek watershed.

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The CCSD and U.S. Army Corp of Engineers (USACE) are currently assessing the feasibility of a seawater desalination plant at the mouth of Santa Rosa Creek. The desalination plant would improve water supply reliability in the CCSD service area, particularly in dry years, by augmenting the San Simeon and Santa Rosa Creek groundwater aquifers that are currently relied upon (CCSD 2008). At the December 9, 2011 California Coastal Commission hearing the USACE was unanimously denied a Coastal Consistency Determination by the Commission to conduct geo-technical drilling in the vicinity of the mean high tide line at the mouth of Santa Rosa Creek. The Commission determined that the proposed geo-technical study site was inappropriate because the mouth of Santa Rosa Creek and the associated lagoon are among the most protected and sensitive habitats on the Central Coast. If ultimately approved, however, a desalination plant could remove one of the key physical controls on population growth in the watershed and surrounding areas. The proposed desalination plant has the potential to produce unlimited amounts of water; however, as currently proposed it would produce 602 acre-feet of water per year. The plant would consist of subterranean seawater intake, pumping and pipeline facilities to transport the seawater to the desalination plant, reverse osmosis desalination treatment, a groundwater blending system, facilities to pump the treated water into the water supply distribution system, and disposal of desalination effluent into the ocean. The site currently being considered for intake and effluent disposal is the beach at the mouth of Santa Rosa Creek (CCSD 2008). Potential impacts related to construction and operation include: disturbance and mobilization of mercury, adverse impacts to protected species such as steelhead, California red-legged frog, and tidewater goby (California Coastal Commission 2010), and drawdown of water levels in the lagoon. To avoid influencing lagoon water levels, the beach wells must be constructed more than 500 feet from both the Santa Rosa and San Simeon creek lagoons (North Coast Engineering, Inc. 1993).

The growth-inducing impacts of a future water supply project such as a desalination plant and the additional water supply it will create, were analyzed in CCSD's Water Master Plan program-level Environmental Impact Report, which was certified by the CCSD Board of Directors on August 21, 2008 (R. Gresens, pers. comm., 2012). The CCSD operates a voluntary Buildout Reduction Program inside the town of Cambria, designed to reduce water demand by retiring and merging buildable lots. In addition, CCSD must also abide by conditions in San Luis Obispo County's (2008) North Coast Area Plan, which states that for any major public works water supply project to support new development within the CCSD service area "[t]he maximum service capacity of the project will not induce growth inconsistent with the protection of coastal resources and public access and recreation opportunities" and that "[t]he project shall assure that CCSD water withdrawals from Santa Rosa and San Simeon Creeks will be sufficiently limited to protect: (1) adequate instream flows necessary to support sensitive species and other riparian/wetland habitats within the reach of the streams affected by CCSD pumping; (2) underlying groundwater aquifers; and (3) agricultural resources." The North Coast Area Plan, however, anticipates that desalination will be a source of water for development outside of Cambria and, as such, the potential for growth-inducing impacts associated with a desalination plant or other major water supply project would primarily be outside of the current CCSD service area. By ordinance, CCSD accepts and processes applications for delivery of water outside of Cambria based on availability of water, which would notably increase if a desalination plant or other major water supply project becomes operational. In 2006, Measure P-06 was passed by CCSD-district voters which requires a majority vote of the CCSD electorate to extend potable water service outside of 2006 CCSD boundaries. Measure P-06 further requires an environmental review under the California Environmental Quality Act and an amendment to the Water Master Plan before potable water service is extended beyond 2006 CCSD boundaries.

2.3 Climate

Coastal watersheds along the western flank of the Coast Ranges experience a two-season Mediterranean-type climate, with wet cool winters and dry warm summers. The regional climate is controlled by the North Pacific High, a high pressure system resting over cold upwelling waters of the eastern Pacific, while the local climate is controlled by the watershed's topography and proximity to the ocean (Carle 2006). The Pacific High system deflects storms from reaching the California coast during summer months, resulting in dry westerly winds blowing over cold ocean water and often producing fog. In the Santa Rosa Creek watershed, this fog belt typically extends inland 8 miles from Cambria. During winter, the Pacific High retreats to the south resulting in high rainfall in California concentrated between November and April. Overall, the California coast experiences highly variable annual rainfall depending on each storm's frequency and magnitude on the landscape relief. Mean annual rainfall across the watershed varies between 21 and 37 in (53 and 94 cm), as reported by the U.S. Department of Agriculture (1971–2000) and San Luis Obispo County Division of Public Works (1954–2008) (Figure 2-5). A clear pattern of increased rainfall with elevation is expressed across the watershed, as the lowlands near Cambria, including much of Perry and Green Valley creeks, receive nearly half the rainfall received in the headwaters of Santa Rosa Creek.

Periodicity in the pattern of the wet/dry years in California is correlated to the El Niño–Southern Oscillation (ENSO) climatic phenomenon. ENSO is characterized by warming and cooling cycles (oscillations) in the waters of the eastern equatorial Pacific Ocean. Specifically, El Niño episodes are initially driven by abnormally low atmospheric pressures in the eastern Pacific, resulting in lower upwelling rates of cold ocean waters and, therefore, a persistence of warmer surface water temperatures (Kousky and Bell 2000). Ultimately, the warmer waters lead to increased precipitation along the eastern Pacific, extending up to California. ENSO cycles typically have a 1- to 1.5-year duration and 3- to 8-year recurrence interval. ENSO-induced climate change occurs on a multi-decadal time scale that is consistent with the recent shift from a relatively drier climate (averaged over the period 1944–1968) to a relatively wetter climate (averaged over the period 1969–1995) in North American's Pacific region (Inman and Jenkins 1999). The most recent El Niño events occurred in water years 2007 and 2010 (NOAA 2009a).

A long-term record of annual precipitation totals in San Luis Obispo County (SLO Cal Poly rain gauge #1.0) from 1870 to present day is presented in Figure 2-5. The precipitation record indicates periods of cumulative wetter and drier periods in the region, where most wet years coincide with large floods (see Section 2.6).

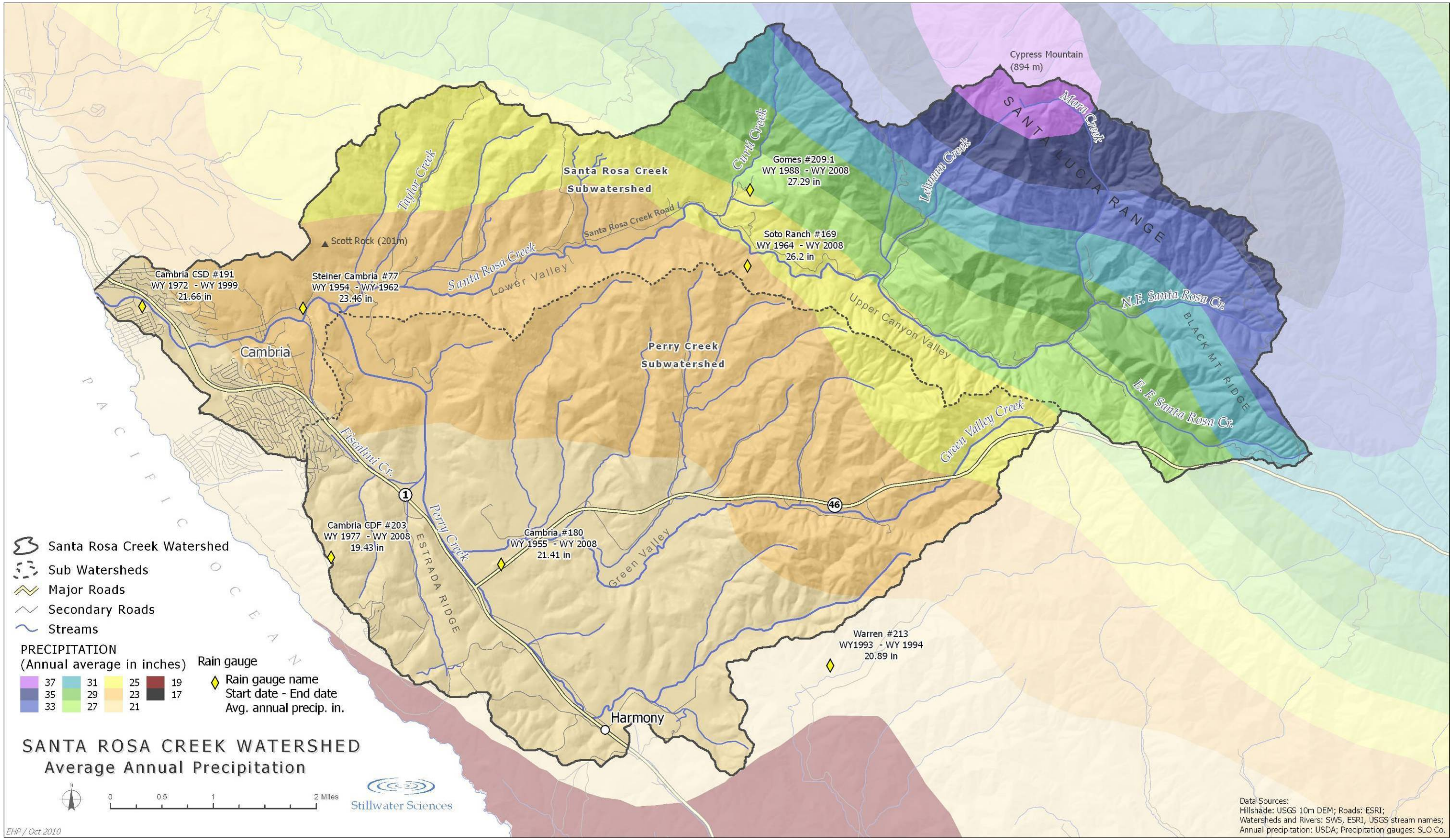

Figure 2-5. Distribution of average annual precipitation in the Santa Rosa Creek watershed. Precipitation contours represent the period of 1960–2001. Rain gauge stations representing various years of data shown for reference.

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In the future, the Santa Rosa Creek watershed is likely to be affected by changes in temperature, precipitation, and sea-level resulting from global warming. Predictions of climate change in California in the next century include warmer winters (by 5–6° F), slightly warmer summers (by 1–2° F), and increased winter precipitation (primarily as rain rather than snow), particularly in the mountains (Field et al. 1999). ENSO events may increase in intensity and/or frequency (Field et al. 1999). In central and southern California the change in precipitation timing is expected to lead to increased winter runoff, decreased summer stream flow, and changes in the frequency and/or intensity of severe storms, droughts, wildfires, and flooding. In addition, global climate change is expected to result in sea-level rise. Based on a set of climate scenarios prepared for the California Energy Commission, Cayan et al. (2009) project that, under medium to medium-high greenhouse gas emissions scenarios, mean sea level along the California coast will rise from 3–5 ft (1–1.4 m) by the year 2100. In the Santa Rosa Creek watershed, such a rise in sea-level would put new areas at risk of flooding, increase the likelihood and intensity of floods in areas that are already at risk, and accelerate shoreline recession due to erosion (Figure 2-6) (Heberger et al. 2009). Such predictions stress the importance of floodplain and coastal conservation, ecosystem restoration, and water conservation to increase the adaptability and resiliency of the watershed to respond to these changes, particularly when considered in conjunction with future land uses and human impacts to the watershed.

Figure 2-6. Predicted flood risk in 2100 in the Cambria area under a 1.4-m sea-level rise scenario. Light blue area is the current coastal base flood (approximate 100-year flood extent), dark blue area is the predicted coastal base flood under sea-level rise (current plus 1.4 m), yellow line is the predicted landward limit of erosion high hazard zone in 2100, and red line is Highway 1. Map used with permission from the Pacific Institute, Oakland, California.

2.4 Geology, Tectonics, and Soils

The Santa Rosa Creek watershed lies along the Santa Lucia Mountain range near the southern end of the geologically distinctive Coast Range geomorphic province. Orientated with the overall NW-SE trending grain of the California topography, the Santa Lucia range follows the southern Coast Range for 93 mi (150 km) between Monterey Bay to the north and the San Rafael Mountains to the south near Santa Barbara. The province resides within a tectonically active zone composed primarily of right-lateral strike-slip (horizontal sliding motion) faults separating the Pacific and North American plates. At the axis of this zone is the 600-mile-long (1,000-km-long) San Andreas Fault, which lies 37 mi (60 km) to the east of the Santa Rosa Creek watershed. Overall, this tectonically and geomorphically active province exhibits intermittent seismicity and asymmetrical drainages offset by faulting. Additionally, the presence of relatively weak rocks at higher elevations in the Santa Rosa Creek watershed has led to naturally high sediment delivery rates, or sediment yields, from those higher relief and steeper tributaries (see Section 2.5).

Much of the Coast Range province, and especially the Santa Rosa Creek watershed, is composed of old, weathered, and partially metamorphosed sedimentary rocks originally formed during the Mesozoic (200 to 100 million years ago [Ma]) and Cenozoic (65 to 25 Ma) eras (Chipping 1987). Today, the majority of the Santa Rosa Creek watershed is predominately (~50%) composed of Franciscan mélange: a mix of hard graywacke (sandstone) and weak, sheared argillite (silt/claystone) (Chipping 1987, Dibblee 2007a 2007b) (Figure 2-7). Following the complete subduction of the Farallon Plate beneath the North American Plate, the eventual transition to a transform (strike-slip) plate boundary began about 25 Ma with the gradual contact between the northwest-moving Pacific Plate and the southeast-moving North American Plate (Atwater and Molnar 1973). This transition marked a geologically brief period of coastal volcanism which locally produced the erosion-resistant Cambria Felsite rocks, as seen today at Scott Rock located east of Cambria near Taylor Creek (Dibblee 2007a). Other volcanic rocks formed during this period include the now highly weathered basalts and hardened tuffs (solidified volcanic ash) of the Obispo Formation that run along a northwest-trending band in the upper watershed. Terrestrial and marine sedimentary rocks formed during this period include a mix of hard, coarse-grained sandstones and weak, fine-grained shales.

The Coast Range orogeny, or mountain-building process, began during the late Pliocene and Pleistocene epochs (≤4 Ma) and continues today. Regional uplift has been driven by crustal convergence that occurs where subtle NW–SE trending bends along the active transform fault zones forcing materials in between the larger faults to "pile up," thereby creating the upland areas of the watershed. Obvious evidence of geologically recent uplift activity is the existence of Pleistocene marine terraces situated along the coastline and the lower watershed. Tectonic movement here may explain the watershed's unusual drainage pattern of being split in two primary halves—Santa Rosa Creek and Perry Creek sub-watersheds—where Perry and Green Valley creeks may have once flowed directly to the coast but were eventually "captured" by Santa Rosa Creek as uplift and transverse migration of the elevated landscape re-directed Perry and Green Valley creeks northward. Coincident with the Coast Range uplift period, the valley floors along Santa Rosa, Perry, and Green Valley creeks have accumulated unconsolidated alluvial and stream-terrace deposits as the uplifted landscape has eroded and delivered its sediments to the valley floors over time. It is within these sediments that the watershed's groundwater basin has developed, which currently serve as a primary water supply source to urban areas and land use activities in the watershed (see Section 2-6).

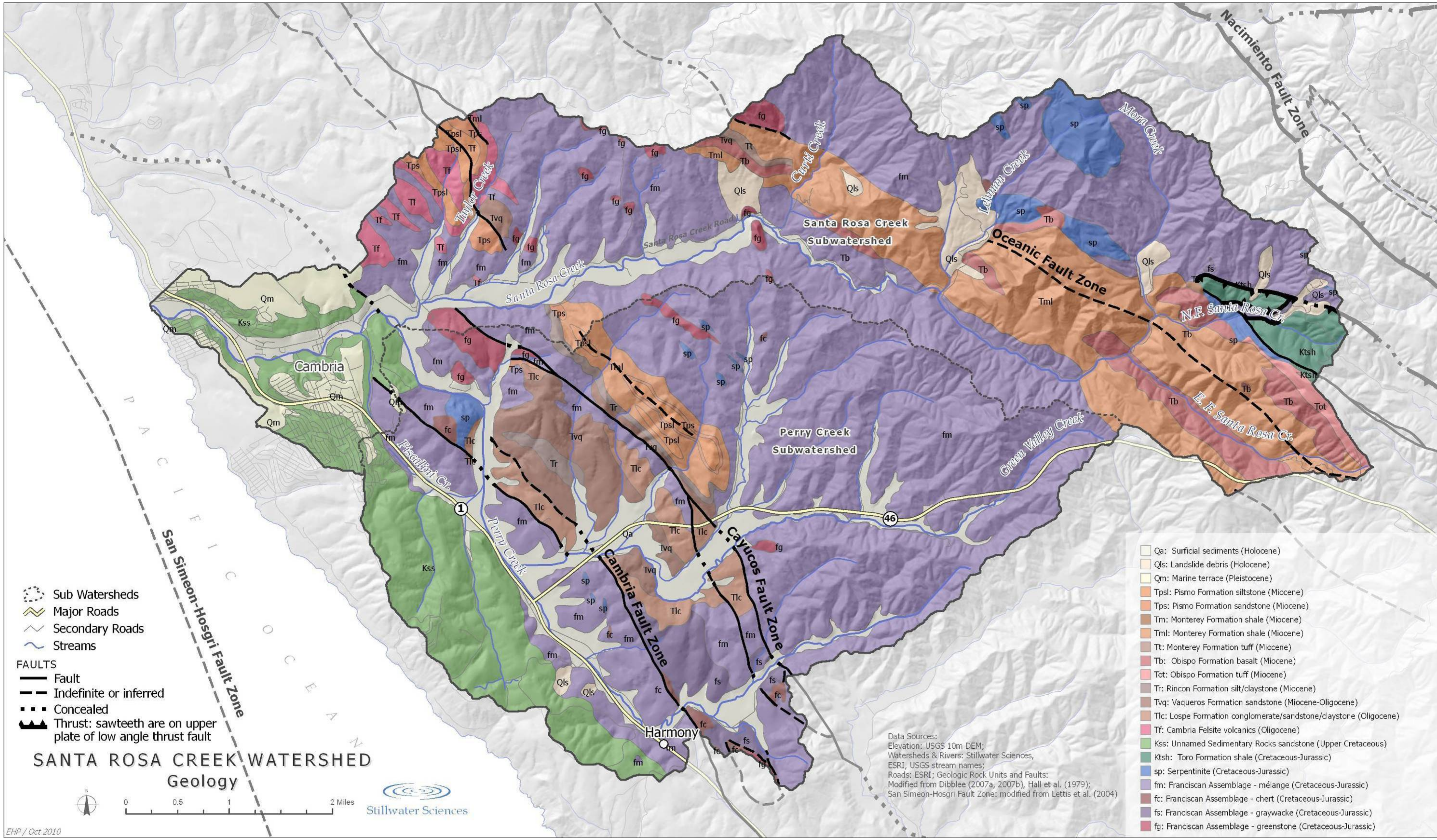

Figure 2-7. Santa Rosa Creek watershed geology.

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With continuous landscape uplift to drive hillslope processes and large areas of highly sheared metamorphic and sedimentary rock units now hundreds of meters above the valley bottoms, the Santa Rosa Creek watershed has geologic characteristics commonly associated with high rates of erosion. Field observations indicate that areas in the watershed displaying relatively high hillslope erosion are chiefly underlain by the fine-grained and easily eroded siltstone and mudstone of the Pismo (shale member), Monterey, Rincon, and Toro formations found traversing the watershed close to the two primary fault traces, and the highly fractured graywacke/argillite of the Franciscan mélange unit that is found throughout the watershed (Figure 2-7).

The sedimentary, metamorphic, and volcanic rocks of the Santa Rosa Creek watershed provide the parent material for much of the watershed's soils, and are one of the primary controls on soil texture and mineral content. As such, topographic form, rainfall runoff patterns, groundwater percolation rates, potential for erosion, and vegetation distribution are strongly influenced by geology. For this reason watershed geology, rather than soils, were used as the basis of the assessment of watershed geomorphology and hillslope sediment production estimates (see Section 2.5 for further discussion). Over 60 different soil types occur in the watershed, most of which are clay to sandy loams (NRCS 1977 and 1984). Additional details on watershed soils are summarized in TLCSLOC (2010).

2.5 Geomorphology

As all aquatic habitat is intimately linked to creek morphology and process, it follows that the habitat also responds to the flux created by sediment sources and storage sites within a watershed. They are particularly affected by changes away from "normal" conditions. For this reason, aquatic habitat is closely linked to geomorphic processes and the influence of human activity. The benefits and hazards of living near to a stream are also linked strongly to changing channel morphology and process: significant erosion of channel banks is often perceived as land loss by the owner, while sediment deposition raises channel bed elevations and makes the adjacent floodplain more prone to flooding. As such, understanding geomorphic processes and their alteration is also central to stream channel and watershed management in general.

A watershed-wide geomorphology study was conducted in 2009–2010 to provide information on the physical watershed and stream channel processes for the development of the watershed management plan. The study subdivided the lower 13 miles (22 km) of Santa Rosa Creek into upper, middle and lower reaches (Figure 2-8), which are referred to throughout this document[3]. The lower reaches begin at the river mouth (stream mile 0) and extend upstream to the confluence with Perry Creek (stream mile 3); the middle reaches extend from the Perry Creek confluence upstream to Mammoth Rock (stream mile 7); and the upper reaches extend from Mammoth Rock to stream mile 14. A detailed technical report of this study is presented in Appendix A, while the major findings have been summarized below.

From the chronology of watershed changes described in Section 2.1 and summarized in Figure 2-1, there are two time periods in recent history that likely had the greatest effect on watershed geomorphic processes: early land clearing in 1860–1880 and population growth, development, and road building from 1950–1990. Overall, the two periods both led to increased flashiness of streamflows, proportionally more rainfall entering the creek as runoff than from baseflow, and increased sediment entering stream channels, especially fine sediment. In comparison, it is likely that land clearing for lumber and agriculture created more extensive geomorphic impacts,

[3] D.W. Alley & Associates (2008) and Nelson et al. (2009) both used different reach delineations for their steelhead monitoring and habitat typing. Reach delineation differences are described in more detail in Section 2.10.1.

including the majority of the over 1,000 gullies still evident across the watershed (see Figure 2-8), whereas the more recent impact of road and urban development primarily impacted Green Valley Creek and the lower reaches of Perry and Santa Rosa creeks.

2.5.1 Sediment production, transfer, and storage

Sediment refers to rock- and soil-derived material that ranges in size from clay to boulder, and includes cobble, gravel, and sand. Coarse sediment refers to gravel-sized material and larger (>2 mm in diameter) and overall has the greatest influence on the morphology of a stream channel (e.g., providing grade control, and forming bar-pool morphology). Fine sediment refers to clay-, silt-, and sand-sized materials (<2 mm in diameter), which in excess can have detrimental affects on aquatic habitat conditions. As a geomorphic unit, a watershed serves to transport sediment from its place of origin to an eventual place of lasting storage. In so doing, a distinctive relief is developed in the watershed that reflects the balance between long-term processes of tectonic uplift and rates of erosion driven by physical, chemical, and biological factors. This balance is generally achieved through the medium of moving water. Sediment sources are those sites predominantly characterized by erosion and often have steep slopes. Sediment storage, particularly in a small coastal watershed such as Santa Rosa Creek, occurs mostly offshore as sediment-laden water exits the watershed, but it also occurs where sediments are deposited on floodplains (where the material is termed alluvium) and at breaks to gentler hillslope gradients (termed colluvium). Connecting sediment sources with their sites of long-term storage is a flux of sediment transport through the watershed, typically occurring on a time scale from years to centuries. The flux of sediment is intermittent and driven mostly by large rainfall or streamflow events, and so most such "short-term" sediment transfer occurs along the creek channel. The exact locations of the short-term sources and storage sites of sediment can, however, be influenced as strongly by human activities as by natural factors. A typical short-term sediment source is the erosion of alluvial stream banks, representing the re-mobilization of previously stored sediment, while short-term sediment storage often occurs on the channel bed in the form of a wave of "excess" sediment deposited after a flood event. Therefore, the typical transfer of sediment through a watershed involves a flux in which changes to the creek morphology is an integral part.

Present day Santa Rosa Creek watershed is characterized, as are most other watersheds, by a wide variety of sediment sources that potentially affect management decisions. The predominant sediment sources and stores in the Santa Rosa Creek watershed, and the dynamics of sediment transfer, are summarized in Table 2-2 and the various source locations mapped in Figure 2-8 (additional detail is also available in Appendix A). The very steep hillslopes in the headwaters of Santa Rosa Creek (and some tributaries to Green Valley Creek) have naturally high sediment yields, and it seems likely that, in geomorphic terms, the historically-noted steelhead populations in the watershed result in part from the habitat created by the delivery of very coarse sediment from the upper reaches of Santa Rosa Creek. The other predominant sediment sources in the watershed have resulted primarily from previous land and channel management, and include gullying, stream bank erosion, and road-related erosion. These processes primarily involve the erosion of the landscape's soils and thus supply primarily only fine sediment to watershed channels.

Historical land clearing for lumber and agriculture is likely responsible for the majority of the over 1,000 gullies still evident across the watershed (Table 2-2, Figure 2-8). Fine sediment yields from these features most likely increased substantially during and following land clearing in the late 1800s and early 1900s, but have probably been reduced closer to historical levels in recent decades (see "Fine Sediment Delivery" in Figure 2-1). This is because, with the exception of development in Cambria over the past several decades, land uses across the vast majority of the watershed have not changed considerably over the past half-century (see Section 2.1). Outside of Cambria's urban boundaries, contemporary views of the landscape are very similar to historical views from the early 1900s, and the number and location of gullies have not noticeably changed since 1937 (see Appendix A for additional detail). Streambank erosion in Santa Rosa Creek is exacerbated by channel incision, a deepening of the channel often resulting from perturbations to the watershed. Channel incision is assumed to have occurred quickly after initial land clearing activities began in the mid-19th century. Over time, channel incision eventually causes the mass instability of channel banks, which then become a source of fine sediment. More recently, channel meandering in the incised reaches has resulted in the erosion of high alluvial banks of the former floodplain (Figure 2-8). Over 250 instances of recorded road-related erosion features exist in the watershed (Figure 2-8), which effectively deliver predominately fine sediment to the channel network. Erosion is focused along cut and fill sections of Highway 46 and Santa Rosa Creek Road, and to a lesser extent Highway 1.

Coarse sediment (gravel and larger) delivered to the mainstem Santa Rosa Creek appears to be delivered primarily from Lehman and Curti creeks in the upper reaches, and from the tributary that runs adjacent to Main Street in the lower reach. Fine sediment (sand and silt) appears to be predominantly derived from tributary sources such as Curti Creek and Perry Creek, which delivers sediment to the lower reach, and local in-channel sources such as bank erosion in the middle reaches.

Table 2-2. Sediment sources, storage, and transfer dynamics in the Santa Rosa Creek watershed.

Location	Process/Description
Sediment Sources	
Landslides	Only 17 landslides are recorded in the areas of watershed without canopy cover, but they are individually high-yielding. Landslides are concentrated in high relief, steep-sided areas, primarily in the headwaters of Santa Rosa Creek. Landslides erode previously stored colluvium on hillslope swales and, potentially, weathered bedrock closer to the failure plane. Mixed-load sediments released as part of large deep-seated landslides, as mapped in geologic maps of the watershed (see Figure 2-7), may reside for years to centuries before eventually being completely delivered to the stream network.
Gullies and rills	Gullies and rills are numerous throughout the watershed. Over 1,000 gullies have been recorded and many have evidently been present since the late 19th century and so may be past their sediment production peak. These features primarily result in the production of fine sediments as they erode soil-mantled, moderately steep hillslopes and, because they are often connected directly to the stream network, a near 100% delivery ratio of sediment can be inferred. Gullying in the watershed is likely to have resulted in far higher volumes of fine sediment delivered to the channel network during and following their formation, which have likely been reduced closer to pre-development levels in recent decades.
High yielding Geomorphic Landscape Units	Areas of the watershed with the highest sediment yield potential are primarily situated on steep, grassland and barren hillslopes composed of weak rock. These areas result in the production of both coarse and fine sediments, but fine sediments are probably derived preferentially from the widespread Franciscan mélange terrain. Sediment delivery from these Geomorphic Landscape Units (GLUs) (see Figure 2-8 and Appendix A) is likely high given the steep hillslopes and confined and steep channels.
Creek incision	Channel incision in the major streams is assumed to have occurred quickly after initial land clearing activities began in the mid-19th century. Incision is widespread but focused in the middle reaches[c] of Santa Rosa Creek and the middle and upper reaches of Perry and Green Valley creeks. Incision initially releases channel bed sediments which may be relatively coarse.

Location	Process/Description
Bank erosion of high bluffs following incision	Over time, channel incision eventually causes the mass instability of channel banks of the former floodplain which then makes them a highly effective source of finer sediment as the channel widens. More recently, meander activity as the incised reaches recover their equilibrium has allowed erosion of high alluvial banks of the former floodplain, causing a net sediment supply biased towards fine sediment.
Road-related erosion	Over 250 instances of recorded road-related erosion features exist in the watershed. Erosion is focused along cut and fill sections of Highway 46 and Santa Rosa Creek Road (and to a lesser extent Highway 1). Because road drainage frequently serves channel road runoff from the road surface efficiently to the channel network, sediment (particularly fine sediment) is also delivered very effectively to the channel network.
Sediment Storage	
Lower Perry Creek in the vicinity of the former Estrada Lake	Historically, Estrada Lake at the downstream end of Perry Creek probably trapped all coarse and most fine sediments delivered by the contributing streams, meaning that few sediments from the Perry Creek sub-watershed ever reached Santa Rosa Creek. Subsequent draining of the lake to create a trapezoidal channel permitted the transport of sediment, especially fine sediment, from the Perry Creek sub-watershed into Santa Rosa Creek. Subsequent incision of the lowest reach of Perry Creek must have resulted in the remobilization of former lake sediment (i.e., fine, organic-rich sediment). The broad-bedded, low gradient ditch farther upstream still favors the deposition of coarse sediments before reaching Santa Rosa Creek, and a noticeable fining of bed material occurs on Santa Rosa Creek downstream of the Perry Creek confluence.
Water storage ponds	There are over 40 small water storage ponds throughout the watershed, with a greater proportion in the Perry Creek sub-watershed (Figure 2-8). They regulate 8% of the watershed area but are likely to have low sediment-trapping efficiencies, trapping primarily a small amount of coarser-grained sediments.
Channel bed in upper reaches	Field evidence indicates temporary storage of coarse sediments delivered from the steep, high relief tributary sub-watersheds (e.g., East Fork Santa Rosa and Curti creeks) into mainstem Santa Rosa Creek. Along the mainstem, there is also field evidence for the temporary storage of coarse material in channel and floodplain locations. Remobilization of the coarse sediment occurs during high flow events with material either wholly entrained or abraded into finer, more easily-transportable particles.
Channel bed in lower reaches	While lower gradient reaches are frequently characterized by finer sediment beds and sediment deposition, field evidence of short-term storage of fine material on the channel bed may reflect high rates of fine sediment supply to the lower reaches, especially from the Perry Creek sub-watershed.
Transfer Dynamics [a]	
Upper reaches	The upper reaches are very capable of mobilizing the median grain size (~2–3 in [~50–90 mm]) of the channel bed during even moderate flow events and the channel morphology rates as highly active. Fine sediment is transferred quickly from the reaches, whereas field evidence indicates the temporary storage and probable breakdown of very coarse material.
Middle reaches	Middle reaches are competent to transport the median grain size (~0.7–2 in [~20–50 mm]) of the channel bed during even moderate flow events and the channel morphology rates as highly. This stream power is borne out by increased sinuosity in these reaches since the early 20th century in which coarse sediment is deposited in the form of channel bars and larger volumes of fine sediment are derived from the high banks of the former floodplain surface.
Lower reaches	Lower reaches are competent to transport the median grain size (~0.2–1 in [~5–45 mm]) of the channel bed during even moderate flow events and the channel morphology rates as highly active. These reaches exhibit unusually high stream power for such low gradient reaches and may reflect bank protection which prevents the exchange of sediment from channel banks and prevents channel widening in response to flood events.

[a] See Figure 2-8 for locations of Santa Rosa Creek reaches.

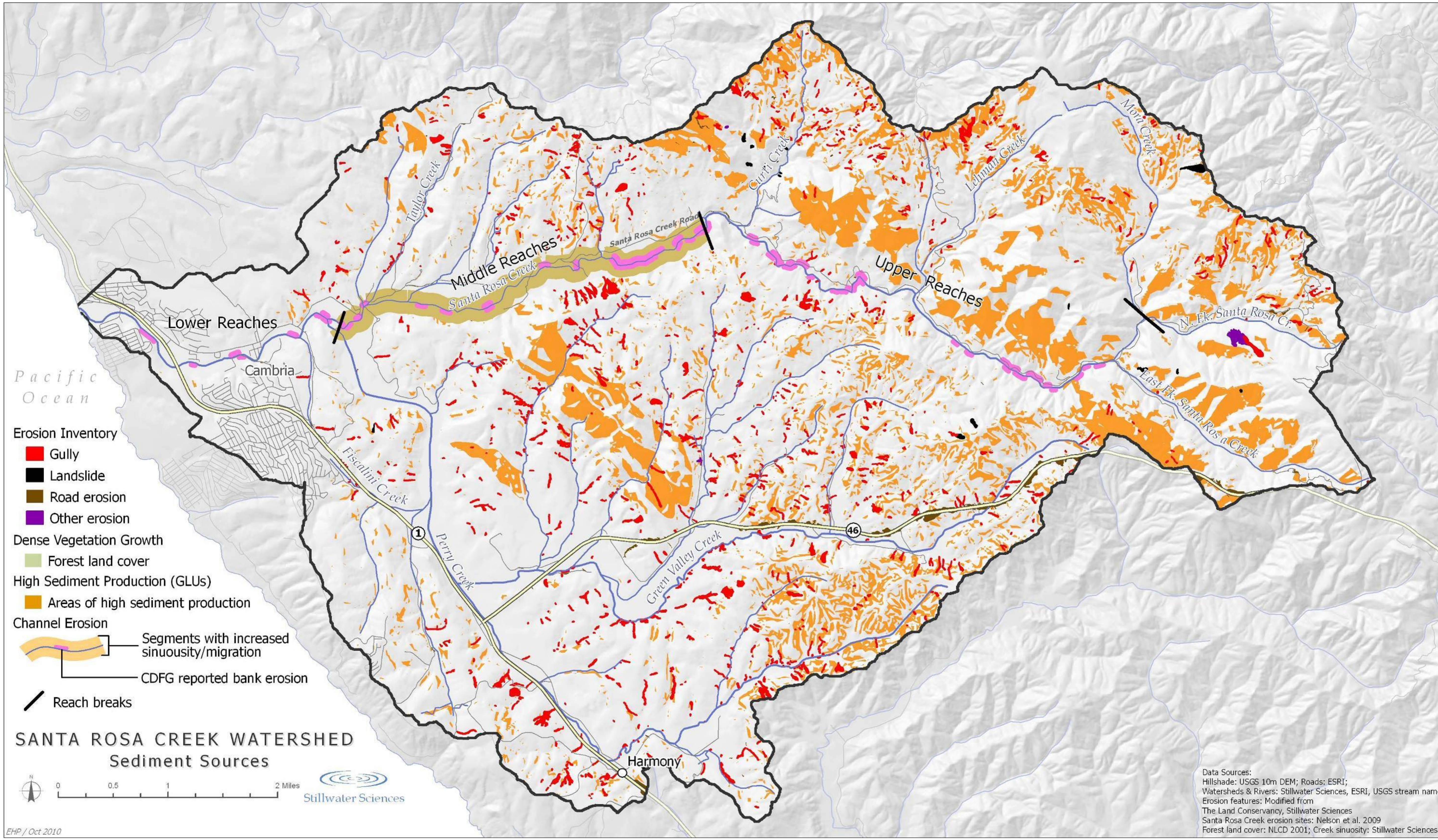

Figure 2-8. Sediment source and transfer areas in the Santa Rosa Creek watershed.

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2.5.2 Channel morphology

Understanding the character of the creek morphology and its sediment is a fundamental component in understanding how fluvial processes will affect the creek, the likely extent and availability of aquatic habitat, the extent of human impacts on the creek, and should be used to devise appropriate management actions into the future. Conditions in the upper, middle and lower reaches of Santa Rosa Creek, the Perry/Green Valley Creek sub-watershed, and lagoon are summarized below.

Examples of conditions in the upper, middle, and lower reaches of Santa Rosa Creek

The upper reaches of Santa Rosa Creek are characteristic of a mountain river, with a steep, confined morphology and a boulder-cobble-gravel bed. Lehman and Curti creeks provide a relatively high supply of coarse to fine sediment to these reaches.

The middle reaches display the features of a classic alluvial channel, with a sinuous channel that meanders through deposited alluvium, and a cobble-gravel bed characterized by pool-riffle bedforms. The middle reaches transition from a highly incised reach with active bank erosion and high sediment input at its upstream extent, to a moderately incised and apparently less dynamic reach as the degree of channel confinement increases and bedrock control once again becomes an influence near the confluence with Perry Creek. Comparing aerial photographs from 1937 to 2007, there has been a significant increase in the sinuosity of the middle reaches (Figure 2-8). The increase in sinuosity of this incised reach is evidence that the channel is still recovering from the impact of land use change in the mid-19th century. Land clearing for lumber and agriculture changed rainfall-runoff dynamics by decreasing landscape surface roughness (i.e., vegetation removal), thereby increasing the stream power in the creek for a given rainfall intensity and duration (i.e., increased hydrograph “flashiness”). Stream bank erosion in the middle reaches is one of the primary sources of fine sediment in Santa Rosa Creek.

Bedrock control returns at the junction with the lower reaches which have a sand-gravel bed and are moderately confined by terrain and development and show signs of aggradation before becoming tidally influenced near the low-gradient creek mouth (described in more detail below). Sediment delivered to the lower reaches from upstream Santa Rosa Creek, Perry Creek, and from local tributaries has resulted in a large amount of stored sediment in the reach. Banks are relatively stable, not least where extensive riprap protection exists.

Perry Creek enters Santa Rosa Creek approximately 2 mi (3 km) upstream of the Highway 1 Bridge and is the largest tributary. It is characterized by a moderately confined channel with finer bed sediment that flows approximately 10 mi (16 km) from the town of Harmony downstream to the confluence with Santa Rosa Creek. Lower Perry Creek was channelized from the former Estrada Lake and begins as a trapezoidal cut roughly paralleling Highway 1 while the lowest reach is incised into the organic-rich sediments of the former lake bed. The major tributary of Perry Creek is Green Valley Creek, which enters approximately 5 km upstream from Santa Rosa Creek confluence. Green Valley Creek originates in the steep, south-facing hillslopes along Highway 46, flows west through a confined alluvial valley, and enters Perry Creek in a broad alluvial zone near Highway 1. From limited field observation and available data, the upper reaches of mainstem Green Valley Creek appear somewhat similar to the upper reaches of Santa Rosa Creek in terms of valley confinement, but unlike Santa Rosa Creek, Green Valley develops a very wide alluvial valley through its middle and lower reaches. These reaches are highly incised and actively eroding their banks. Together, Green Valley and Perry creeks transport a mixed sediment load skewed toward finer sediment that includes silt/fine sand to fine cobbles, with the dominant sediment bed particle size ranging from coarse gravel in the upper reaches to fine gravel in the lower reaches. The Perry/Green Valley Creek sub-watershed is another of the primary sources of fine sediment in Santa Rosa Creek.

Perry/Green Valley Creek sub-watershed

The morphology of the coastal barrier lagoon at the mouth of Santa Rosa Creek is influenced by prevailing onshore currents and the effects of a rock island close offshore, by flows from Santa Rosa Creek, and by topographic constraints that are both geologic and a function of a landfill and riprap (at present-day Shamel Park). The upstream end of the lagoon is defined by the upstream extent of tidal influence, which is well below the Highway 1 Bridge. Overall, the lagoon responds largely to incoming streamflow including its pattern of seasonal breaching which is usually in response to overwash from ocean swells and to high flows from Santa Rosa Creek that overwhelm the capacity of the lagoon. The morphology of the lagoon has remained remarkably static since at least 1919, when the earliest USGS (1919) topographic maps and aerial photographs of the area are available (see Appendix A for additional detail). In a comparison of the lagoon over time, two main patterns are apparent: (1) the mouth has nearly always occupied its current position, on the north end of the beach adjacent to the marine terrace, with few exceptions (e.g., 1986); and (2) the amount of vegetation adjacent to the lower creek channel and lagoon has increased considerably since the earliest aerial photograph in 1937 (see Appendix A for additional details). It can be inferred from historical aerial photographs that neither net aggradation nor erosion has occurred during the past 70-plus years based on the following: (1) the lower stream channel and lagoon have maintained a relatively static position (i.e., no meandering or avulsions); and (2) the lower stream channel exhibits a similar, albeit transitory, bar and pool morphology. This has positive implications for the continued functionality of an ecologically-important lagoon.

2.6 Surface and Groundwater Hydrology

2.6.1 Hydrologic conditions

The climatic and hydrologic characteristics of the watershed produce a perennial flow regime along the majority of Santa Rosa Creek, while most tributaries, including Perry and Green Valley creeks, experience intermittent flows (Figure 2-9). Discharge has been measured over the past 50 years in both the upper (i.e., upstream of Mammoth Rock) and lower watershed (i.e., downstream of the Perry Creek confluence) by three gauges operating at different time periods (Table 2-3, Figure 2-9). During this time annual maximum flow has ranged by a factor of ~50 (60 to 3,350 cfs [1.7 to 95 $m^3 s^{-1}$]) in the upper watershed, and even more widely (<1 to <12,000 cfs [<0.03 to 340 $m^3 s^{-1}$]) in the lower watershed between water years (WY) 1962–1994, with the largest flow recorded at both locations occurring in WY 1969. The monthly streamflow patterns closely follow the seasonal precipitation patterns, where the highest flows occur in winter (Figure 2-10). In summer and fall, monthly average flows are often less than 5 cfs (0.14 $m^3 s^{-1}$), leaving many stream reaches dry, such as immediately downstream of Mammoth Rock where any surface water delivered from upstream reaches seeps down to the groundwater table (Figure 2-9).

The discussion of watershed hydrologic conditions in this section are informed by two stream gauges: one in the upper watershed (USGS 11142200) and one in the lower watershed at the Highway 1 Bridge crossing (SLO County Station 16). The active stream gauge at the Main Street Bridge crossing (SLO County Station 21) is not included because it was found to have large variations in reported annual maximum discharge, likely as a result of a lack of flow calibration. For consistency, this discussion focuses instead on the Highway 1 gauge in the lower watershed because it was used as part of a recent USGS groundwater recharge study conducted in the watershed (Yates and Van Konyenburg 1998).

Table 2-3. Stream gauges of Santa Rosa Creek.

Stream gauge ID	Stream gauge operator	Stream gauge location	Period of record (water years)
USGS 11142200	U.S. Geological Survey	0.4 mi (0.7 km) upstream of Curti Creek	1958–1972
SLO County Station 16	San Luis Obispo County Water Resources, Division of Public Works	Highway 1 Bridge	1976–1992
SLO County Station 21	San Luis Obispo County Water Resources, Division of Public Works	Main Street Bridge	1989–present

From the extended annual maximum flow data, the annual maximum discharge expected to be equaled or exceeded approximately once every 1.5 to 2 years (the statistical “bankfull” flow event) during this time period is approximately 760–1,100 cfs (21–30 $m^3 s^{-1}$) in the upper watershed and 1,800–2,700 cfs (50–78 $m^3 s^{-1}$) in the lower watershed. These “bankfull” flow events, which are geomorphically significant (see below), have the potential to occur in any month, but are more likely to occur in February or March (Figure 2-10).

Similar to other Coast Range watersheds, flood flows in Santa Rosa Creek typically increase, peak, and subside rapidly in response to high intensity rainfall. This hydrologic attribute is characteristic of a “flashy” hydrograph, whereby a rapid increase in discharge occurs over a relatively short time period with a quickly developed peak discharge in relation to normal baseflow (Ward 1978). Since 1958, large flood events have occurred in 1967, 1969, 1973, 1978, 1986, 1993, 1995, and 2005, frequently (but not always) corresponding with ENSO years (NOAA 2009b), which is consistent with an understanding that ENSO years in the Coast Ranges, especially south of 35ºN (Cambria is at 35.6ºN), are characterized by relatively high rainfall intensities, with rivers and streams exhibiting higher annual peak flows than they do in non-ENSO years (Cayan et al. 1999, Andrews et al. 2004).

Inundated floodplain during high flows

The Santa Rosa Valley groundwater basin underlies the Santa Rosa, Green Valley, and Perry creek valleys and is approximately 4,480 ac (7 mi^2) in size (Figure 2-9) (CDWR 2004). The groundwater storage capacity of the basin has been estimated at 24,700 ac-ft, although the actual volume is unknown and likely fluctuates in response to seasonal variations in rainfall and groundwater extraction (Yates and Van Konyenburg 1998, CDWR 2004). Groundwater levels in the basin are typically highest during the wet season, decline during the dry season, and then recover to higher levels in the following wet season. The groundwater basin is recharged primarily from seepage of surface flows in Santa Rosa Creek and its tributaries, deep percolation of precipitation, and residential/agricultural return flows (Yates and Van Konyenburg 1998). During dry periods, flows in Santa Rosa Creek can be insufficient to recharge the basin, which can lead to seawater intrusion and water quality degradation (Yates and Van Konyenburg 1998). Since the 1950's there has been one temporary seawater intrusion event (in 1961), although there is not a good understanding of why this occurred (Yates and Van Konyenburg 1998).

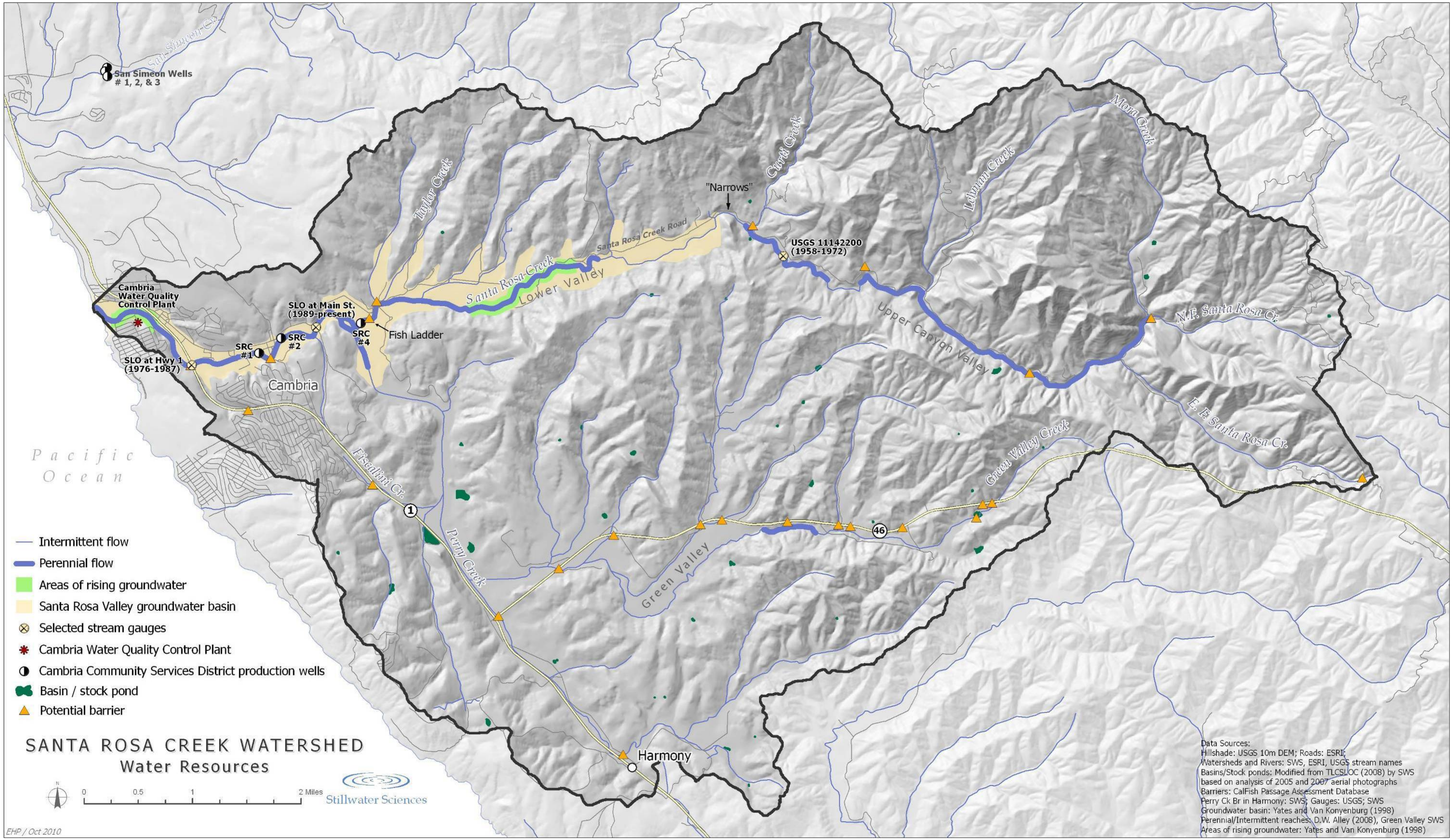

Figure 2-9. Water resources in the Santa Rosa Creek watershed. Perennial and intermittent streams, groundwater basin, and stream gauge locations are shown.

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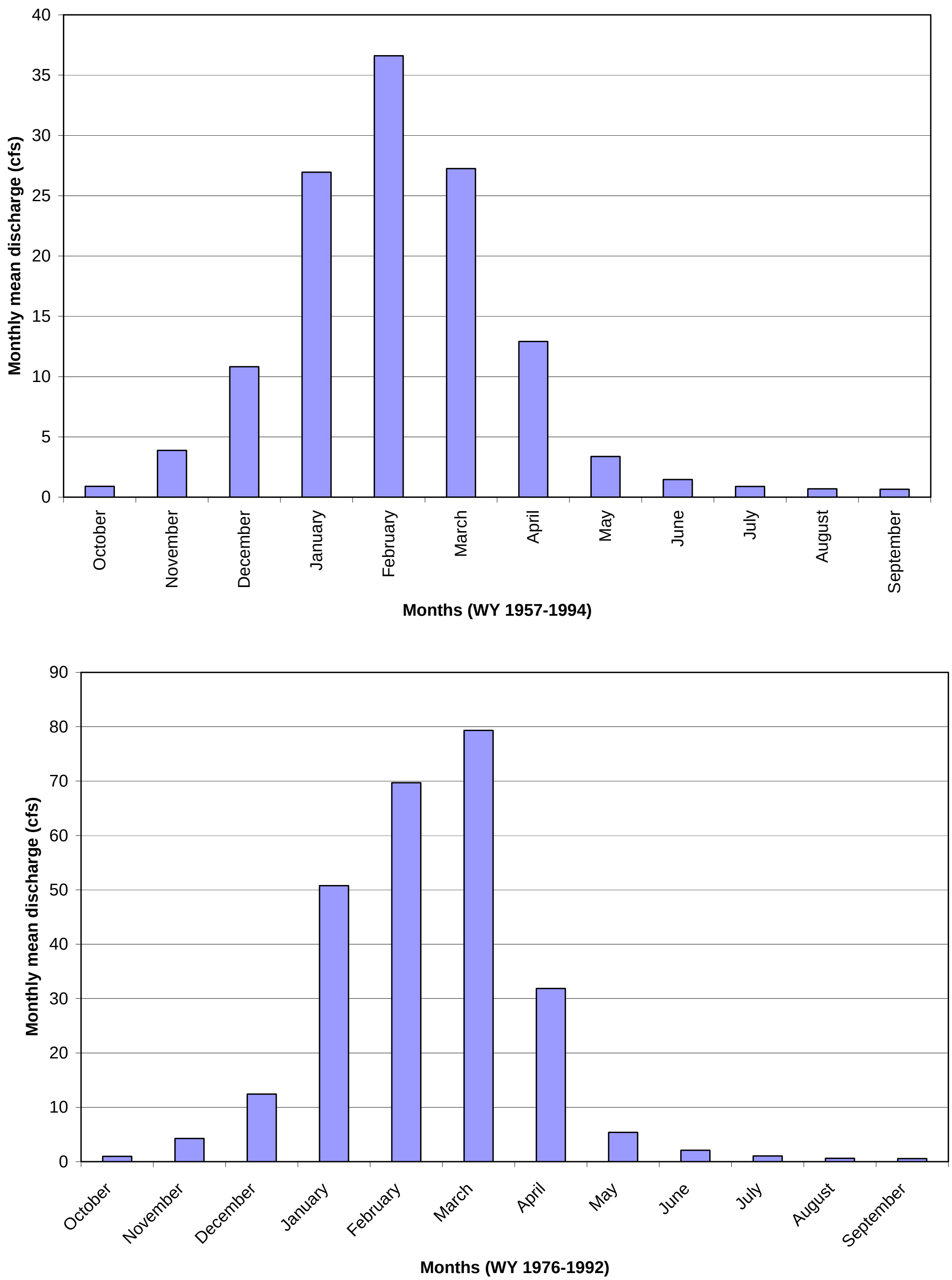

Figure 2-10. Monthly mean discharge for Santa Rosa Creek at Cambria based on USGS gauge 11142200 (from correlation with USGS gauge 11147070 to extend period beyond WY 1972 through 1994) (top) and SLO County Station 16 (bottom).

2.6.2 Groundwater extraction and surface water diversion

The urbanization time period between 1960 and the 1990s also represents an expansion of water use, primarily through groundwater pumping, to irrigate crops and provide drinking water to Cambria. The likely impact of groundwater extraction and limited surface water diversion has been an overall reduction in baseflow within Santa Rosa Creek, and potentially within Perry and Green Valley creeks. Until the San Simeon well field was established in 1979 (see Figure 2-9) to supplement municipal water demands in Cambria, the peak of groundwater extraction by CCSD for municipal water use in the Santa Rosa Creek watershed occurred in 1976 and totaled 520 acre-feet (CCSD 2009), or 3.6 times the total annual stream flow measured at the Highway 1 Bridge stream gauge (annual flow in 1976 = 144 acre-feet; 1976 was a dry water year) (Figure 2-11). Since 1979, annual extraction rates from the Santa Rosa wells have been strongly dependent on water year conditions, where rates peaked above 200 acre-feet during drought (or near-drought) years—1987, 1988, 1990, and 2008—and dropped close to zero during wet (or near-wet) years—1980, 1981, 1982, 1993, 1995, 1996, and 1998. Overall, extraction from the groundwater basin by CCSD has not exceeded the annual permitted limit of 518 acre-feet (CCSD 2008). In late 1990s, CCSD shut down its Santa Rosa wells (SRC-1 and SRC-2; see Figure 2-9) due to contamination risks from hydrocarbons from nearby leaking fuel tanks in Cambria. CCSD subsequently installed a new well (SRC-4) up-gradient of the fuel leak plume close to Coast Union High School and the confluence with Perry Creek (see Figure 2-9); it remains the sole municipal water production well in the watershed. Even with the San Simeon wells in place, the municipal water supply of Cambria has a severity rating of Level III (resource capacity has been met or exceeded) due to unreliability of the groundwater supply to meet existing demands, as designated in the 2011 San Luis Obispo County Draft Master Water Plan (Carollo 2011).

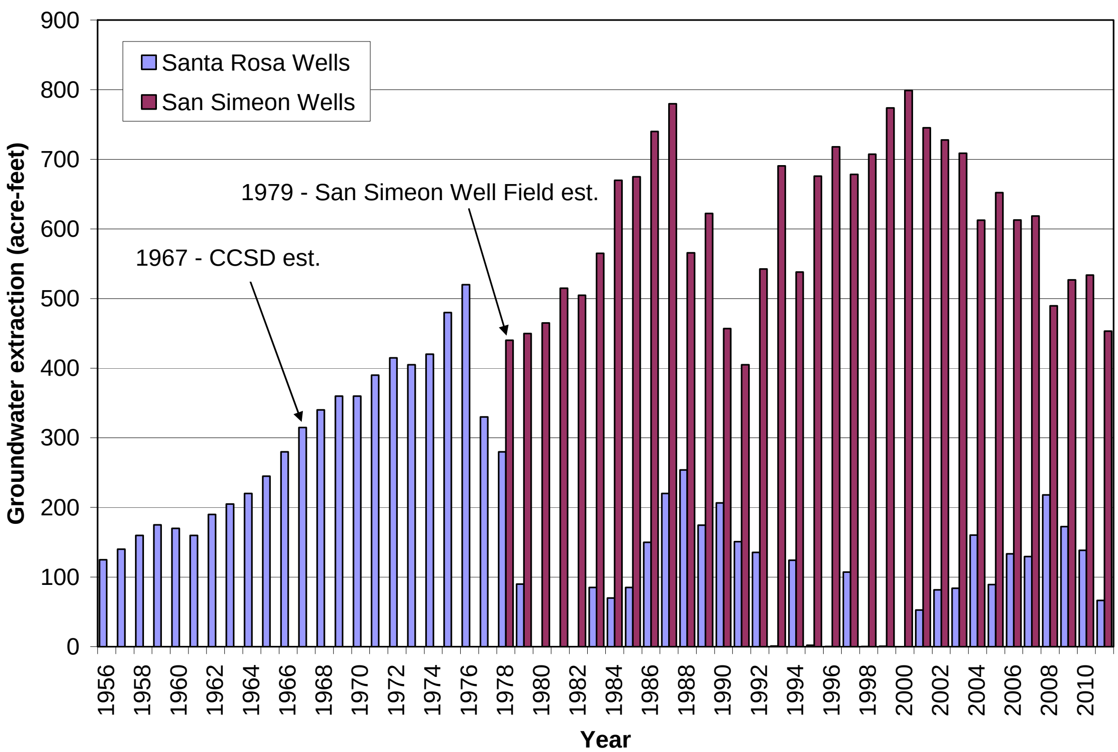

Figure 2-11. Annual groundwater extraction by CCSD from the Santa Rosa and San Simeon groundwater wells to provide Cambria water supply. Data from 1956–1988 provided by Yates and Van Konyenburg (1998) based on CCSD pumping records, and data from 1989–2011 provided by CCSD (2011). All years have recorded data.

Since the majority of municipal water is now supplied by the San Simeon wells (Figure 2-11), groundwater pumping in the Santa Rosa Creek watershed is primarily for private residential and/or agricultural use. Overall, the amount of groundwater extracted by entities other than CCSD is not well known. There are only few estimates of groundwater pumping by private entities available. USGS estimated that groundwater extracted by private entities for agricultural uses in 1988–1989 (after the establishment of the San Simeon wells) was approximately 3.5 times the amount pumped by the CCSD for municipal uses (Table 4 in Yates and Van Konyenburg 1998). The present-day amounts of urban and agricultural groundwater extraction are approximately equal (815 acre-feet per year [AFY] for urban, 830 AFY for agricultural) in the Cambria Water Planning Area, which includes Santa Rosa Creek, San Simeon Creek, Leffingwell Creek, and Villa Creek watersheds (ESA 2010). Agricultural pumping in the watershed typically peaks in the height of the growing season, usually July–August, and is close to zero in winter (Yates and Van Konyenburg 1998). Summer months also have the highest water demand due to increased occupancy and tourism in Cambria (San Luis Obispo County 2008).

Surface water diversion is limited in the watershed (for example, the recent update of the San Luis Obispo Water Master Plan makes no mention of surface water diversions in the Cambria Water Planning Area [Carollo 2011]), primarily because there is little to no instream flow during summer and fall when agricultural water demand is highest. Where surface diversions do occur, ditch pumps are generally employed (Yates and Van Konyenburg 1998). Ditch pumps have low yields and are, therefore, unlikely to significantly reduce surface water availability. The watershed does, however, host approximately 28 stock ponds, all situated on small, low-order tributaries. Taken together, these small ponds, which average 0.5–3.5 acre-feet in storage, intercept surface runoff from about 8% of the total watershed drainage area. In a given year, the amount of surface water intercepted by these ponds potentially ranges between 10 and 100 acre-feet based on their number and size. It is not known whether any of the ponds are supplemented with well water.

As discussed in Section 2.2, the CCSD and USACE are currently assessing the feasibility of a seawater desalination plant at the mouth of Santa Rosa Creek that would supplement the amount of municipal water currently being pumped from the San Simeon and Santa Rosa Creek aquifers, which is intended to improve the water supply reliability in the CCSD service area (CCSD 2008). There is the potential that, if desalinated water is ever used in place of pumped groundwater for the municipal water supply, the decreased extraction of groundwater from the Santa Rosa Creek aquifer could partially restore instream flows within Santa Rosa Creek. However, the extent to which, or even if, desalinated water may be used to replace the use of groundwater for the municipal water supply is unknown based on information available in CCSD (2008) and preliminary plans for the desalination plant. In addition, the majority of groundwater now pumped from the Santa Rosa Creek aquifer is by private entities for residential and/or agricultural water use. There is no indication that desalinated water would be used in place of privately pumped or diverted water from the watershed.

2.6.3 Lagoon hydrology

Similar to other lagoons along the California coast, the Santa Rosa Creek lagoon exhibits a “wet” and “dry” state during any given year, whereby winter and spring flows fill up the lagoon and the lack of flows during late summer and early fall often result in a dry lagoon. During the relatively wet year of 2005, D. W. Alley & Associates (2006) reported that the lagoon remained full throughout the summer. They also reported that lagoon water depth was predominantly controlled by streamflow and that tidal overwash and through-flow (i.e., subsurface flow through the sandbar) had a minimal effect. Flows into the lagoon during summer and fall are likely worsened by low stream flows resulting from excessive groundwater pumping and diversions (Rathbun et al. 1991, Yates and Van Konyenburg 1998, D. W. Alley & Associates 2006, 2008). From 1993 to 2007, summer and fall streamflows immediately upstream of the lagoon ranged from 0 cfs (1994 and 2007) to 2 cfs (2005), with a median of 0.4 cfs (D. W. Alley & Associates 2008). In some lower flow years such as 2003 and 2004, entire sections of the lower lagoon dried up, reducing the area of suitable steelhead rearing habitat (D. W. Alley & Associates 2008). Prior to its relocation farther upstream in 2001, a CCSD groundwater well was located at the upstream end of the lagoon. Groundwater pumping at this location had observable impacts on water levels in the lagoon (Elliott 1995), which have increased since the well was relocated. Depending upon the location, water extraction for the desalination plant proposed by CCSD and the U.S. Army Corps of Engineer's could also decrease water levels in the lagoon (e.g., if the extraction point is located in an area that is hydrologically connected with the lagoon). As such, the extraction point location is likely to be the subject of additional data collection and impact analysis. Low flows and water diversion may also contribute to extended periods of saltwater and freshwater stratification in the lagoon, which results in warmer temperatures and anoxic conditions along the bottom (where denser saltwater settles) (see Section 2.8).

The sandbar typically breaches after high rainfall and remains open for a week or more depending on streamflows; then the sandbar reforms to create the lagoon (M. Walgren, pers. comm., 2010). Often, high wave energy can also contribute to sandbar breaching. Reformation of the sandbar and closure of the lagoon occurs when lower stream discharges and lower-intensity wave action facilitate onshore sediment transport and deposition at the mouth. Lagoon closure can take weeks to months, depending on the stream discharge and wave conditions. While the sandbar is open, the lagoon drains and is subject to the tides. From 1993–2007 the median date of sandbar closure was May 27, with the earliest closure on March 15 in 2007, and the latest closure on July 13 in 1998 (D. W. Alley & Associates 2008). During these years, date of sandbar closure was positively and significantly related to rainfall in the preceding water year, although the relationship was not strong ($r^2 = 0.347$; $P = 0.0209$; n = 15).

Open sandbar at the lagoon

2.7 Infrastructure and Channel Modifications

Infrastructure involves man-made constructs such as dams, roads, and bridges, and facilities related to water diversion and return. Channel modifications include straightening channels, construction of levees for flood control purposes, and bed and/or bank revetments as protection against bank erosion. Generally, these modifications are related to the development of floodplains including routing of roads near stream channels.

2.7.1 Creek crossings and fish passage barriers

There are numerous creek crossings (i.e., bridges and culverts) along Highways 1 and 46 and Santa Rosa Creek Road that may locally influence the dynamics of sediment deposition and erosion and prevent or impede fish migration and movement. Bridges and other crossings frequently cause hydraulic constrictions during high flow, which promote local geomorphic changes including sediment deposition upstream of the structure and erosion of the bed and banks of the creek downstream of the structure as flow accelerates. Likewise, when crossing structures are not built to grade seamlessly with the channel bed, similar impacts are likely. Both causes may result in a significant "step" in the channel bed thereby disrupting geomorphic processes locally and impeding upstream fish passage.

Stream crossings and channel conditions in the Santa Rosa Creek watershed have been assessed by a number of entities to determine the extent to which they may limit fish migration and movement. The results of these assessments have been consolidated in the California Fish Passage Assessment Database (PAD)[4] (CalFish 2009). The potential barriers identified for the watershed in the PAD are summarized in Table 2-4 and mapped in Figure 2-12. The previous downstream-most barrier in the watershed, the Burton Street Bridge apron (PAD ID #707020) was modified in 2006 to provide fish passage under a wider range of flow conditions. In addition, the culverts and fish ladder at Ferrasci Road (PAD ID #700068) that were previously identified as a passage barrier were replaced with a free-spanning bridge in 2011. Without these two barriers, steelhead and other fish species, have unimpeded access to approximately 12 stream miles (19 km) on the mainstem creek between the ocean and East Fork Santa Rosa Creek, which presents the natural limit of anadromy.

Ferrasci Road crossing before (above) and after (below) replacement

There is a concentration of road drainage and crossing-related impacts along Green Valley Creek as part of the Highway 46 construction in the 1970s. The status of these creek crossings in impeding fish passage is largely unknown (Table 2-4), but it is possible that they exclude steelhead from nearly the entire Perry/Green Valley Creek sub-watershed (Figure 2-12). Perhaps the greatest geomorphic impact of these crossings has come from drainage modification approximately 3 mi (5 km) upstream from the junction of Highways 1 and 46. The increase in flow to Green Valley Creek at this location appears to have, at least in part, caused substantial downstream channel enlargement (i.e., bed incision and channel widening) in Green Valley Creek and erosion of the tributary channel downstream of the culvert. The impact appears to extend approximately 1 mi (2 km) downstream to where the channel gradient decreases, the channel width increases, and sediment deposition is observed to occur. Upstream of the road drainage and culvert, exposed bedrock and coarse bed material seem to be controlling the channel grade, thereby inhibiting channel enlargement due to the flow increase.

[4] While the PAD is not an error-proof database, many of the barriers identified in the Santa Rosa Creek watershed (Table 2-4 and Figure 2-10) have been previously field verified.

Table 2-4. Potential fish passage barriers in the Santa Rosa Creek watershed.

PAD ID No. [a]	Barrier location				Barrier description	Barrier status	Barrier priority	Information sources
	USGS-designated stream name	Unofficial stream name [b]	Station					
			mi	km				
712027	Unnamed	Unnamed tributary to Santa Rosa Creek	3.5	5.6	Culvert at Santa Rosa Creek Road crossing	Partial	Low	CCC, Greenspace
712044	Unnamed	Curti Creek	7.6	12.2	Culvert at Santa Rosa Creek Road crossing	Total	Low	CCC, Greenspace
712043	Unnamed	Unnamed tributary to Santa Rosa Creek	9.2	14.7	Culvert at Santa Rosa Creek Road crossing	Total	Low	CCC, Greenspace
712045	Unnamed	North Fork Santa Rosa Creek	12.6	20.2	Culvert at Santa Rosa Creek Road crossing	Total	Low	CCC, Greenspace
731782	Unnamed	Unnamed tributary	2.0	3.3	Culvert at Highway 1 crossing	Unknown	Medium	Caltrans
731365	Fiscalini Creek		6.0	9.6	Culvert at road crossing	Unknown	Medium	Caltrans
736678	Perry Creek		6.5	10.4	Highway 46 Bridge with potential passage constraints	Unknown	Medium	Caltrans
No ID	Perry Creek		8.3	13.4	Culvert at road crossing	Unknown	Medium	Caltrans
736483	Green Valley Creek		7.0	11.2	Highway 46 Bridge with potential passage constraints	Unknown	High	Caltrans
736475	Unnamed	Unnamed trib. to Green Valley Creek	7.5	12.1	Culvert at Highway 46 crossing	Unknown	Medium	Caltrans
736538	Unnamed	Unnamed trib. to Green Valley Creek	9.0	14.5	Culvert at Highway 46 crossing	Unknown	Medium	Caltrans
736487	Unnamed	Unnamed trib. to Green Valley Creek	10.0	16.0	Culvert at Highway 46 crossing	Unknown	Medium	Caltrans
736431	Unnamed	Unnamed trib. to Green Valley Creek	10.5	16.8	Culvert at Highway 46 crossing	Unknown	Medium	Caltrans
736457	Unnamed	Unnamed trib. to Green Valley Creek	10.6	17.0	Culvert at Highway 46 crossing	Unknown	Medium	Caltrans

PAD ID No. [a]	Barrier location				Barrier description	Barrier status	Barrier priority	Information sources
	USGS-designated stream name	Unofficial stream name [b]	Station					
			mi	km				
736621	Unnamed	Unnamed trib. to Green Valley Creek	11.1	17.8	Culvert at Highway 46 crossing	Unknown	Medium	Caltrans
716213	Green Valley Creek		11.9	19.2	Unspecified	Unknown	Unspecified	CDWR
736625	Unnamed	Unnamed trib. to Green Valley Creek	12.0	19.4	Culvert at Highway 46 crossing	Unknown	Medium	Caltrans
736583	Green Valley Creek		12.1	19.5	Culvert at Highway 46 crossing	Unknown	High	Caltrans

[a] Data source: California Fish Passage Assessment Database (PAD) (CalFish 2009).
[b] To help identify unnamed tributaries on USGS topographic maps (USGS 1979a, 1979b) that are referred to elsewhere in this document unofficial tributary names from D.W. Alley & Associates (2008) are presented.

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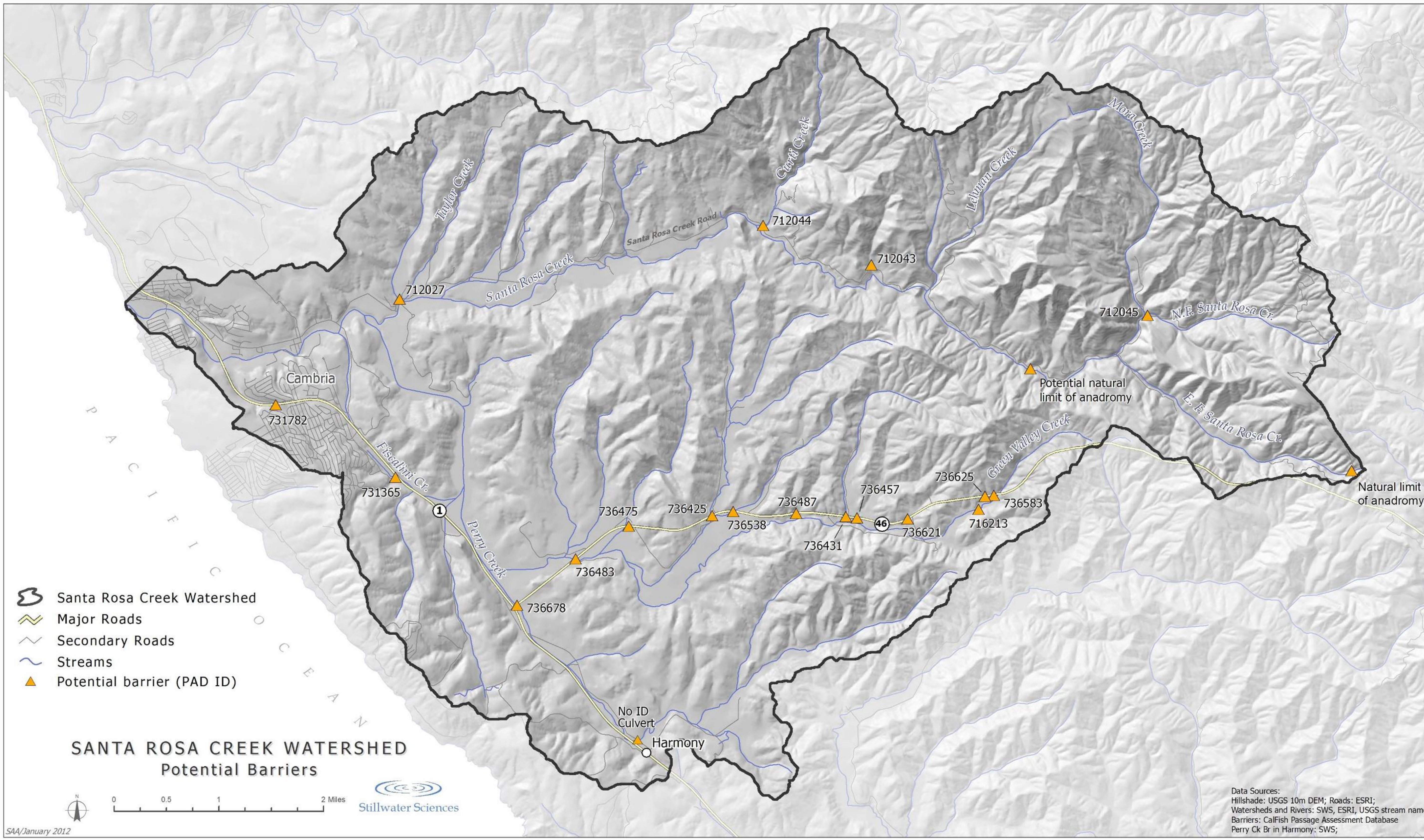

Figure 2-12. Potential fish passage barriers in the Santa Rosa Creek watershed (see Table 2-4 for details).

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2.7.2 Bank revetment and floodplain development

While no levees have been constructed along Santa Rosa Creek or its tributaries, there are numerous instances of bank revetment in the watershed, lining one or both banks of the creek (Nelson et al. 2009). The majority of riprap between the high school and old grammar school, which is composed primarily of boulder-size quarry rock, was reportedly installed immediately following the damaging floods of 1969 to repair banks that had eroded during the floods (D. Dunlap, pers. comm., 2009). In most instances, bank revetment is installed as a piecemeal solution to an on-going bank erosion concern that either threatens infrastructure or results in land loss. Unfortunately, bank revetment is also a symptomatic solution that does not account for the reason that high energy flow exists and is causing erosion. Therefore, bank revetments frequently cause flow to be deflected back across the channel resulting in further erosion downstream. The subsequent threat to downstream land and infrastructure promotes the continuing construction of further revetments and maintenance of existing revetments until such time that the channel is almost entirely revetted. Extensive revetment tends to cause channel incision, more rapid flows, channel bed armoring (i.e., coarse bed surface layer), and reduced topographic complexity of the channel bed resulting in significant reductions in habitat suitability for native aquatic organisms including salmonids.

In addition to in-channel structures, development along channel banks and the adjacent floodplain can have a significant impact on channel morphology. Floodplain development increases runoff associated with impervious area and increases channel confinement associated with bank hardening and structures built along channel banks, both of which have the potential to cause channel incision and/or widening due to increased flow velocities during high flow events. Since 1937, there has been concentrated development on the north bank (i.e., right bank) floodplain along Santa Rosa Creek from Highway 1 downstream. During the improvement of Highway 1 in the mid 1960’s (bypass construction), many of the lower reaches of the channel were modified. In an effort to improve building conditions, an abandoned channel meander approximately 0.3 mi (0.5 km) downstream of the Highway 1 Bridge was filled-in sometime after 1937. These development features have undoubtedly played some role in controlling the current channel geomorphic character.

2.8 Water Quality

Surface water in the Santa Rosa Creek watershed has a number of beneficial uses, which are designated by Central Coast Regional Water Quality Control Board’s (CCRWQCB) 1994 Basin Plan in order to inform water quality criteria (Table 2-5). A beneficial use is defined as the historical, present, and potential uses of water in the Basin as defined by the RWQCB. The intent is to ensure the continuance of beneficial uses and establish compatible water quality standards as well as the level of treatment necessary to maintain the standards.

Water quality monitoring by the CCRWQCB’s Central Coast Ambient Monitoring Program (CCAMP) indicate that a number of water quality parameters occasionally exceed established criteria such that beneficial uses may no longer be supported in portions of the watershed at some times (CCRWQCB 2002). These include total dissolved solids (TDS), sulfates, sodium and chloride. In particular, a criterion for sulfate was exceeded 91% of the time on Santa Rosa Creek, at sites both upstream and downstream of Cambria. However, for all four of these parameters, the CCRWQCB acknowledged that because no upstream data exist it is unclear whether the elevated levels of these parameters are from anthropogenic sources and recommended that these parameters be evaluated throughout the watershed (CCRWQCB 2002).

Table 2-5. Beneficial uses of Santa Rosa Creek watershed surface waters.

Beneficial use	Estuary	Creek
Municipal and Domestic Supply (MUN)		X
Agricultural Supply (AGR)		X
Industrial Service Supply (IND)		X
Ground Water Recharge (GWR)	X	X
Freshwater Replenishment (FRSH)		X
Water Contact Recreation (REC-1)	X	X
Non-Contact Water Recreation (REC-2)	X	X
Commercial and Sport Fishing (COMM)	X	X
Warm Fresh Water Habitat (WARM)		X
Cold Fresh Water Habitat (COLD)	X	X
Estuarine Habitat (EST)	X	
Wildlife Habitat (WILD)	X	X
Preservation of Biological Habitats of Special Significance (BIOL)	X	
Rare, Threatened, or Endangered Species (RARE)	X	X
Migration of Aquatic Organisms (MIGR)	X	X
Spawning, Reproduction, and/or Early Development (SPWN)	X	X
Shellfish Harvesting (SHELL)	X	

Source: CCRWQCB (1994)

Additional monitoring by the CCRWQCB (Shwartzbart 1993), as well as CDFG (Nelson et al. 2009), and D. W. Alley & Associates (2008) identified a number of other water quality parameters that may be impairing instream conditions and potentially limiting the population of native aquatic species. These include temperature, dissolved oxygen (DO), and mercury, which are discussed in more detail below. In addition, development of this watershed management plan included a survey of benthic macroinvertebrates as a measure of overall water quality and stream health. The methods and results of this survey are also described below.

2.8.1 Temperature

Santa Rosa Creek is being considered for placement on the Clean Water Act 303d list of impaired waterbodies for temperature (CCRWQCB 2010). In streams such as Santa Rosa Creek with designated beneficial uses such as cold freshwater habitat (Table 2-5), objectives for water temperature are based, in part, on species-specific temperature tolerances (CCRWQCB 1994, SWRCB 1998). During their decision to recommend Santa Rosa Creek for placement on the 303(d) list, the CCRWQCB used 55–70°F (13–21°C), the optimal range for steelhead trout growth and other lifestages based on Moyle (1976), as their evaluation guideline (CCRWQCB 2010). However, some populations of steelhead have been shown to display local adaptation to higher water temperatures and there are many central California coast examples of steelhead surviving and growing well at water temperatures above 70°F (21ºC) (Moyle 2002, Spina 2007, Smith 1990, D. W. Alley & Associates 2008).

While there is still considerable uncertainty of what optimal temperatures for steelhead are in this region (A. Spina, pers. comm., 2010), available data for Santa Rosa Creek indicate that, in most years, summer water temperatures are suitable for successful steelhead rearing in the majority of stream reaches (see Section 3.4 for additional detail). A relatively intact riparian corridor in most reaches and the influence of coastal fog likely help moderate stream temperatures in Santa Rosa Creek. In 2004–2006, D. W. Alley & Associates (2008) recorded maximum daily summer (July to September 10) water temperatures ranging from 67–75°F (20–24°C) in the lower reaches (stream miles 0.5–2.9); 69–74°F (20–23°C) in the middle reaches (stream miles 3.4–4.2); and 64–71°F (18–22°C) at two sites in the upper reach (stream miles 9.6–10.1 and 11.5–12.4). In 2005, CDFG recorded maximum daily summer (June through October) water temperature at stream miles 0.6, 8.0, and 14.5 (Nelson et al. 2009). Temperatures ranged from 55–79°F (13–26°C) at stream mile 0.6, 50–71°F (10–22°C) at stream mile 8.0, and 51–70°F (11–21°C) at stream mile 14.5 (Nelson et al. 2009).

D. W. Alley & Associates (2008) recorded summer (July 10 through October) water temperatures at two locations in the lagoon—adjacent to the Moonstone Beach parking lot and to Shamel Park—in 2001, 2002, 2005, and 2006. In all four years, temperatures reached or exceeded 77°F (25°C) at one or both of the monitoring sites for some portion of the summer. While temperatures of this magnitude likely make the lagoon inhospitable for summer rearing, steelhead were observed using the lagoon in both 2001 and 2006 (D. W. Alley & Associates 2008). Low instream flows and water diversion likely contribute to extended periods of saltwater and freshwater stratification, with warmer temperatures and anoxic conditions along the bottom where denser saltwater settles.

2.8.2 Dissolved oxygen

Dissolved oxygen (DO) levels measured by the CCAMP suggest that it may be a potential water quality limiting factor and that beneficial uses may no longer be supported (CCRWQCB 2002). At DO levels <5–6 mg/l, stress can begin to effect fish and other organisms. At high temperatures, steelhead can survive DO concentrations as low as 1.5–2.0 mg/l for brief periods, though concentrations closer to 8–12 mg/L are normally required for growth (Moyle 2002).

D. W. Alley & Associates (2008) recorded DO levels in the lagoon for 14 years (1992–2005) and during that time DO levels rarely met the 5 mg/l criterion or the 2 mg/l lethal limit for steelhead. They concluded that a reduction in tidal overwash could help to reduce the low DO saline layer at the bottom of the lagoon (tidal overwash increases lagoon salinity which can result in higher salinity, higher temperature, and lower DO layer at the bottom of the lagoon) and an increase in lagoon depth from increased stream inflow and increased shading could help to prevent filamentous algae growth (D. W. Alley & Associates 2008). Further, they found that, while DO levels frequently failed to meet guidelines and likely restricted the activity of steelhead in the lagoon, they were likely less limiting than temperature to steelhead survival in the lagoon since steelhead could avoid the low DO zones in the saline layer at the bottom of the lagoon and in the vicinity of high density filamentous algae (D. W. Alley & Associates 2008).

2.8.3 Mercury

A 1993 CCRWQCB study documented elevated levels of mercury in stream sediment, and to a lesser extent in water, in and downstream of Curti Creek (Schwartzbart 1993). Cinnabar, the common ore of mercury, was historically mined at several locations in the watershed, most notably at the Oceanic Mine located in the Curti Creek sub-watershed. Active mining at the site began in 1865 and continued intermittently through the 1900s. Records during this time indicate that a total of over 38,000 flasks of mercury were produced from the Oceanic Mine, nearly equal to the production from all other mercury deposits in the County combined (CCRWCQB 1999). During peak production, ore was milled and processed into pure forms of mercury in a furnace located approximately ½-mile downhill from the mine (Eckel et al. 1941, as cited in CCRWQCB 1999). In 1964, the mine was sold to Buena Vista Mines, Inc., while the former mill site was sold to a different owner (Holcombe 1970, as cited in CCRWQCB 1999).

During a study of inactive mercury mines in San Luis Obispo County, the Central Coast Regional Water Quality Control Board documented iron-rich, red seepage from the mine, which reportedly pollutes and discolors Curti Creek for most of the downstream distance to Santa Rosa Creek, and the erosion of mercury-rich waste rock by Curti Creek at the former mill site (Schwartzbart 1993, CCRWQCB 1999). Stream sediment samples contained elevated mercury levels ranging between 1.095 to 8.48 mg/kg (ppm) downstream of the mine and former mill site (Schwartzbart 1993) (Table 2-6). These values exceed the concentrations above which adverse biological effects are expected to occur frequently in freshwater sediment (Buchman 2008).[5] Of the 49 inactive mines investigated during the study, the CCRWQCB concluded that Santa Rosa Creek was one of the most heavily metal-mined-impacted watersheds as a result of the Oceanic Mine former mill site (Schwartzbart 1993, CCRWQCB 1999). More recently, several sediment samples from lower Santa Rosa Creek have been tested for mercury (CCRWQCB 2002, L. Harkins and Sierra Club, unpubl. data, 2009). The results of all total mercury (THg) in sediment measurements taken in the watershed are summarized in Table 2-6 and sample points are mapped in Figure 2-13.

One sample point, HSC-4 in the lagoon, was analyzed for methyl mercury, the form of mercury that can bioaccumulate in living tissue, and was found to have 3 μg/kg (parts per billion), or 0.60% of THg (L. Harkins and Sierra Club, unpubl. data, 2009). Three-spined stickleback (*Gasterosteus aculeatus*) were collected in the lagoon by CCAMP in 1999 and 2001 and tested for mercury. The mercury concentration in the 1999 sample measured 0.318 ppm, while the 2001 sample measured 0.085 ppm; neither of which exceeded the CCRWQCB's (1994) 0.5 ppm criteria for mercury in aquatic organisms. Additional information is needed to more fully understand the magnitude of mercury methylation in the lagoon (which is the primary area in the watershed with the low dissolved oxygen conditions that facilitate the methylation process) and the extent to which mercury is being taken up by the aquatic foodweb.

CCRWQCB (1999) recommended that erosion control be implemented throughout the Ocean Mine area to stabilize the eroding mercury-rich waste rock at the former mill site. In addition, they determined that constructed wetlands could be a practical solution to retain and treat pollutants entering Curti Creek from the mine and former mill site. Remediation requirements from the CCRWQCB have been in place since 1997, however, no reclamation activities have been conducted at the mine or former mill site (CCRWQCB 1999).

[5] The following mercury levels in sediment are provided for reference:
0.08 mg/kg (ppm) = estimated pre-mining mercury levels in California stream sediments (SFBRWQCB 2008)
0.174 mg/kg (ppm) = mercury threshold effect level (TEL), the concentration above which adverse biological effects are expected to occur rarely, in freshwater sediment (Buchman 2008)
0.486 mg/kg (ppm) = mercury probable effect level (PEL), the concentration above which adverse biological effects are expected to occur frequently, in freshwater sediment (Buchman 2008)
20 mg/kg (ppm) = mercury hazardous waste limit

Table 2-6. Sediment mercury levels in Santa Rosa Creek watershed.

Sample point ID	Location	Date	Sediment THg (mg/kg) (ppm)
RB-SR-D1 [a]	Santa Rosa Creek upstream of Curti Creek	2/12/1992	0.192
RB-SR-C1 [a]	Curti Creek upstream of Oceanic Mine tributary	2/12/1992	0.511
RB-SR-A1 [a]	Tributary north of Oceanic Mine	2/12/1992	0.601
RB-SR-A2 [a]	Tributary at Oceanic Mine	2/12/1992	1.095/1.75 [d]
RB-FD-16 [a]	Tributary in vicinity of Oceanic Mine	5/19/1986	3 [e]
RB-SR-B [a]	Tributary south of Oceanic Mine	2/12/1992	6.79
RB-SR-C2 [a]	Tributary at Oceanic Mine just upstream of Curti Creek	2/12/1992	5.01
RB-SR-C3 [a]	Curti Ceek just downstream of Oceanic Mine tributary	2/12/1992	1.104
RB-SR-D2 [a]	Lower Curti Creek	2/12/1992	1.194/8.48 [d]
RB-SR-D3 [a]	Santa Rosa Creek downstream of Curti Creek	2/12/1992	0.161
HSC-1 [b]	Santa Rosa Creek 20 ft (6 m) upstream of Main Street Bridge	7/15/2009	0.12
HSC-2 [b]	Santa Rosa Creek at Creekside Reserve at Center St	7/15/2009	0.16
HSC-3 [b]	Santa Rosa Creek lagoon, 350 ft (106 m) upstream of bench at Shamel Park	10/12/2009	0.18
HSC-4 [b]	Santa Rosa Creek lagoon, at Shamel Park bench	10/12/2009	0.54
SWAMP-1 [c]	Mouth of Santa Rosa Creek	3/1/1998	0.55

[a] Source: Schwartzbart 1993
[b] Source: L. Harkins and Sierra Club, unpubl. data, 2009
[c] Source: CCRWQCB 2002
[d] Two measurements were taken at this sample point
[e] Another lab measured 41 mg/kg at this point

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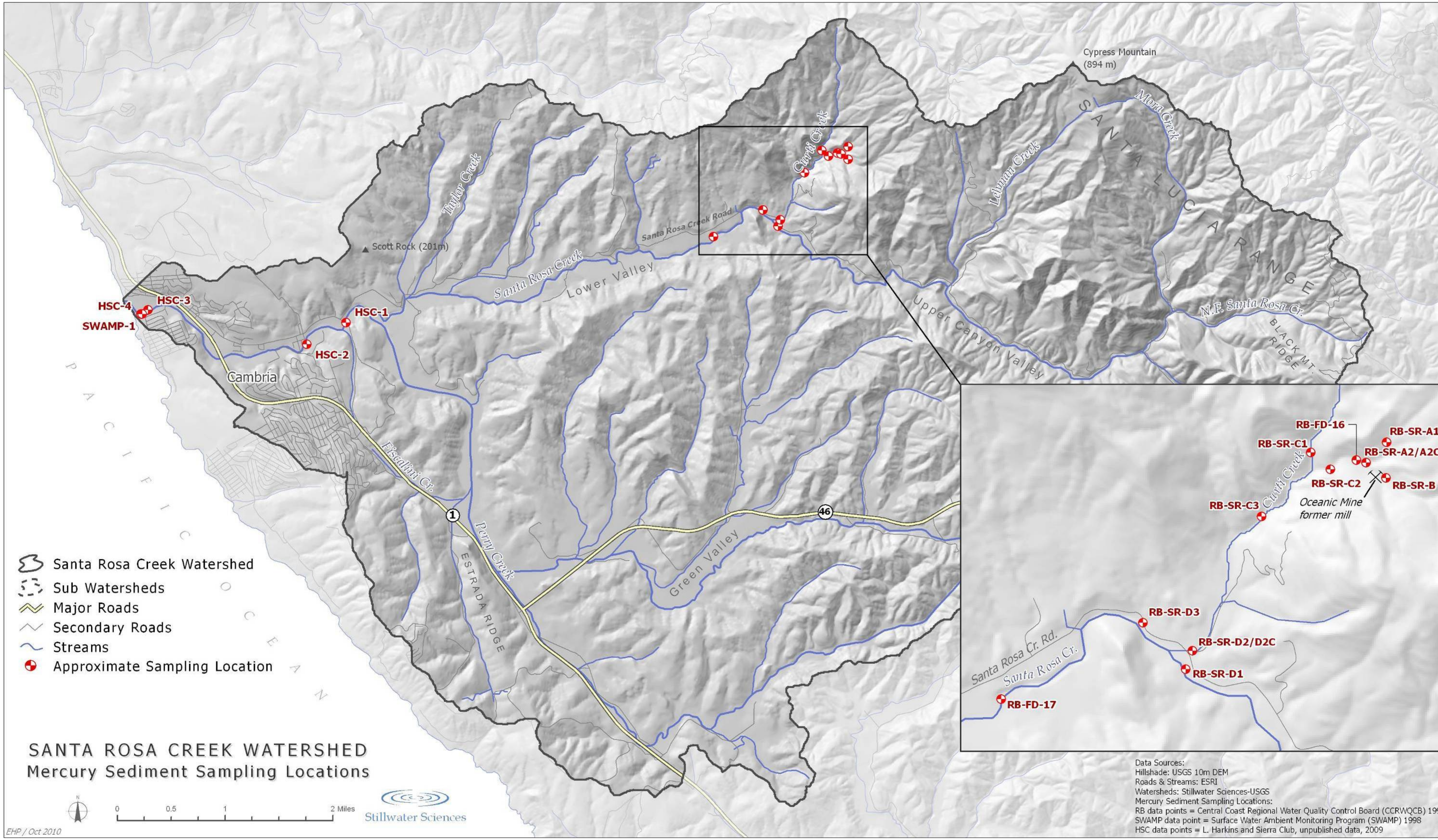

Figure 2-13. Mercury sample points in the Santa Rosa Creek watershed (see Table 2-6 for sampling entity and results).

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2.8.4 Benthic macroinvertebrates


Hydropsychid caddisflies

As a part of the development of this watershed management plan, the benthic macroinvertebrate population was sampled in lower Santa Rosa Creek to evaluate water quality and biological conditions of stream habitat in the watershed (Appendix B). Benthic macroinvertebrates are organisms that utilize the stream bed substrate as habitat. The distribution of benthic macroinvertebrates is dependent on seasonal weather variations (which influence water volume, velocity, and temperature), food availability, and water and habitat quality (Plotnikoff et al. 1997). Stream benthic macroinvertebrates respond to impacts related to pollution, sedimentation, and other changes in their habitat. The number, composition, and distribution of benthic macroinvertebrates can be a strong indicator of instream habitat quality. Benthic macroinvertebrates are also a primary food source for steelhead. Therefore, assessment of the benthic macroinvertebrate community can provide valuable insight into potential limiting factors for steelhead productivity.

In general, benthic macroinvertebrate diversity in Santa Rosa Creek is higher upstream, where the benthic macroinvertebrate assemblage is less tolerant of degraded conditions, and lower downstream, where the species assemblage is more tolerant of poor water quality conditions.

2.8.4.1 Sampling methods

On May 5, 6, and 7 of 2010, benthic macroinvertebrates were collected using an abridged version of the State Water Resource Control Board's (SWRCB) Surface Water Ambient Monitoring Program (SWAMP) bioassessment protocol (Ode 2007) at seven sites along Santa Rosa Creek (Figure 2-14):

- Site 1 (stream mile 0.3)
- Site 2 (stream mile 1.0)
- Site 3 (stream mile 1.5)
- Site 4 (stream mile 1.8)
- Site 5 (stream mile 2.8)
- Site 6 (stream mile 3.3)
- Site 7 (stream mile 5.0)

Sampling sites were selected in part based on personal communications with Mary Adams of CCAMP and Jennifer Nelson of CDFG, both of whom have experience on Santa Rosa Creek. Physical accessibility and permission for access from landowners also played a role in site selection. Selected sampling sites reflect a variety of land uses and human influences, including urbanization, agriculture, and ranching. The four downstream-most sites are located within the town of Cambria.

Figure 2-14. Benthic macroinvertebrate sampling sites on Santa Rosa Creek.

Sampling took place at base flow conditions, at riffles no deeper than 2 ft, using the targeted riffle composite procedure (Ode 2007). A 450-ft reach of riffle habitat was defined at each site. Riffles are shallower stream habitats characterized by water that flows over and between rocks, creating mild to moderate water turbulence (Ode 2007). Riffles are commonly used for benthic macroinvertebrate sampling because they usually offer the highest diversity of benthic macroinvertebrate species (Ode 2007). Each 450-ft reach was randomly divided into eight transects, and sampling began at the lower-most transect and progressed upstream. At one location along each transect, a D-frame net with a mesh size of 0.5 micrometers was placed perpendicular to flow and flat on the substrate. Organisms in a 1-ft^2 sample area immediately upstream of the net were first removed from larger rocks and then the substrate within the sampling area was disturbed by hand for 60 seconds. Care was taken to ensure that all sample material flowed downstream and was captured by the net. Sample material from each transect was placed into a sample jar and preserved in 95% ethanol for lab analysis.

Water temperature, pH, dissolved oxygen, and velocity were measured at the downstream end of each reach using a digital Vernier LabQuest water quality meter. Wetted width of the stream, water depth, substrate, the presence of organic matter, and cobble embeddedness were measured and recorded at each transect. In addition, visual estimates and habitat scoring methods were used to assess the complexity of instream habitat, riparian vegetation, bank stability, and level of human influences at each transect.

2.8.4.2 Analysis and results

Transect samples were compiled for each site, sorted, and identified to 600 individual organisms per sample. Biometric values, including richness, composition, functional feeding group, and the Southern California Index of Biological Integrity (So Cal IBI), were calculated for each site. (Appendix B, Table 4.1 provides a list of all biometrics calculated, as well as a comparison of the results for Santa Rosa Creek with Coon Creek, San Luis Obispo County.) Each biometric is a characteristic of the benthic macroinvertebrate community that changes in a predictable way relative to a habitat stressor (Fore 1996). Biometrics are used as a diagnostic tool and are useful in evaluating stream health and for comparing conditions between sites, between sampling events, and with other streams.

Richness—Richness, or diversity, is the total number of individual benthic macroinvertebrate species in a sample. The more diverse a benthic macroinvertebrate assemblage, the greater the likelihood that the local habitat is also diverse and robust. Sites 2 and 3 had the lowest richness values (17 and 18 total species, respectively), while sites further upstream had greater richness (e.g., 25 to 29 total species) (Figure 2-15).

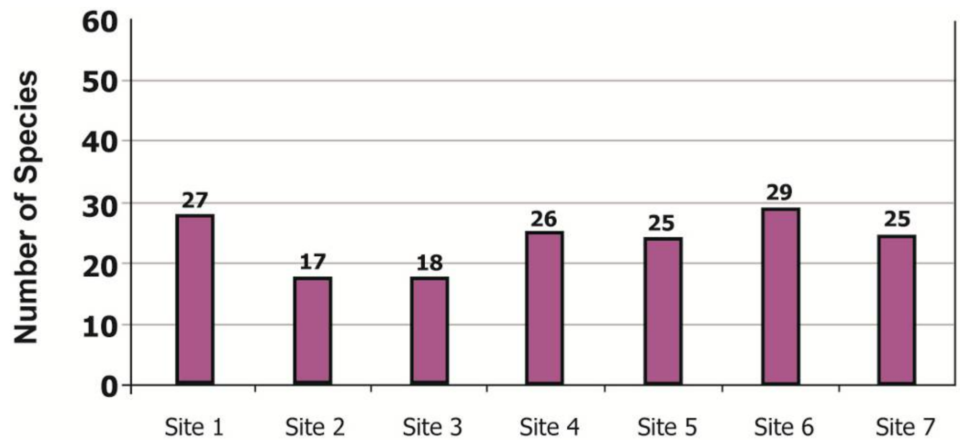

Figure 2-15. Benthic macroinvertebrate taxonomic richness at sampling sites on Santa Rosa Creek in 2010.

Composition—Composition is the percentage, or relative abundance, of particular taxa in a sample. The two composition metrics reported here are the sensitive EPT Index and the Dominant Taxa index. The sensitive EPT Index is the percentage of three pollution-sensitive orders of benthic macroinvertebrates: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). The higher the percent of sensitive EPT in a sample, the greater the likelihood that local water quality is good. In general, downstream sites on Santa Rosa Creek had lower sensitive EPT Index values than upstream sites (Figure 2-16).

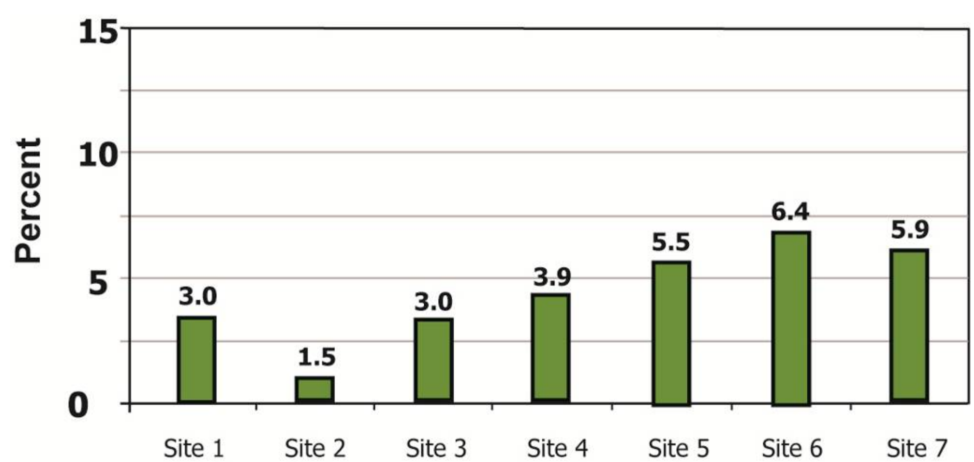

Figure 2-16. Benthic macroinvertebrate sensitive EPT Index values at sampling sites on Santa Rosa Creek in 2010.

The Dominant Taxa metric is the percentage of the third, second, and single most dominant benthic macroinvertebrate taxa in a sample. A stream with excellent water quality can support a greater number of taxa. If dominant taxa make up 40% or more of the total sample, it is an indication of instability in the macroinvertebrate community and that a stressor is present (MBNEP 2008). On Santa Rosa Creek, the three downstream-most sample sites had higher percentages of dominant taxa, indicating that a stressor is present (Figure 2-17).

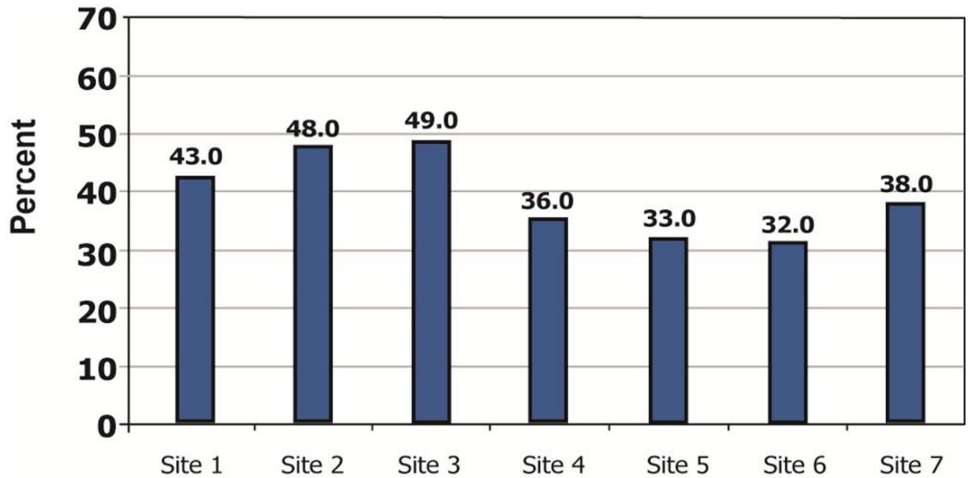

Figure 2-17. Percent of dominant benthic macroinvertebrate taxa at sampling sites on Santa Rosa Creek in 2010.

Functional Feeding Group—The functional feeding group metric is the proportion of taxa with different feeding strategies within a sample. Two types of functional feeding group metrics were calculated: the Scrappers Taxa metric and the Shredder Taxa metric. The Scrappers Taxa metric identifies the proportion of benthic macroinvertebrate taxa that graze upon periphyton. The greater the proportion of scrapper taxa, the higher the primary productivity at a sample location. On Santa Rosa Creek, downstream sites (e.g., Sites 1 through 4) had lower Scrapper Taxa values that upstream sites (e.g., Sites 5 through 7).

The Shredder Taxa metric is the percentage of benthic macroinvertebrate taxa that shred leaf litter. Higher proportions of shredder taxa indicate habitats with high retention of organic matter and food sources such as overhanging leaves and branches. On Santa Rosa Creek, Shredder Taxa values were much higher for Site 6 (3.1) and Site 7 (2.2), compared to Sites 3 and 4, where no shredder taxa where identified.

Southern California Index of Biotic Integrity—For each site, a standardized So Cal IBI score was determined. The So Cal IBI is a “condition” score that expresses the health of sites in a single qualitative number ranging from 0 to 100, with 0 representing an environment of very poor quality and low diversity and 100 being a very healthy environment with high diversity. The So Cal IBI is the sum of the following uncorrelated biometric values: (1) the number of Coleoptra (beetle) taxa; (2) the number of Ephemeroptera (mayflies), Plecoterea (stoneflies), and Trichoptera (caddisflies) (EPT) taxa; (3) the number of Predator taxa; (4) the percentage of sensitive individuals; (5) the percentage of Collector individuals; (6) the percentage of tolerant taxa; and (7) the percentage of non-insect taxa.

The So Cal IBI scores for the Santa Rosa Creek sites range from poor (34 at Site 2) to moderately good (63 at Site 6) (Figure 2-18). Site 2 (34) and Site 3 (37) exhibited the two lowest So Cal IBI scores, which suggest the likelihood of poor water quality at those sites. These sites are adjacent to the town of Cambria and, as such, experience higher levels of urban runoff. Urban runoff commonly contains higher levels of certain pollutants such as, but not limited to, heavy metals and petroleum-based pollutants, as compared to non-urban areas. These pollutants, along with physical changes to the riparian zone and stream channel that are common in urban areas, can affect the benthic macroinvertebrate community. The So Cal IBI score at Site 1, the most downstream site, is comparable to Sites 4 and 5, further upstream (Figure 2-18). The So Cal IBI scores suggest that the two most urban sampling sites, Sites 2 and 3, deserve a closer inspection of the potential influences on water quality in these areas and may warrant recommendations for land use best management practices to improve water quality in drainages leading to these sites. It should be noted however, that So Cal IBI scores can also be influenced by parameters other than water quality, such the size and quality of the riparian buffer. Thus, So Cal IBI scores should be utilized in conjunction with an understanding of local riparian conditions to guide management practices. The two upstream-most sites—Site 6 (63) and Site 7 (60)—exhibited moderately good water quality. These sites are not as affected by urban runoff but may be affected by adjacent lands uses of agriculture and ranching.

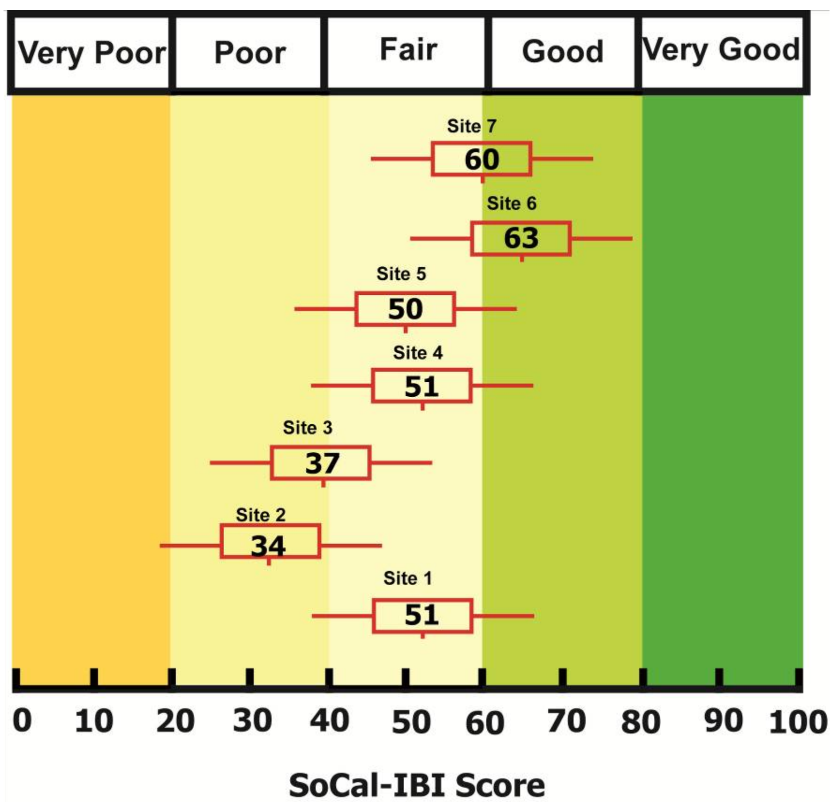

Figure 2-18. Southern California Index of Biological Integrity scores for benthic macroinvertebrate sampling sites on Santa Rosa Creek in 2010.

Another result of this study was to verify if the food supply in the Santa Rosa Creek is adequate to sustain populations of steelhead. The taxonomic lists for each site proved to have large populations of *Baetis* (mayflies) and *Simulium* (blackfly) populations, which are considered a valuable food source for steelhead (Appendix B).

The results in Appendix B can be used as a baseline for the establishment of a bio-monitoring program that tracks the impact of increased urbanization and other changes in land uses on the water quality of Santa Rosa Creek. In turn, repeated monitoring data can be useful in identifying areas that are in need of water quality improvement, and to help monitor the success of implemented restoration actions. Benthic macroinvertebrate sampling and analysis is increasingly recognized as an effective and efficient diagnostic tool for assessing water quality. The State of California is in the process of integrating benthic macroinvertebrate assessment into the water quality regulatory framework.

2.8.5 Storm water

2.8.5.1 First flush stormdrain monitoring

As a part of the development of this watershed management plan, water samples were collected in the late fall of 2010 to evaluate pollutants in the first stormwater runoff of the water year, or first flush, in the more urbanized portion of the watershed. The first flush is a unique opportunity to assess the quality of water entering creeks and streams as it carries materials, ranging from trash to road-way pollutants, which have accumulated on the landscape since the last rainfall. These constituents can be identified and analyzed in the lab, and can be used to guide the development of focused management actions to minimize the pollutants and/or prevent them from washing into waterways. Santa Rosa Creek 2010 first flush sampling sites are mapped in Figure 2-19 (sampling also occurred at the Burton Bridge and Bridge Street sites in 2011).

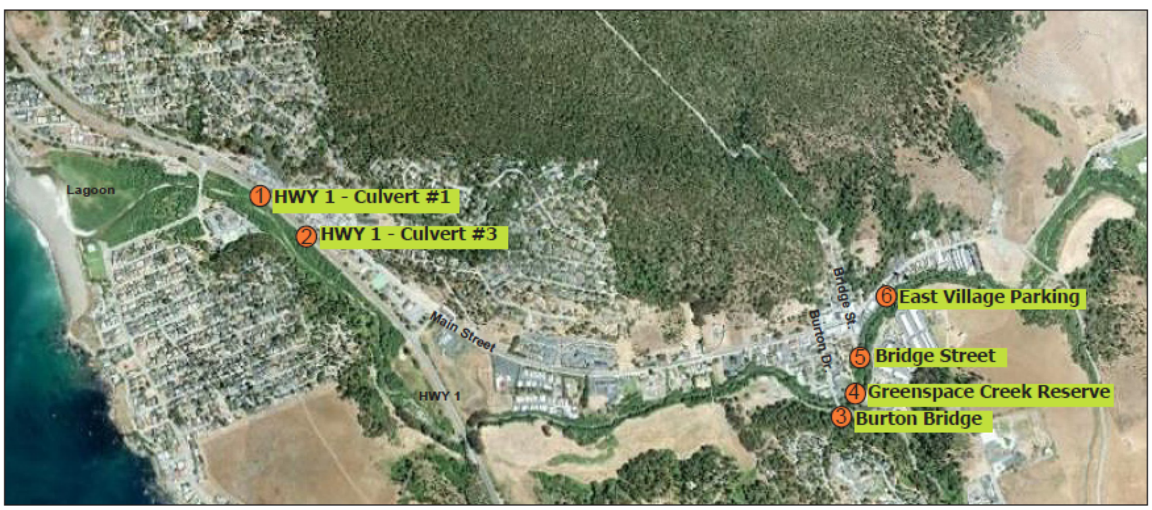

Figure 2-19. First flush sampling sites on lower Santa Rosa Creek.

Samples were collected using the Monterey Bay Sanctuary Citizen Watershed Monitoring Network's stormdrain monitoring protocol (Conrad et al. 2000). Water samples were collected directly from outfall pipes at all sample locations, except the Greenspace Creek Reserve, where samples were taken directly from the thalweg of the creek. Samples were collected in sterile Whirlpaks, stored in an ice chest, and transported to a lab for analysis at the earliest opportunity. Constituents identified in the Santa Rosa Creek first flush samples included total dissolved solids, nitrate, copper, zinc, and coliform bacteria (Table 2-7).

Table 2-7. 2010 first flush results for lower Santa Rosa Creek.

Analyte	High-way 1 Culvert #1	High-way 1 Culvert #3	Burton Bridge [a]	Green-space Creek Reserve	Bridge Street [a]	East Village Parking	RWQCB attention level
Total Dissolved Solids (mg/L)	1,600	not detected	3,700 (80)	1,100	210 (400)	6,200	500
Nitrate as N (mg/L)	not detected	0.5	0.48	not detected	0.78	1.1	2.25
Copper (mg/L)	0.0095	0.031	0.05	0.0023	0.041 (0.73)	0.066	0.01
Zinc (mg/L)	0.04	0.075	0.15	not detected	0.18 (0.51)	0.21	0.01
Total Coliform (MPN/100 ml) [b]			(>1,600)		(>1,600)		100
Total Oil and Grease (mg/L)			(not detected)		(8)		n/a

[a] 2011 results, as available, are provided in parentheses.
[b] Total coliform is measured using the most probable number (MPN) index, which is the concentration of coliform bacteria in a sample expressed as the number of bacteria per 100 mL.

Total dissolved solids are all inorganic and organic substances that are smaller than 2 microns (0.0002 cm) in size. Total dissolved solids is not generally considered a primary pollutant but is used as an indicator of the presence of a broad array of chemical contaminants. Sources of total dissolved solids are agricultural and residential runoff (including pesticides), leaching of soil contamination, point source water pollution discharge from industrial or sewage treatment plants, and natural weathering and dissolution of rocks and soils. Total dissolved solids in the lower Santa Rosa Creek first flush samples are presented in Figure 2-20. Four of six sites exceeded the attention level set by the CCRWQCB (1994). An attention level is the concentration of a substance in a particular medium (water, soil, etc.) that may be of concern when exceeded (CCRWQCB 1994).

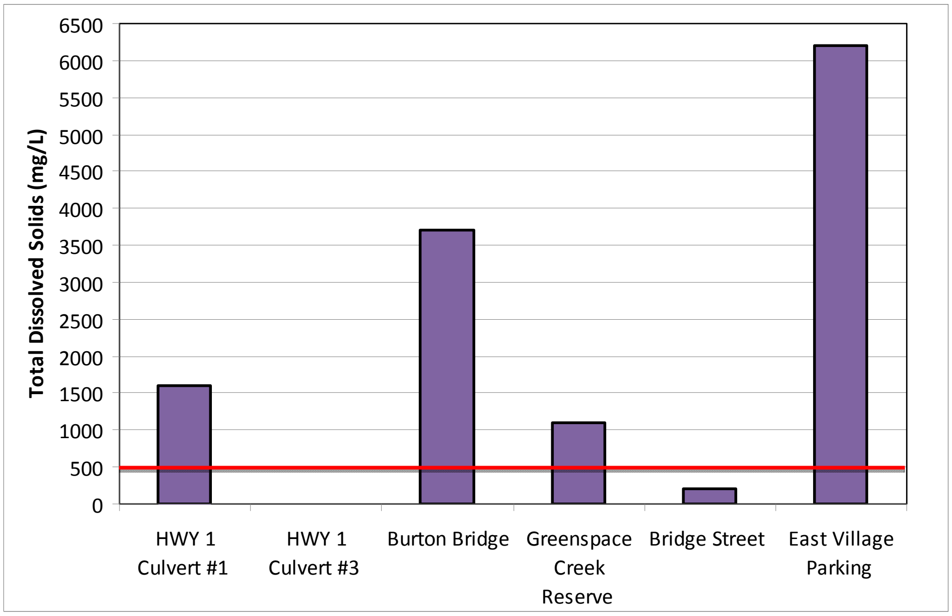

Figure 2-20. Total dissolved solids in 2010 lower Santa Rosa Creek first flush samples. The red line is 500 mg/L, the CCRWQCB (1994) attention level for total dissolved solids.

Nitrogen is a nutrient that acts as a fertilizer. When nutrient levels are high, excessive plant and algae growth can create water quality problems. Nitrogen enters water from human and animal waste, decomposing organic matter, and run-off of fertilizer from lawns and crops. Nitrate as nitrogen in the lower Santa Rosa Creek first flush samples is presented in Figure 2-21. While upstream sites have higher nitrate levels than downstream sites, none of the sites exceed the CCRWQCB (1994) attention level.

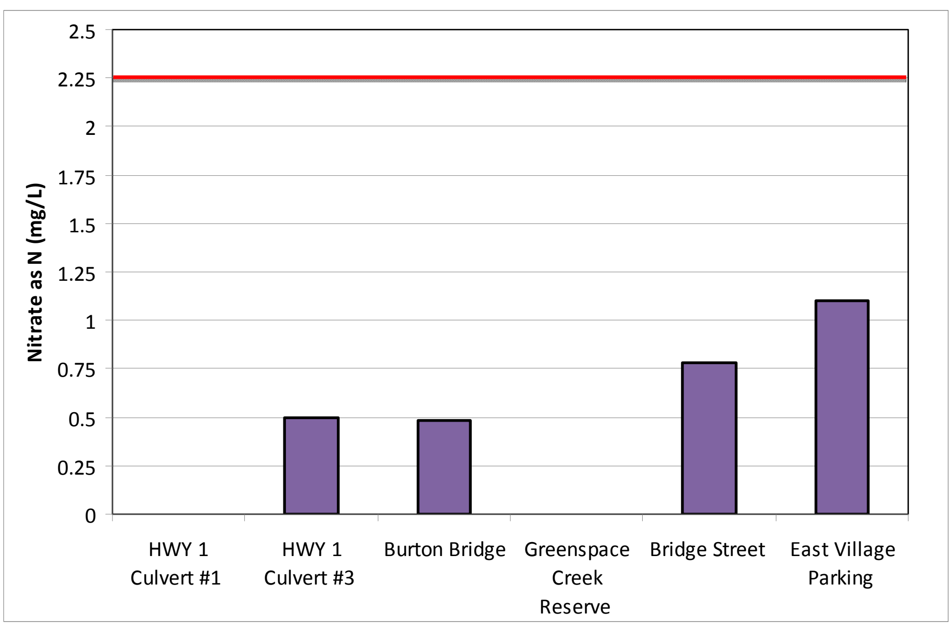

Figure 2-21. Nitrate as nitrogen in 2010 lower Santa Rosa Creek first flush samples. The red line is 2.25 mg/L, the CCRWQCB (1994) attention level for nitrate as nitrogen.

Metals such as copper and zinc may come from erosion of natural deposits, pesticides, industrial waste discharges, car brakes, agricultural waste, or corroding metal pipes and storage tanks. Trace metals can have direct toxic effects on aquatic plants and animals, and can bioaccumulate in aquatic species and have negative impacts throughout the food chain. Metals can also accumulate in sediment and be resuspended during storm events. Dissolved copper and zinc concentrations in the lower Santa Rosa Creek first flush samples are presented in Figures 2-22 and 2-23, respectively. The majority of sites on lower Santa Rosa Creek exceed CCRWQCB (1994) attention levels, but the attention levels are dependent on water hardness: copper and zinc are more toxic in softer water and less toxic in harder water (Ebrahimpour 2010). The Santa Rosa Creek results have not been adjusted for water hardness. Given the documented copper and zinc levels, a toxicity threshold that incorporates water hardness should be calculated.

Fecal coliform in the 2011 samples at the Bridge Street and Burton Bridge sites exceeded the limits of the lab test that was conducted. As such, it is not possible to determine if coliform levels in the creek exceeded the CCRWQCB (1994) attention level. However, the documented levels are high enough to suggest septic system or sewer leaks and fecal test should be conducted.

The first flush results represent an initial attempt at characterizing the types and quantities of pollutants in stormwater runoff in the more urban areas of the watershed. With additional resources a more robust first flush program could be initiated and conducted over time to more fully understand the trends in and degree of urban water quality influence on Santa Rosa Creek habitats and aquatic species.

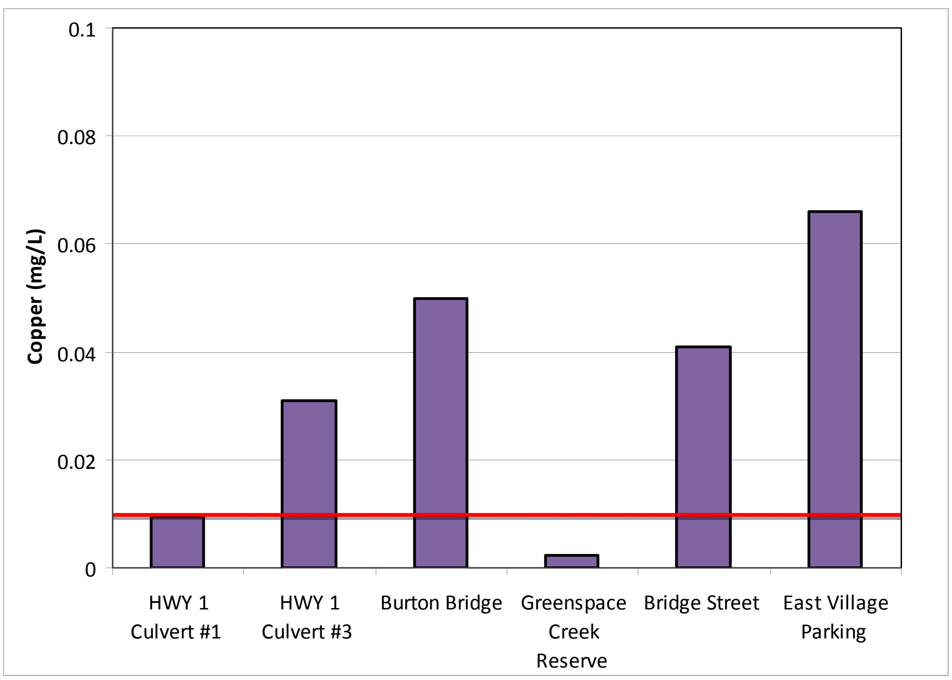

Figure 2-22. Dissolved copper in 2010 lower Santa Rosa Creek first flush samples. The red line is 0.01 mg/L, the CCRWQCB (1994) attention level for copper.

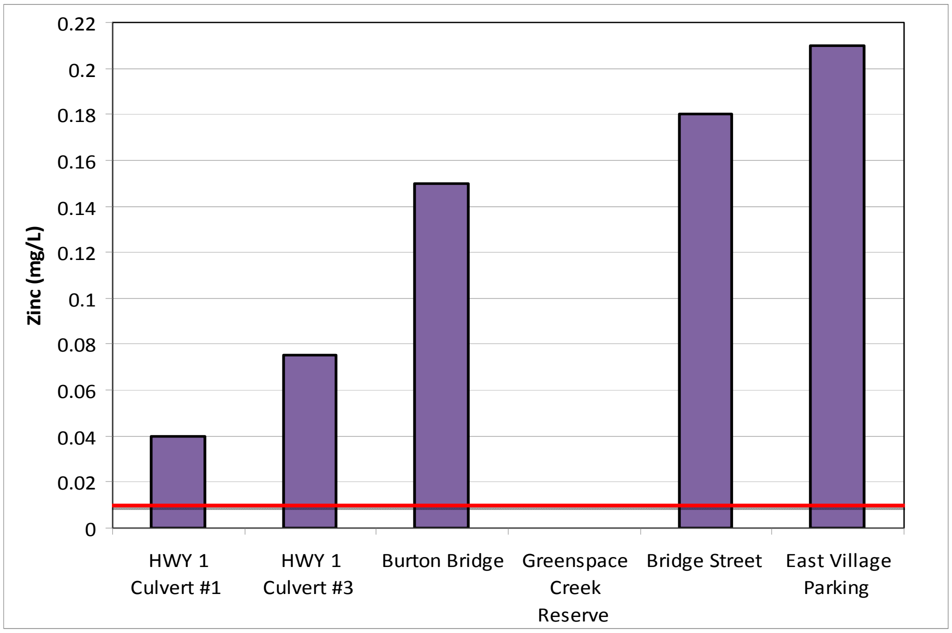

Figure 2-23. Dissolved zinc in 2010 lower Santa Rosa Creek first flush samples. The red line is 0.01 mg/L, the CCRWQCB (1994) attention level for copper.

2.8.5.2 Drainage-related erosion and flooding

Storm water related erosion, drainage problems, and flooding have been documented in a number of Cambria's residential neighborhoods. In 1999 an erosion and sediment study was commissioned for the Lodge Hill neighborhood after local residents, San Luis Obispo County staff, and local media documented storm water related drainage problems in the neighborhood (USDA NRCS 1999). While the study concluded that storm water erosion rates were not high enough to be a major source of sediment to nearby waterways and the Pacific Ocean, it documented steeply sloped unpaved roads, tire action from large vehicles, and construction sites with inadequate erosion control measures as sources of fine sediment during storm water flows (USDA NRCS 1999). The study report warned that without a coherent system of storm water management in the neighborhood, storm water drainage and erosion issues would worsen as more residences are constructed (USDA NRCS 1999). Study recommendations included developing a comprehensive master plan for built-out neighborhood conditions that incorporates a street drainage network, paved roads, and measures to address concentrated storm water flow and reduce impacts on forest resources (USDA NRCS 1999).

Flood damage to homes and businesses in March 2001 prompted San Luis Obispo County to commission another drainage study for additional Cambria neighborhoods (RMC 2004). The study found that the combination of steep topography in many Cambria neighborhoods, the lack of underground drainage facilities, and the location of many parcels below street grade results in localized poor drainage and flooding of some residences, buildings, and roadways during storm events (RMC 2004). Storm water-related flooding and erosion were found to be a result primarily of upslope concentrated flows entering downhill lots without any storm drain facilities. The study proposed a number of projects to capture storm water runoff from residential lots and roadways and convey it to a creek or to the ocean. Projects include paving roads with rolled asphalt berms, installing drop inlets or catch basins, and constructing roadside ditches and drainage channels (RMC 2004). Project implementation is likely to be the responsibility of individual property owners, developers, and/or a local entity, working in collaboration with the County Flood Control and Water Conservation District. The 2004 study noted that new development is expected to substantially increase storm water runoff in Cambria neighborhoods, particularly in Lodge Hill where many roads are unpaved, and that any proposed development in the Cambria area should be planned with drainage improvements.

Together the 1999 and 2004 drainage studies indicate that storm water is not being adequately planned for or managed in Cambria's residential neighborhoods. Although current rates of runoff and erosion from neighborhoods do not appear to be significantly affecting habitat conditions in Santa Rosa Creek, both studies warned that storm water issues can be expected to worsen if development continues in the Cambria area, unless meaningful steps are taken to plan for and address road- and home lot-related storm water runoff.

2.9 Vegetation

2.9.1 Vegetation types and distribution

The Santa Rosa Creek watershed is dominated (63% of watershed total) by grassland/herbaceous vegetation, much of which is used for cattle ranching and dairy cattle pasture (Homer et al. 2004) (Table 2-8, Figure 2-24). Throughout the watershed, scrub/shrub (coastal and chaparral) is found in steeper, upland areas and mixed-hardwood forest types, such as California bay tree (*Umbellularia californica*), occur in riparian areas. In the inland portions of the watershed, mixed-hardwood forest, such as coast live oak (*Quercus agrifolia*), and stands of evergreen forest occur on ungrazed hillslopes. Closer to the coast, stands of Monterey pine (*Pinus radiata*) evergreen forest occur near Cambria, and woody and emergent herbaceous wetland vegetation, such as willows (*Salix* spp.) are found primarily around the lagoon (Figure 2-24). While the National Landcover Dataset of 2001 (Homer et al. 2004) was used to generate the summary of data in Table 2-8 and map of vegetation in the watershed (Figure 2-24), the vegetation descriptions provided below are based, in part, on the compilation and description of multiple vegetation maps for the watershed by TLCSLOC (2010).

Table 2-8. Vegetation types in the Santa Rosa Creek watershed.[a]

Landcover/Vegetation type		Area (acres)	Area (hectares)	% of watershed area[b]
Grassland/Herbaceous		19,256	7,793	63
Scrub/Shrub		3,235	1,309	11
Mixed Forest		2,899	1,173	10
Developed	Open Space	1,951	790	6
	Low Intensity	409	165	1
	Medium Intensity	124	50	0.4
	High Intensity	3	1	0.01
Evergreen Forest		1,958	792	6
Cultivated Crops		360	146	1
Woody Wetlands		153	62	1
Pasture/Hay		37	14	0.1
Emergent Herbaceous Wetland		4	2	0.01

[a] Source: 2001 National Land Cover Data (Homer et al. 2004)
[b] Proportion of land cover category within the total watershed area determined in GIS.

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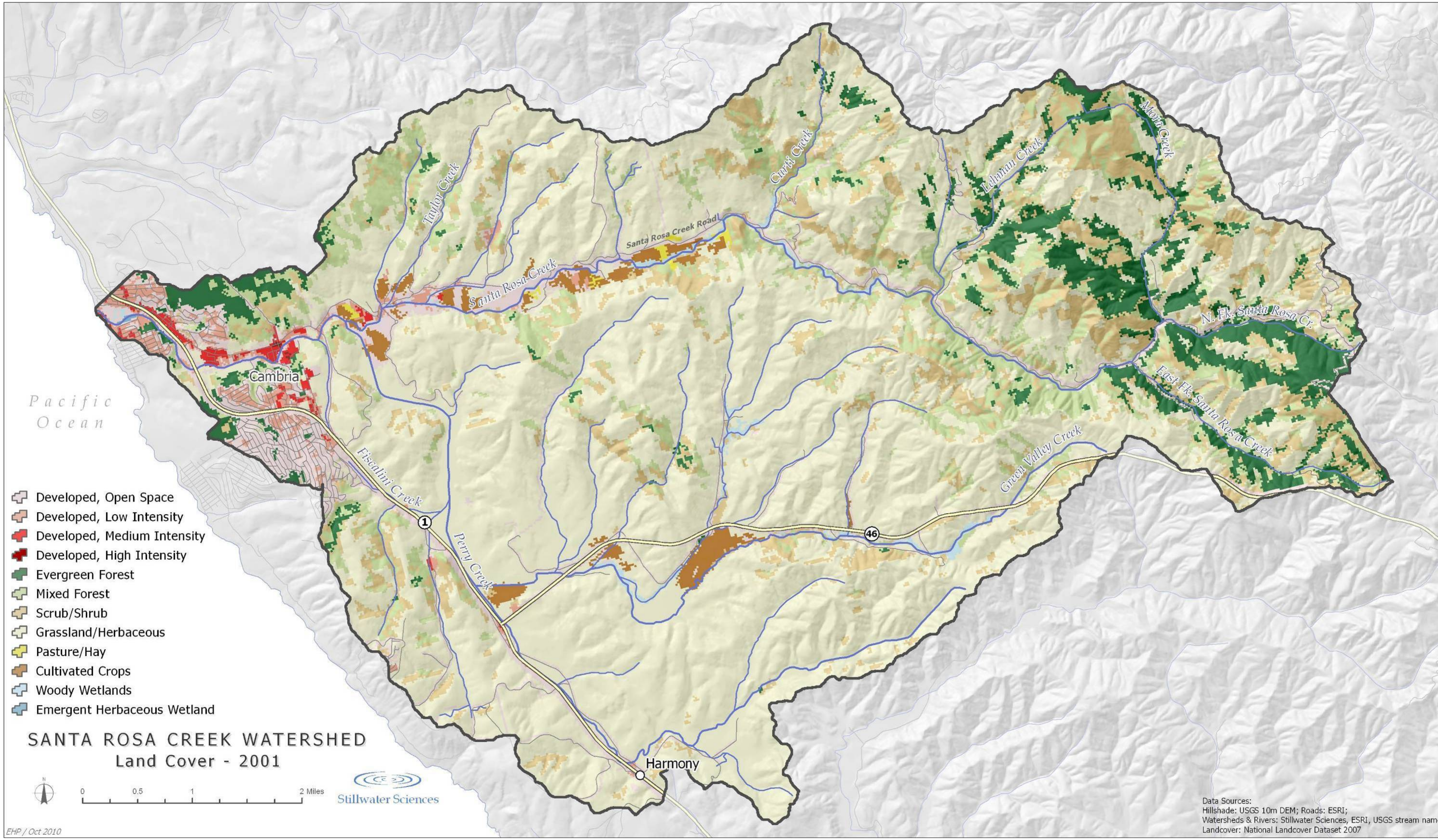

Figure 2-24. Vegetation/land cover types within the Santa Rosa Creek watershed.

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2.9.1.1 Grassland/Herbaceous

Grasslands dominate much of the watershed (Figure 2-24). Like most grasslands in California, those in the Santa Rosa Creek watershed are likely dominated by non-native grass species that are now considered naturalized (TLCSLOC 2010). For example, non-native wild oat (*Avena* spp.), soft chess (*Bromus hordeacous*), rip-gut brome (*B. diandrus*), and Italian ryegrass (*Lolium multiflorum*) are the dominant grass species in the Fiscalini Ranch Preserve (the old East-West Ranch), along with common weedy species such as filaree (*Erodium cicutarium*), vetch (*Vicia* sp.), black mustard (*Brassica nigra*), prickly lettuce (*Lactuca serriola*), storksbill (*Erodium botrys*), summer mustard (*Hirschfeldia incana*), milk thistle (*Silybum marianum*), wild radish (*Raphanus sativa*), mayweed (*Anthemis cotula*), Italian thistle (*Carduus pyncnocephalus*), coast morning glory (*Calystegia macrostegia* ssp. *cyclostegia*), and scarlet pimpernel (*Anagallis arvensis*) (Morro Group 2009). Despite being dominated by non-native species, grasslands in the Fiscalini Ranch Preserve have been documented to contain several native grasses and forbs that are indicative of native coastal prairie, such as California oat grass (*Danthonia californica*), hairgrass (*Deschampsia elongata*), purple needle grass (*Nassella pulchra*), sky lupine (*Lupinus nanus*), California poppy (*Eschscholzia californica*), tidy tips (*Layia platyglossa*), and California buttercup (*Ranunculus californicus*) (Ford and Hayes 2006, Morro Group 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 cattle, goat, and/or sheep 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 grassland/herbaceous. As a result of this loss and the number of protected plant and animal species associated with this vegetation type, there is increasing interest and effort to preserve and maintain coastal prairie through land acquisition, and grazing and fire management.

2.9.1.2 Scrub/Shrub

Chaparral, coastal scrub, and coast mixed shrub occur in patches throughout the watershed (Figure 2-24). Chaparral and southern coastal scrub communities generally grow in dense thickets, and are dominated by drought-tolerant long-lived shrubs, such as manzanita (*Arctostaphylos* spp.), California sagebrush (*Artemisia californica*), sage (*Salvia* spp.), and coyote bush (*Baccharis pilularis*) (TLCSLOC 2010). These communities are also highly flammable and adapted to occasional disturbance by fire, which facilitates seed germination and regeneration of some dominant species. 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 special natural communities or as the host of state-protected plant and animal species (CDFG 2003a; Hillyard 2009).

Scrub/Shrub and Mixed Forest vegetation in the upper Santa Rosa Creek watershed

2.9.1.3 Mixed forest

Both coast live oak and blue oak woodlands are components of areas mapped as Mixed Forest in the Santa Rosa Creek watershed. Coast live oak woodlands can occur on more moist, often north-facing slopes or in drier, more exposed areas (TLCSLOC 2010). In moister areas, coast live oak (*Quercus agrifolia*) generally forms dense forests with California bay-laurel (*Umbellularia californica*), madrone (*Arbutus menziesii*), and big-leaf maple (*Acer macrophyllum*), with a variety of shade-tolerant understory plants (TLCSLOC 2010). In drier areas, coast live oak woodlands are characterized by sparsely scattered oaks among either shrubby or herbaceous understory plants, or integrated with grasslands (TLCSLOC 2010). Blue oak (*Q. douglasii*) woodlands occur in the warmer, drier eastern portion of the watershed.

Areas of Mixed Forest also include bands of riparian vegetation that occur along most of the larger channels in the watershed (Figure 2-24). CDFG (Nelson et al. 2009) noted abrupt changes in the composition and condition of riparian vegetation as one moves downstream:

> From the headwaters down to stream mile 7.8, the creek flows through a sinuous confined canyon where oaks, California bay and alder are the dominant tree species. Grasses, sedges and other herbaceous species comprised the understory. At stream mile 7.8, the creek abruptly discharges from the narrow canyon into a broad valley with a poorly defined creek channel, extensive gravel bars and flood plains, short, denuded stream banks and intermittent willow trees, mule fat and grasses. … From stream mile 6.5 downstream to stream mile 3, the valley floor is still broad, however the stream channel is incised. Riparian species include alder, willow, cottonwood, sycamore and a dense herbaceous understory. Downstream of this point the valley constricts somewhat and the town of Cambria surrounds the creek. Much of channel in this area is lined with rip rap and the riparian has been encroached upon by development. The native vegetation along the creek includes willow, poison oak, stinging nettle and blackberry, however extensive stands of non-native trees, shrubs and ivy dominate the riparian zone to the exclusion of native vegetation.

Riparian canopy conditions are further described in Section 2.9.4 below.

2.9.1.4 Evergreen forest

Much of the Evergreen forest mapped in the lower watershed is Monterey pine (*Pinus radiata*) (Figure 2-24). There are approximately 3,500 acres of Monterey pine forest in and around the community of Cambria (both within and outside the Santa Rosa Creek watershed), which constitutes approximately 17% of the remaining native Monterey pine forest in California and Baja California (Cambria Forest Committee 2002). In natural stands, Monterey pine forms a closed canopy forest with coast live oak, and toyon (*Heteromeles arbutifolia*), with various shrubs and herbs in the understory (Cambria Forest Committee 2002, TLCSLOC 2010). Approximately 1/3 of the Cambria Monterey pine forest intergrades with developed areas (Cambria Forest Committee 2002). The Cambria Forest Management Plan was developed in 2002 to guide conservation and management of the Cambria Monterey pine forest, in part as a response to continued threats to the forest by pine pitch canker disease and urban development. Monterey pine has also been planted extensively outside of its indigenous range, both in California and around the world.

Evergreen forest in the upper watershed is likely a mix of hardwoods, gray pine (*Pinus sabiniana*), and potentially Douglas fir (*Pseudotsuga douglasii*).

2.9.1.5 Woody and emergent herbaceous wetlands

During periods of low flow and when the sandbar at Moonstone Beach is closed, a seasonal lagoon forms at the downstream end of Santa Rosa Creek. The seasonal lagoon supports a fringe of riparian vegetation at its upstream end and wetland species, such as cattail (*Typha* spp.) that are tolerant of continuous inundation, along the water's edge. Small patches of salt marsh vegetation that are tolerant of the brackish water conditions closer to the ocean occur along the waters edge at the downstream end of the seasonal lagoon. Small patches of dune vegetation occur on the beach, outside of the seasonal lagoon inundation area (Z. Diggory, pers. obs., 2009).

2.9.2 Rare plant species and vegetation types

TLCSLOC (2010) identified special-status plant species with the potential to occur in the watershed using CDFG's California Natural Diversity Data Base (CNDDB) and the California Native Plant Society's (CNPS) Inventory of Rare and Endangered Plants online database. Queries of these databases, which included the Cambria and Cypress Mountain 7.5 minute quadrangles, identified 21 plant species with the potential to occur in the watershed that are listed by CNPS as rare, threatened, or endangered in California and elsewhere (CNPS List 1B). These are primarily perennial herb species, but also include five manzanita species and several other shrubs, as well as Monterey pine (TLCSLOC 2010). Of these, Cambria morning-glory (*Calystegia subacaulis* ssp. *episcopalism*), Obispo Indian paintbrush (*Castilleja densiflora* ssp. *obispoensis*), compact cobwebby thistle (*Cirsium occidentale* var. *compactum*), and Monterey pine (*Pinus radiata*) have been documented to occur in the watershed, specifically in the Fiscalini Ranch Preserve (Morro Group 2009).

As described earlier, Cambria supports a notable percentage of the remaining natural stands of Monterey pine in California and Baja California (Cambria Forest Committee 2002). Natural Monterey pine forests are recognized in the CNDDB as a special natural community (CDFG 2003a), and this population in particular is protected by the Coastal Commission as an Environmentally Sensitive Habitat Area (ESHA). In addition, the Fiscalini Ranch Preserve supports Valley Needlegrass Grassland vegetation, which is composed of purple needlegrass (*Nassella pulchra*), a native bunchgrass that was once an abundant component of the California grassland flora and is recognized in the CNDDB as a special natural community (CDFG 2003a, Morro Group 2009).

2.9.3 Non-native invasive plant species

Combined, over 200 non-native invasive plants observed or with the potential to occur in the Santa Rosa Creek watershed have been identified by CDFG (Nelson et al. 2009), TLCSLOC (2010), Morro Group (2009), and Cambria Forest Committee (2002). This includes the non-native grassland species described in Section 2.9.1. Several of these species are particularly troublesome as they are already widely distributed, are highly effective at replacing native vegetation, are known to disrupt and impair native habitat, or require aggressive treatment to control. These include:

- arundo/giant reed (*Arundo donax*)
- pampas grass (*Cortaderia selloana and/or C. jubata*)
- Scotch broom (*Cytisus scoparius)*
- cape ivy (*Delairea odorata*)
- eucalyptus (*Eucalyptus* sp.)
- French broom (*Genista monspessulana*)

During a survey of the lower 14 mi (22 km) of Santa Rosa Creek, CDFG noted the presence and general distribution of non-native plants in the riparian corridor (Nelson et al. 2009). The greatest diversity of non-native invasive plants in the riparian corridor was found to occur in the lower 6 mi (10 km) of the creek, and at stream mile two specifically (Nelson et al. 2009). The residential and commercial land uses that occur close to the creek in this area are likely responsible for the intentional and/or accidental introduction of most of these plants, many of which are commonly found in gardens (e.g., palm trees, nasturtium, and periwinkle). With only two exceptions, no non-native plant species were observed between stream miles 11 and 14 (Nelson et al. 2009).

Eucalyptus, planted throughout California in the late 1800's for wharf construction and fence post production and to provide wind breaks, was recorded as relatively dense stands on the streambank in some locations. Eucalyptus often precludes the establishment and/or growth of understory species because of its allelopathic properties; oils in the leaves and bark that fall to the ground prevent or greatly reduce the ability of other plants to grow. CCSD is currently planning a eucalyptus removal project along the lower creek, downstream of the Highway 1 Bridge (B. Boer, pers. comm., 2010).


Cape ivy infestation near the lagoon

CDFG noted that "cape ivy was found from stream mile 10 downstream, but was most extensive in stream miles 5 and 6" (Nelson et al. 2009). In some areas, cape ivy was found to completely cover the streambank. In these and other cases, the extent of cape ivy is likely sufficient to preclude the establishment of native plants that would better shade the creek and help moderate stream temperatures as well as provide habitat for native wildlife species. Although Nelson et al. (2009) noted pampas grass in several areas in the lower 6 mi (9 km) of the creek, this was most likely jubata grass, which is easily confused with pampas grass but is more prevalent along the San Luis Obispo County coast (DiTomaso 2000). Large infestations of pampas grass and jubata grass threaten California's coastal ecosystems by crowding out native species, particularly in sensitive coastal dune areas.

Only one patch of arundo was recorded by CDFG, near stream mile 14 (Nelson et al. 2009). Arundo is a highly invasive species in central and southern California riparian environments and can rapidly displace native vegetation and alter riparian habitat conditions. This occurrence of arundo should be an extremely high priority for eradication to prevent it from spreading farther downstream.

In addition to cape ivy and pampas grass, the Cambria Forest Committee (2002) also noted that French broom and Scotch broom are the most abundant invasive species in the Cambria area, and the ones that will require the most aggressive treatments.

2.9.4 Riparian vegetation conditions

When of sufficient width and density, riparian vegetation performs many functions in natural river systems. It provides a buffer between the stream and adjacent land uses, reduces erosion, and filters runoff and nutrients, thereby reducing the delivery of fine sediment and pollutants to the stream. Riparian vegetation provides habitat for terrestrial wildlife and nesting birds, movement corridors for wildlife, and woody debris for instream habitat. Riparian canopy cover supplies leaf litter and terrestrial invertebrates for the aquatic foodweb and moderates stream temperatures by shading the channel and reducing near-stream windspeed (Poole and Berman 2001). The conservation and restoration of riparian vegetation, therefore, provides a relatively straightforward and cost-effective way for landowners and other watershed stakeholders to conserve and enhance myriad ecosystem conditions.

Following California statehood in 1850, Americans quickly settled the watershed and greatly increased the pace of land clearing, which was reportedly achieved by cutting and/or burning the native vegetation (Coffman 1995, D. Dunlap, pers. comm., 2009). Historical accounts from across the coastal region tell of coordinated efforts by land owners to clear valley-bottom forests along major rivers (Boughton et al. 2006), which was likely practiced along Santa Rosa, Perry, and Green Valley creek valleys. Historical illustrations of ranches in the watershed from the late 1800s and the earliest aerial photographs of the watershed in 1937 indicate only narrow strands of riparian vegetation along streams. Aerial photography taken in 2009 reveals a considerable increase in riparian vegetation extent and density compared with 1937 (Figure 2-5).

Outside of Cambria, the ability of riparian vegetation to recruit and grow is limited by cattle grazing in the riparian corridor, the effect of which is apparent in the denuded streambanks in much of the Perry/Green Valley Creek sub-watershed, and to some extent by groundwater conditions, such as in the middle reaches of Santa Rosa Creek. Encroaching riparian vegetation is also occasionally removed from the channel in wet water years in the vicinity of bridges and other public works by the San Luis Obispo County Public Works Department to reduce the risk of flooding (B. Boer, pers. comm., 2010).

While riparian vegetation extent has recovered since the 1930s, it is now limited by urban development and infrastructure, which limits the area where riparian vegetation can establish (see Figure 2-25) and is a source of non-native invasive plant species (see Section 2.9.3 above). Riparian canopy cover conditions on Santa Rosa Creek vary by reach and are strongly influenced by stream flow. Between 1994 and 2006, tree canopy closure (i.e., the percent of the channel covered by the riparian tree canopy) was measured every four years in the lower 13 mi (20 km) of Santa Rosa Creek in association with steelhead population and habitat surveys (D. W. Alley & Associates 2008). CDFG also measured riparian canopy density at approximately one-third of the habitat units mapped during a survey of steelhead in the lower 14 mi (22 km) of the creek (Nelson et al. 2009). Table 2-9 summarizes the results of the D. W. Alley & Associates (2008) tree canopy measurements.

Figure 2-25. Historical (1937) and current (2009) aerial photographs of riparian corridor conditions in the lower reach of Santa Rosa Creek and near the town of Cambria.

Table 2-9. Tree canopy closure in the lower 13 mi (20 km) of Santa Rosa Creek.[a]

Reach location (stream miles)	Tree canopy closure (percent) [b]				
	1994	1998	2002	2006	Average
0.5–2.9	n/a	33	42	27	34
2.9–3.4	n/a	40	54	42	45
3.4–4.2	44	36	53	42	44
4.2–7.9	44	32	33	24	33
7.9–9.6	57	34	55	44	48
9.6–10.1	72	63	67	58	65
10.1–11.2	63	63	77	67	68
11.2–11.5	52	70	80	85 [c]	72
11.5–12.4	59	71	77	70	69
12.4–13.0	59	70	74	68	68
Average	56	51	61	53	

[a] Source: D. W. Alley & Associates (2008). Values are estimated from Figure A18 and correspond with values reported in the text, with the exception of reaches 0b and 2 in 2002. The text reports these values as 61 and 54 percent, respectively.
[b] Measurements were taken in the fall and are estimated to be between 5 and 10 percent lower than during summer due to the onset of leaf-fall (D. W. Alley & Associates 2008).
[c] The Reach 5 sampling site was relocated into the upper portion of Reach 4 in 2006 (D. W. Alley & Associates 2008).

Tree canopy closure ranged from a low of 24% between stream miles 4.2–7.9 to a high of 85% between stream miles 11.2–11.5 (both in 2006), and varied by both reach and year (Table 2-9). The lower 8 mi (12 km) of the creek (reaches 0a–2), where the channel is widest, had consistently lower ranges and average canopy closure than in the upper reaches (Table 2-9). This is to be expected since higher levels of canopy closure are easier to maintain across narrower channels. This same pattern was observed by CDFG, who recorded canopy closures between 17% and 46% in the lower 8 mi (12 km) of the creek, and 23% to 57% in the upper 6 mi (9 km) (Nelson et al. 2009).

The lower 10 mi (16 km) of the creek experienced a decline in canopy closure between 1994 and 1998 in response to the March 1995 flood. D. W. Alley & Associates (2008) report that "[t]he entire riparian corridor, with all of its trees, was washed away for miles in the lower valley during that one storm flow. Many tree-less vertical banks were left afterwards, even in the straight-aways." Conversely, the canopy closure in the upper three reaches increased by approximately 10% between 1994 and 1998. By 2002, canopy closure had recovered to at least 1994-levels in most of the lower reaches. The high-flow event of 2005, which was a particularly wet year, likely contributed to the decline in canopy closure experienced in all reaches between 2002 and 2006.

The difference in canopy closure between the lower and upper reaches suggests that riparian vegetation is more effective at moderating stream temperatures in the upper reaches. This is demonstrated by the generally lower water temperature measured in the upper watershed by CDFG (see Section 2.8.1 above). The variation in canopy closure over the years, which appears to be driven largely by high-flow events, implies that the ability of riparian vegetation to shade the channel and effectively moderate stream temperatures also varies over time. In the years immediately following a scouring high-flow event, riparian vegetation is likely less effective at moderating stream temperatures and providing other ecosystem services, regaining its effectiveness as it re-grows. The typically more pronounced decline in canopy closure in the lower reaches of the creek following high-flow events further limits the ability of riparian vegetation to moderate stream temperatures in these reaches.

2.10 Wildlife

The diversity of vegetation types, as well as aquatic environments, in the Santa Rosa Creek watershed support a wide variety of habitat for a number of fish and wildlife species. TLCSLOC (2010) and Fiscalini Ranch Preserve final Master Environmental Impact Report (Morro Group 2009) both summarize the wildlife species that have been observed or are likely to occur in the habitat types found throughout the watershed. As the focal species of this watershed management plan, steelhead life history, habitat requirements, and population in the Santa Rosa Creek watershed is the primary focus of this section. In addition, this section summarizes other special-status species that occur in the watershed, with an emphasis on those species whose life history, habitat requirements, and population trends provide further insight into watershed conditions and the development of appropriate management and restoration action, as well as documented non-native invasive species.

2.10.1 Steelhead

Steelhead (*Oncorhynchus mykiss irideus*) found in the Santa Rosa Creek watershed belong to the South-Central California Coast Distinct Population Segment (DPS), which includes most streams in Monterey, San Benito, Santa Clara, Santa Cruz, and San Luis Obispo counties between the Pajaro (inclusive) and Santa Maria (exclusive) rivers (NMFS 1997, 2006). This DPS is listed as threatened under the federal Endangered Species Act (NMFS 1997, 2006), and is a CDFG species of special concern. The life history of south-central California coast steelhead and their population trends in Santa Rosa Creek are described below. As the focal species of this watershed management plan, factors limiting steelhead in the watershed are discussed in detail in Section 3.

2.10.1.1 Life history

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 Santa Rosa Creek watershed (Nelson et al. 2009), although detailed information on the relative proportion of each life history type is not available. The relationship between anadromous and resident life history forms of this species is the subject of ongoing research. The two forms are capable of interbreeding and current evidence suggests 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, Donohoe et al. 2008, Zimmerman et al. 2009), although in some watersheds the two life histories are distinct (e.g., Pearse et al. 2009).

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 (Shapovalov and Taft 1954, Behnke 1992). Adult steelhead are known to stray from their natal streams to spawn in nearby streams and, in more hydrologically variable streams of the central coast such as Santa Rosa Creek, straying is often more prevalent (Clemento et al. 2009, Pearse et al. 2009). Based on variability in life history timing, steelhead are broadly categorized into winter and summer reproductive ecotypes. Only the winter ecotype (winter-run) occurs in Santa Rosa 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, Behnke 1992, Busby et al. 1996). Little data on steelhead spawning time exist for Santa Rosa Creek, although both spawning time and distribution within the watershed appear to be related to time and duration of sandbar opening at the Santa Rosa Creek lagoon and winter discharge (D. W. Alley & Associates 2008, Nelson et al. 2009). Peak spawning time for other steelhead populations in the South-Central California Coast ESU is generally between January and March (Busby et al. 1996).

Female steelhead construct redds in suitable gravels, often in pool tailouts, or in isolated gravel patches in cobble and boulder dominated streams (McEwan and Jackson 1996). Eggs incubate in redds for 3–14 weeks, depending on water temperatures (Shapovalov and Taft 1954, Moyle 2002). 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 (Moyle 2002). After emergence in late-spring and summer, steelhead fry move to shallow-water, low-velocity habitat, such as stream margins and low-gradient riffles, and forage in open areas lacking instream cover (Hartman 1965, Fontaine 1988). 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) (Hartman 1965, Everest and Chapman 1972, Fontaine 1988). Juvenile steelhead occupy a wide range of habitats, using deep pools as well as higher-velocity riffle and run habitat (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 habitat with large rocky substrate or woody debris for cover (Hartman 1965, Raleigh et al. 1984, Fontaine 1988).

Juvenile[6] steelhead in northern and central California typically spend one to two years in freshwater prior to smolting[7] and outmigration to the ocean (Shapovalov and Taft 1954). The duration of time they spend in fresh water appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Hayes et al. 2008). Depending partly on growing conditions in their rearing habitat, steelhead may migrate downstream to estuaries as young-of-the-year (YOY) or may rear in streams for up to four years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Some steelhead in the lower 8 mi of Santa Rosa Creek likely require only one year of growth before reaching smolt size (approximately 6–7 in [150–180 mm]), whereas most fish above stream mile 8 typically require two years depending on availability of food and streamflow (D. W. Alley & Associates 2008). Age data from scale analysis and corresponding length data from individuals collected in the lower 8 mi of Santa Rosa Creek indicate that many individuals reach 4–5 in (120–140 mm) fork length[8] by their first fall (D. W. Alley & Associates 2008).

There is very little data describing juvenile steelhead life history strategies expressed in Santa Rosa Creek. Limited outmigrant trapping in Santa Rosa Creek suggests some individuals rear in upstream reaches before outmigrating as smolt, and some migrate to the lower reaches and lagoon at smaller sizes/younger ages (D. W. Alley & Associates 2008, Nelson et al. 2009). A portion of Santa Rosa Creek juvenile steelhead appear to have historically reared in the lagoon prior to outmigration (Puckett 1970, as cited in Rathbun et al. 1991), and recent evidence suggests some individuals likely still do in some years (Nelson et al. 2009, Alley and Sherman 2006, D. W. Alley & Associates 2008). During summer and fall sampling in 2004, Alley and Sherman (2006) captured 101 and 69 juvenile steelhead (varying in size from approximately 1–4 in [35–94 mm]

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[6] In this report juvenile steelhead refers to both young-of-the-year (YOY) and age 1+/2+, unless indicated separately. YOY are age 0+ individuals less than one year old that hatched the previous spring or early-summer and are the offspring of adults that spawned the previous winter or early-spring. Age 1+/2+ refers to all pre-smolt juveniles one year old or older. This report presents age-class-specific juvenile data from D. W. Alley & Associates (2008), who assigned age-classes based on site-specific divisions in the frequency distribution of steelhead standard-lengths (SL). Based on this sampling, YOY are likely to be between 3 and 6 months old, and age 1+/2+ are likely between 1.25 and 2.5 years old.

[7] Smolts are juvenile steelhead migrating to the ocean (i.e., smolting) that exhibiting silver coloration and have no parr marks.

[8] Fork length is measured from the tip of the snout to the fork, or middle, of the caudal (tail) fin

standard length[9]), respectively between Shamel Park and Windsor Bridge. Available water quality data also suggests that, at least in some years, conditions are suitable for steelhead rearing in the lagoon (see Section 3.5). In nearby San Luis Obispo Creek, many YOY steelhead that hatch in upper tributaries and reaches migrate downstream and rear in lower mainstem reaches prior to entering the ocean (Spina et al. 2005).

Smolt downstream migration in Santa Rosa Creek typically occurs from March through early June (D. W. Alley & Associates 2008). Trapping at Santa Rosa Creek stream mile 0.35 in 2005 revealed a peak in smolt capture from mid to late April (Nelson et al. 2009), which is consistent with that documented in nearby San Luis Obispo Creek (Spina et al. 2005). Steelhead exhibiting smolt coloration ranged from approximately 5–10 in (130–250 mm) fork length, with 6–7 in (150–180 mm) fork length being most common (Nelson et al. 2009).

2.10.1.2 Distribution and status

Annual estimates of adult escapement, the number of adults returning to spawn, are arguably the best measure of steelhead population trends (Gallagher and Gallagher 2005). Unfortunately, no actual adult steelhead escapement data are available for Santa Rosa Creek. Information on the historical adult steelhead population abundance in Santa Rosa Creek is largely anecdotal, but all available evidence points towards a decline. A study from 1969–1970 indicated that the adult steelhead run in the creek was approximately 600 individuals (Seldon 1972, as cited in Becker and Reining 2008). Based on CDFG unpublished reports and field logs, Rathbun et al. (1991) reported that steelhead were "abundant" in the Santa Rosa Creek drainage as recently as the early 1980's, but provided no adult population estimate. However, anecdotal fishermen reports indicated declines in the numbers of adult fish entering the creek between 1987 and 1991 (Rathbun et al. 1991). From 1988–1991, CDFG received only a few reports of spawning adults, and no steelhead were seen during a survey of the lower 2 miles of the creek in mid-July 1991 (Rathbun et al. 1991, Titus et al. 2006).

The apparent decline of the adult steelhead population is supported by more quantified juvenile population data. In 1972 the total juvenile population was estimate to be over 60,000 fish (Bailey 1973, as cited in Nelson 1994). An apparent population crash occurred between 1972 and 1978, when the juvenile population was estimated to be less than 10,000 (Knable 1978, as cited in Nelson 1994). The juvenile population in 1993 remained at just over 10,000 individuals (Nelson 1994). More recent population estimates (1998–2006) reported by D. W. Alley & Associates (2008), indicate an apparent rebound, with the juvenile population ranging from approximately 25,000 to 65,000. However, the different methodology used for these recent estimates makes it difficult to accurately compare them with the older estimates (Titus et al. 2006). Moreover, between 1998 and 2006 the abundance of both age 0+, also referred to as young-of-the-year (YOY), and age 1+/2+ juvenile steelhead in Santa Rosa Creek significantly declined (D. W. Alley & Associates 2008) (Figures 2-26 and 2-27).

[9] Standard length is measured from the tip of the snout to the anterior edge of the caudal fin (excludes caudal fin).

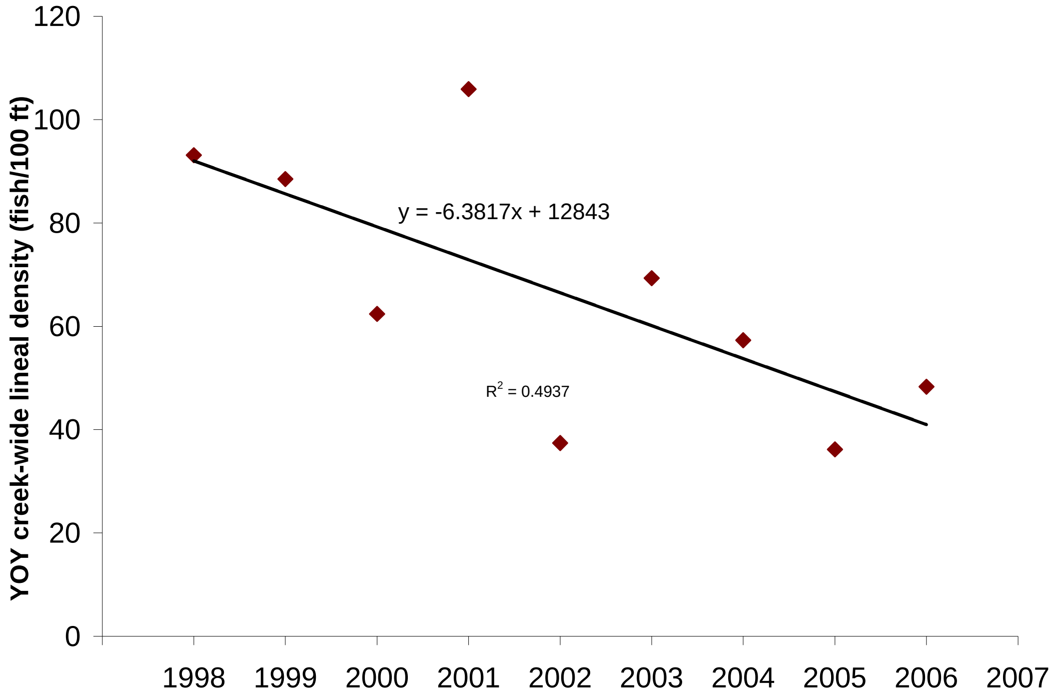

Figure 2-26. Lineal density (fish/100 ft) of YOY steelhead in Santa Rosa Creek from 1998 to 2006 (r^2 = 0.4937; *P* = 0.0348; n = 9). Data source: D. W. Alley and Associates (2007, Table 25a).

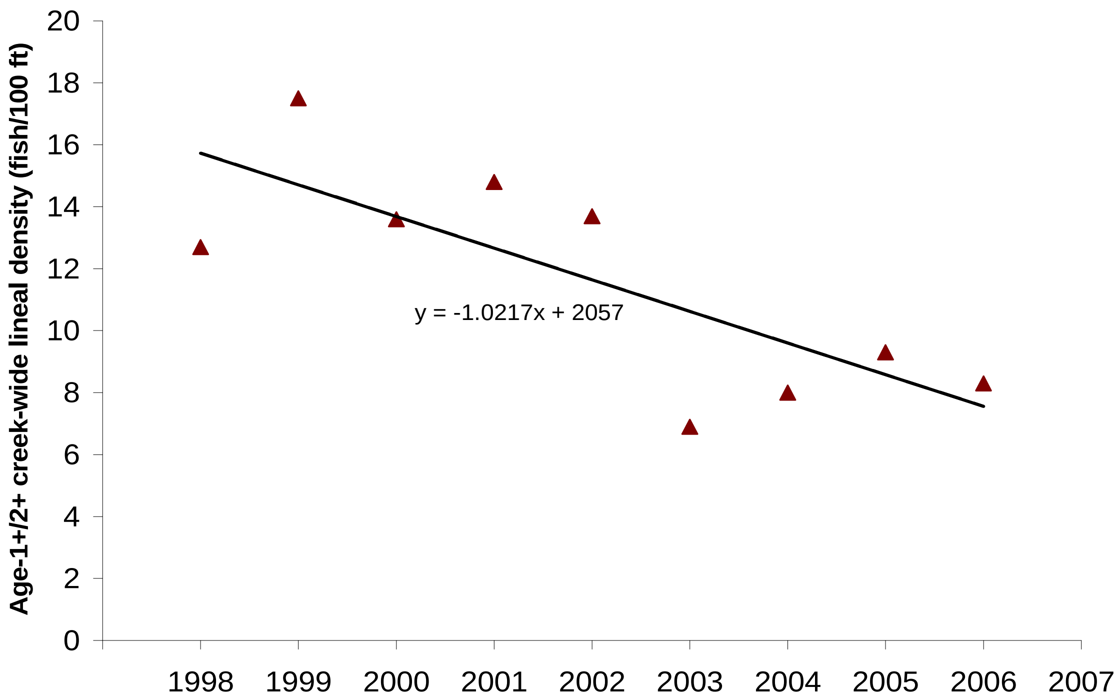

Figure 2-27. Lineal density (fish/100 ft) of age-1+/2+ steelhead in Santa Rosa Creek from 1998 to 2006 (r^2 = 0.592; *P* = 0.0154; n = 9). Data source: D. W. Alley & Associates (2007, Table 25a).

Juvenile steelhead densities are consistently higher in the upper reaches (approximately stream miles 8–13) than in the middle and lower reaches (approximately stream miles 0–8) of Santa Rosa Creek (D. W. Alley & Associates 2008, Nelson et al. 2009) (Figures 2-28 and 2-29).[10] The generally higher densities in the upper reaches suggest that a greater number of steelhead spawned there, that food availability and habitat quality are higher (and thus capable of supporting higher densities of fish), and/or that embryo and/or juvenile survival was higher in these reaches than in the lower watershed. In addition, the upper reaches are more likely to support some level of resident rainbow trout production due to water quality and habitat features, although this cannot be ascertained based on existing information. Habitat conditions vary considerably between the reaches, with the upper reaches generally containing larger substrates, less fine sediment, deeper pools, lower summer base flows, and more stream shading due to higher percentage of canopy closure, than the middle and lower reaches, which run through a marine terrace and are lower gradient and less confined (D. W. Alley & Associates 2008, Nelson et al. 2009).

Using average densities of juvenile steelhead from previous monitoring results, Titus et al. (2006) documented a statistically significant shift in the use between the upper (approximately stream miles 8–13) and lower reaches (approximately stream miles 0–8) over a 23-year period, with increasing use of the upper creek and decreasing use of the lower creek. These results suggest that the degraded physical habitat and reduced instream flows in the lower creek (see discussions in Section 3) have progressively rendered this area less and less suitable for rearing juveniles.

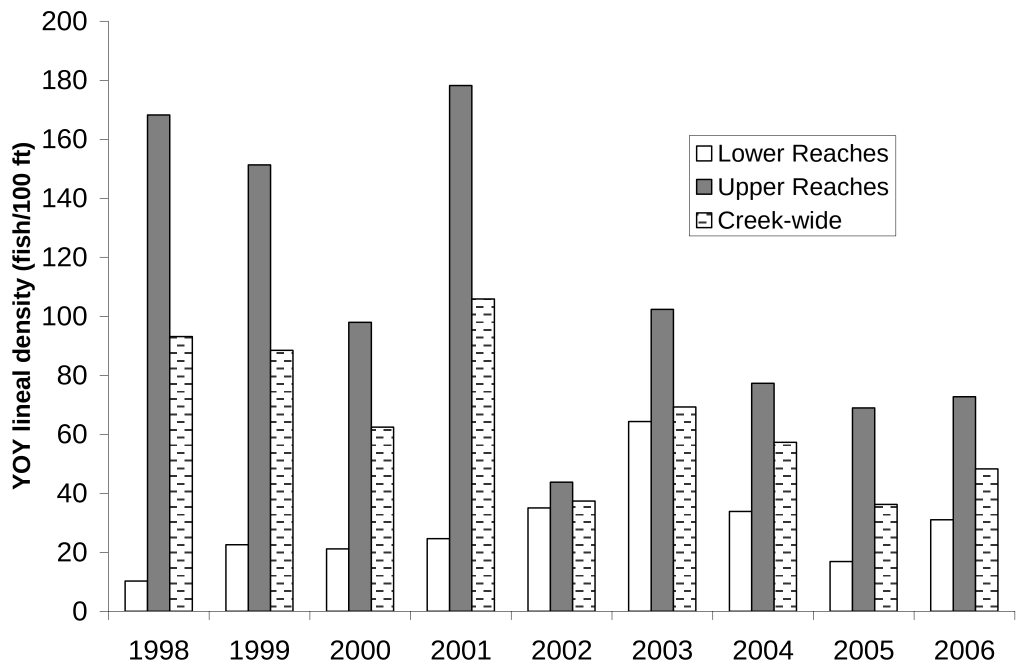

Figure 2-28. Mean lineal density of YOY steelhead at sample sites in the lower reaches (stream miles 0–8), upper reaches (stream miles 8–13), and creek-wide from 1998–2006. Data source: D. W. Alley & Associates (2007, Tables 26a and 26b).

[10] D. W. Alley & Associates (2008) and Nelson et al. (2009) used different reach delineations than those used and described previously in this document. These reports delineated lower reaches, also referred to as lower valley, from stream mile 0 to 8, and upper reaches, also referred to as upper canyon, from stream mile 8 to 13. These reach delineations are used when presenting data from D. W. Alley and Associates (2008) and Nelson et al. (2009).

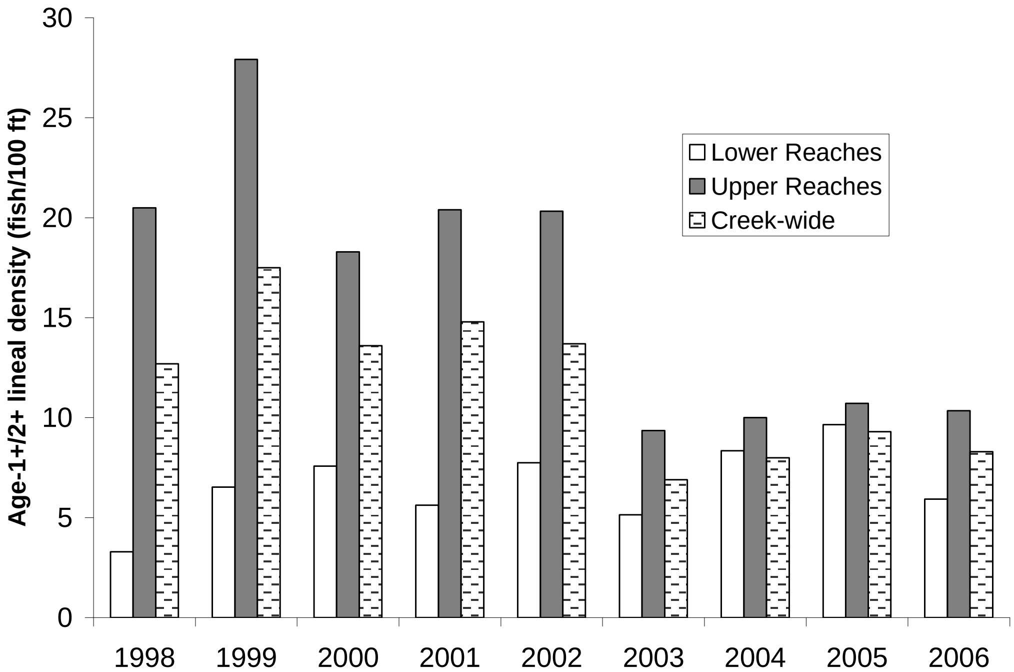

Figure 2-29. Mean lineal density of 1+/2+ steelhead at sample sites in the lower reaches (stream miles 0–8), upper reaches (stream miles 8–13), and creek-wide from 1998–2006. Data source: D. W. Alley & Associates (2007, Tables 26a and 26b).

Despite the evident decline in steelhead population since historical levels, compared to most other watersheds with populations in the DPS, Santa Rosa Creek contains a relatively high quantity of suitable spawning habitat and relatively high densities of juvenile steelhead have been observed in recent years (D. W. Alley & Associates 2008). For this reason, habitat restoration and continued monitoring of Santa Rosa Creek's steelhead population is considered important for the recovery of the DPS (NMFS 2007, CDFG 2010).

2.10.2 Other rare species

In addition to steelhead, TLCSLOC, Cambria Forest Management Plan, and Fiscalini Ranch Preserve final Master EIR all identified special-status wildlife species—those listed as threatened or endangered under either the federal or state Endangered Species Acts, or as a species of special concern (SC) by CDFG—with the potential to occur in the watershed (Cambria Forest Committee 2002, Morro Group 2009, TLCSLOC 2010). Of these, the following have been observed in the watershed (Rathbun et al. 1991, Nelson et al. 2009, D. W. Alley & Associates 2008, Morro Group 2009):

- Pacific (previously southwestern) pond turtle (*Actinemys marmorata*; SC)
- monarch butterfly (*Danaus plexippus*; CNDDB vulnerable species)
- tidewater goby (*Eucyclogobius newberryi*; federally endangered and SC)
- Monterey dusky-footed (Santa Lucia) woodrat (*Neotoma macrotis luciana*; SC)
- California red-legged frog (*Rana draytonii*; federally threatened and SC)
- American badger (*Taxidea taxus*; SC)
- two-striped gartersnake (*Thamnophis hammondii*; SC)

Pacific pond turtle, tidewater goby, California red-legged frog, and two-striped gartersnake have all been the subject of relatively recent surveys and reports in the Santa Rosa Creek watershed, as detailed below. The life history, habitat requirements, and population trends of these "umbrella species" provide additional insight, beyond that provided by steelhead, into the state of the watershed. In some cases, the habitat and life history requirements of these species are connected or overlap with those of steelhead and, as a result, appropriate management for steelhead is expected to benefit these species as well. In other cases, appropriate management for steelhead could conflict with the habitat and life history requirements of these other species. This section provides a brief overview of these species and their population trends in Santa Rosa Creek, and identifies potential synergies and/or conflict between these species and management for steelhead.

2.10.2.1 Pacific pond turtle

Pacific pond turtles inhabit fresh or brackish water characterized by areas of deep water, low flow velocities, moderate amounts of riparian vegetation, warm water and/or ample exposed basking sites, and underwater cover elements such as large woody debris and rocks (Jennings and Hayes 1994). In California, Pacific pond turtles are found from the Oregon border south to the border with Baja California, including the Central Valley and Sierra Nevada foothills, and along the Coast ranges (Stebbins 2003). The species has experienced population declines as conversion of wetland and riparian habitat to urban and agricultural use has accelerated (Jennings and Hayes 1994, Germano and Bury 2001). In addition, hatchlings and juveniles are vulnerable to predation by a variety of native and non-native mammals, birds, fish and amphibians (Moyle 1973, Holland 1985, both as cited in Rathbun et al. 1991).

Along major rivers, Pacific pond turtles are often concentrated in side channel and backwater areas. Turtles may move to off-channel habitats, such as oxbows, during periods of high flows (Holland 1994). While highly aquatic, Pacific pond turtles also spend time on land basking, over-wintering, nesting, and to seek refuge/cover, up to a reported 0.3–0.6 mi (0.5–1 km) away from aquatic habitats (Rathbun et al. 1992, Holland 1994, Reese and Welsh 1997, Rathbun et al. 2002). Egg-laying sites vary from sandy shoreline to forest soil types, though are generally located in grassy meadows, away from trees and shrubs (Rathbun et al. 1992, Holland 1994, Rathbun et al. 2002), with canopy cover commonly less than about 10% (Reese 1996). In an 8-year study of several creeks just north of Santa Rosa Creek, Pacific pond turtles left the drying creek beds in late summer for nearby woodland and coastal sage scrub habitat, and returned after winter floods, and females laid their eggs in sunny upland habitat, such as grazed pastures (Scott and Rathbun 2001, Rathbun et al. 2002).

Surveys of lower Santa Rosa Creek in the late 1970s consistently observed Pacific pond turtles hauled-out on logs in the lower end of the seasonal lagoon (D. Holland, unpubl. data, as cited in Rathbun et al. 1991). Since 1986, however, observations of Pacific pond turtles have decreased, and only two to three individuals were recorded downstream of the Highway 1 Bridge in 1991 (Rathbun et al. 1991). At least one Pacific pond turtle was captured in the lower 14 mi (22 km) of Santa Rosa Creek during CDFG's steelhead surveys in 2005 (Nelson et al. 2009). Rathbun et al. (1991) attribute this apparent decline to insufficient instream flows resulting from a combination of below-average precipitation that year and groundwater pumping in the lower reaches of the creek.

In general, management actions to enhance steelhead habitat should also benefit Pacific pond turtles. For example, actions to increase instream flow, enhance the riparian corridor, reduce fine sediment delivery to channels, and provide instream woody debris should improve aquatic habitat conditions for Pacific pond turtle. However, the conservation of upland scrub and grassland habitat adjacent to the creek is equally important for egg-laying, refuge, and basking habitat.

2.10.2.2 Tidewater goby

Tidewater goby is a small fish that inhabits coastal lagoons, marshes, estuaries, and lower stream reaches along the California coast from Del Norte County to San Diego County (Swift et al. 1989, Moyle 2002, USFWS 2005). The fish still occurs within this range, but at over half of the sites within the distribution, populations have been extirpated or are extremely small with uncertain long-term persistence (USFWS 2005). The decline in this species resulted in it being listed as federally endangered in 1994 (USFWS 1994). Tidewater gobies are an important part of estuarine food webs because they provide prey for larger fish, aquatic snakes, and piscivorous birds (Swenson and McCray 1996). Tidewater gobies are threatened by changes in water quality, degradation and loss of winter and summer habitat due to urbanization and sandbar breaching, and predation from invasive species.

During reproduction/spawning, juvenile, and adult life stages, tidewater goby appear to prefer shallow depths (20–100 cm [8–39 in]) near emergent vegetation at the fringe of large estuaries and within lagoon and tidal slough systems, though possibly deeper since most previous surveys did not effectively sample in deeper waters (Stillwater Sciences 2006a).

Tidewater gobies were documented as abundant in the Santa Rosa Creek lagoon in 1977, but subsequent surveys in the early to late 1980s documented only small numbers (Swift 1977, 1981, and Dudley 1988, as cited in Rathbun et al. 1991). As with other species in the lower creek, Rathbun et al. (1991) attributed this decline to a lack of instream flow from primarily agricultural and urban water use. D. W. Alley & Associates surveyed tidewater goby in Santa Rosa Creek lagoon from 1995 to 2007 and documented highly variable abundance (Alley and Sherman 2006, D. W. Alley & Associates 2008).

Habitat restoration may be mutually beneficial to steelhead and tidewater gobies. For example, enhancement of brackish marshes and lagoon habitat can increase steelhead rearing habitat while also providing year-round habitat for tidewater goby (Stillwater Sciences 2006a). However, the habitat requirements of the tidewater goby differ enough such that restoration for steelhead may not always be beneficial, and under some circumstances may be detrimental, to tidewater goby populations (Stillwater Sciences 2006a). Therefore, care must be taken when implementing actions to enhance steelhead habitat to minimize unintended consequences on tidewater goby habitat. Accurate predictions of the effect of restoration on both water depths and salinity dynamics are crucial in determining the long-term effect of restoration on tidewater goby habitat quality and extent (Stillwater Sciences 2006a).

2.10.2.3 California red-legged frog

California red-legged frogs are found in ephemeral or permanent bodies of water, including wetlands, natural and artificial ponds and reservoirs, wet meadows, lakes, and low-gradient, slow-moving stream reaches with permanent pools, primarily in coastal drainages along California's central coast. The frog's range covers Mendocino County to Baja California, with isolated remnant populations occurring in the Sierra foothills, from sea level to approximately 8,000 ft (2,440 m) (Stebbins 2003, Shaffer et al. 2004). They are considered extirpated from the foothills of the Sierra San Pedro Martir, the coastal plain of Baja California Norte, and the Central Valley region, which represents an approximate 70% reduction of its historical range (CDFG 2009, USFWS 2002). California red-legged frog populations are threatened within their remaining range by a variety of human-influenced impacts, including urban encroachment, altered hydrological regimes that are not suitable for their life history needs, introduction of exotic predators and competitors, contaminants including pesticides and fertilizers, and habitat fragmentation (USFWS 2002). It is a threatened species under the federal Endangered Species Act (USFWS 1996) and a California species of special concern.


California red-legged frog

California red-legged frog habitat is generally characterized by still or slow-moving water with deep pools (usually at least 2 ft [0.7 m], though frogs have been known to breed in shallower pools) and emergent and overhanging vegetation, usually cattails, rushes, or willows (Jennings and Hayes 1994). Although some adults may remain resident year-round at favorable breeding sites, others may disperse overland up to a mile or more (Fellers and Kleeman 2007). Movements may be along riparian corridors, but some individuals move directly from one site to another without apparent regard for topography or watershed corridors (Bulger et al. 2003). California red-legged frogs sometimes enter a dormant state during summer or in dry weather, finding cover in small mammal burrows, moist leaf litter, root wads, or cracks in the soil. 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). In the study of several creeks north of Santa Rosa Creek, high spring flows were found to inhibit California red-legged frog breeding and eliminate egg masses in some creeks in some years (Scott and Rathbun 2001). In general frogs were always found in or very near water, but could be found farther upland in wet winters. Overhanging willow branches, bulrush/ cattails, exposed tree roots, and upland thickets were the most common cover types used by frogs during the study (Scott and Rathbun 2001).

Annual herpetological surveys of lower Santa Rosa Creek from the mid-1970s to 1989 consistently documented California red-legged frogs, but in decreasing numbers (Rathbun et al. 1991). In 1991, only two red-legged frogs—one dead—were observed in the creek between the Windsor Street bridge and Highway 1 bridge (Rathbun et al. 1991). An unspecified number of California red-legged frogs were captured in the lower 14 mi (22 km) of Santa Rosa Creek during CDFG's steelhead surveys in 2005 (Nelson et al. 2009). Rathbun et al. (1991) identified insufficient instream flow in lower Santa Rosa Creek, as a result of agricultural and urban water use, and a lack of adequate cover as the primary causes of the decline in red-legged frogs in this area.

In general, management actions to enhance steelhead habitat should also benefit California red-legged frogs, including increasing instream flows, enhancing riparian habitat, reducing fine sediment delivery to channels, providing instream woody debris and undercut banks for cover, and managing for non-native species (USFWS 2002). For California red-legged frog, it is also important to provide adequate connectivity between breeding, non-breeding, and dispersal habitats (Fellers and Kleeman 2007), as well as to conserve a well-distributed array of natural habitat elements in terrestrial areas upland from occupied aquatic sites (Bulger et al. 2003). Habitat for early life stages of steelhead tend to be similar for California red-legged frogs tadpoles, including low-velocity areas near streambanks.

2.10.2.4 Two-striped garter snake

The two-striped garter snake is generally found around pools, creeks, cattle tanks, and other water sources along the California coast from Monterey County to northern Baja California (Stebbins 2003). Two-striped garter snakes are threatened by a loss of wetland habitat, which has contributed to a reduction in their range. It is currently a California species of special concern.

Although generally considered an aquatic species, preferred retreat habitat is terrestrial, such as mammal burrows, crevices, and surface objects (Rathbun et al. 1993). Juveniles and adults feed primarily on small fish, fish eggs, tadpoles, frog metamorphs, and small invertebrates (Jennings and Hayes 1994). A study of several creeks just north of Santa Rosa Creek found that female two-striped garter snakes spent most of the year in various terrestrial habitats, either on the surface, under surface objects, or in animal burrows (Scott and Rathbun 2001). In the water, snakes were most often found among aquatic vegetation, cattails, bulrushes, and overhanging willow branches. Upland, snakes were often associated with grassy areas and small mammal borrows (Scott and Rathbun 2001).

Numerous two-striped garter snakes were observed in lower Santa Rosa Creek during surveys in the late 1970s, but none were observed in subsequent surveys (Rathbun et al. 1991). As with other aquatic species in the lower creek, Rathbun et al. (1991) attributed this decline to a lack of instream flow from primarily agricultural and urban water use, which is likely correlated with a decrease in aquatic prey species, such as small fish and frogs/tadpoles.

In general, management actions to enhance steelhead habitat should also benefit two-striped garter snakes. Primarily, actions to increase instream flow, enhance the riparian corridor, and reduce fine sediment delivery to streams should improve aquatic habitat conditions for two-striped garter snake by increasing their prey base. However, the conservation of upland habitats adjacent to the creek is equally important for refuge and basking.

2.10.3 Non-native, invasive wildlife species

While most non-native species are not particularly invasive or detrimental, some have no natural controls in their new environmental and are able to spread unchecked, causing significant and sometimes irreparable damage to native habitat and species. For example, non-native invasive species can prey on native species, out-compete native species for food and other resources, and/or degrade habitat for native species. While there has been no comprehensive survey for non-native invasive fish and wildlife species in the Santa Rosa Creek watershed, incidental observations during surveys for steelhead and other native species provide an indication of the primary non-native invasive species that occur in the watershed.

2.10.3.1 Aquatic species

Dr. Dan Holland (unpublished data, as cited in Rathbun et al. 1991), CDFG (Nelson 1994, Nelson et al. 2009), and D. W. Alley & Associates (2008) recorded the presence of several non-native aquatic species in creeks in the watershed. These include:

- brown bullhead catfish (*Ictalurus nebulosus*)
- green sunfish (*Lepomis cyanellus*)
- bluegill (*Lepomis macrochirus*)
- crayfish (*Pacifastacus leniusculus*)
- bullfrog (*Rana catesbeiana*)

Mosquitofish (*Gambusia affinis*) are also likely to occur in the creek and ponds in the watershed (G. Rathbun, pers. comm., 2010). Many of these non-native species have been documented to prey upon native species and are capable of continually dispersing into Santa Rosa Creek from the many stock ponds in the watershed. Preventing their further establishment and eradication has been identified as an important step in protecting native species populations in Santa Rosa Creek (Rathbun et al. 1991, D. W. Alley & Associates 2008, Nelson et al. 2009). Rathbun et al. (1991) implicated bullfrogs and bass in the extirpation of tidewater goby in nearby Old Creek (near the town of Cayucos) and noted that bluegill may be a serious predator of tidewater gobies and red-legged frog eggs in Santa Rosa Creek. Similarly, D. W. Alley & Associates (2008) identifies introduced non-native predators, such as centrarchids (bass family of fishes), bullfrog and possibly crayfish as one of the four major threats to tidewater goby in the watershed. In an assessment of steelhead habitat and limiting factors, Nelson et al. (2009) notes that while crayfish have been shown to consume salmonid eggs, the impact of their ubiquitous presence in Santa Rosa Creek is not understood and their eradication would be difficult at best. Nelson et al. (2009) were particularly disconcerted by the presence of bullfrogs and green sunfish, which can prey upon steelhead eggs and young-of-the-year, but are generally less common in small coastal streams like Santa Rosa Creek. They continued: "Given the warm water temperatures in the lower watershed both of these non-native species will thrive during the summer months. It is doubtful that the sunfish could withstand the higher winter flows, but the adult bullfrogs will move to higher ground during these flow events, re-occupying the creek when flows subside."

There have been no documented reports of Asian clam (*Corbicula fluminea*), a highly invasive aquatic invertebrate, in the Santa Rosa Creek watershed, but it has been documented in the Salinas River and in Lake Nacimiento by the USGS Nonindigenous Aquatic Species program (NAS 2010).

2.10.3.2 Terrestrial species

European starlings (*Sturnus vulgaris)* and brown-headed cowbirds (*Molothrus ater*) are both widespread non-native birds that can affect native bird populations and occur or are likely to occur in the Santa Rosa Creek watershed. European starlings are aggressive competitors for nest holes, often evicting native species, while brown-headed cowbirds are 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. There have been no documented reports of brown-headed cowbirds in the Santa Rosa Creek watershed specifically, but high counts of the birds have consistently been recorded during the annual Christmas Day bird count in San Luis Obispo County (MCAS 2005, 2006). European starling populations appear, at least anecdotally, to be increasing in the watershed (R. Hawley, pers. comm., 2010).

Feral pigs (*Sus scrofa*) are known to occur and cause damage to creek channels and other areas in the watershed (S. Soto, pers. comm., 2010; G. Kendall, pers. comm., 2010; M. Smith, pers. comm., 2010). California's feral pig population likely started in San Benito and Monterey counties with escaped domestic swine brought over by Mexican settlers, who commonly released swine to forage in woodlands (Groves and Di Castri 1991, Kreith 2007). Since then feral pigs have been deliberately (and illegally) relocated elsewhere in the state for hunting (Kreith 2007). In the Santa Rosa Creek watershed, wild Russian boars and sows were brought in for hunting in the 1930's by a landowner to amuse his guests (D. Dunlap, pers. comm. 2010). 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 pigs degrade ecosystems through predation and competitive impacts on native fauna, grazing on native plants, and physically altering habitat by rooting. Rooting creates large, disturbed areas that can lead to extensive erosion, displace native species, facilitate invasion by non-native, invasive plant species (Barrett 1977), and contribute to fine sediment delivery to waterways. Feral pig disturbance causes several million dollars in damages to crops, fencing, roads and trails annually in California, and, between 2002 and 2006, for over $275,000 in damages in San Luis Obispo County alone. Feral pig is regulated as a big game mammal by CDFG. Hunting is believed to have thinned the feral pig population in the Santa Rosa Creek watershed dramatically compared with levels in the 1960s through 1980s, but the population appears to be increasing again in the upper watershed (S. Soto, pers. comm., 2010; D. Dunlop, pers. comm., 2010).

2.11 Critical Issues

There are several issues that are impairing or have the potential to affect ecological conditions in the Santa Rosa Creek watershed and make obvious focal points for restoration and management planning. These issues are summarized below and include water quantity, water quality, fine sediment, non-native invasive species, and changes in land use. Several of these issues feature prominently in the steelhead limiting factors analysis (Section 3), and recommendations to address them are included in Section 4.

2.11.1 Water quantity

While the Santa Rosa Creek 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, groundwater pumping and riparian water diversions are removing water that would otherwise be available to the stream channel (see Section 2.6). Since the establishment of the San Simeon well field in 1979, groundwater extraction in the Santa Rosa Creek watershed by CCSD for municipal use has ranged from 0 to just over 200 acre-feet annually. Through the early 1990s, the amount of groundwater and surface water extracted by private entities was estimated to be approximately 3.5 times the amount pumped by the CCSD. The precise effects of groundwater pumping and water diversion on the volume of instream flow are not currently known, but there is general consensus among the resource scientists who have surveyed the watershed that low instream flows have contributed to the decline of several special-status aquatic species in the watershed (Rathbun et al. 1991, D. W. Alley & Associates 2008, Nelson et al. 2009).

Reduced instream flows are particularly problematic in the intermittent reach of the creek and in the lagoon. In the intermittent reach of the creek (see Figure 2-8), where surface flows readily percolate into the subsurface, reduced instream flows constrain, and may entirely eliminate, connectivity between upstream and downstream habitat. The mechanisms for water loss in this reach, and thus for restoring flows, are not currently well understood. In the lowest reaches of the creek and in the lagoon, reduced instream flows limit the extent of aquatic habitat and likely contribute to elevated stream temperatures and low DO levels in the lagoon.

2.11.2 Water quality

In general, water quality in the middle and upper reaches of Santa Rosa Creek is good: relatively low summer stream temperatures and a diverse assemblage of benthic macroinvertebrates that are indicative of high water quality are maintained. As one moves downstream, however, water quality becomes increasingly reduced. Water temperatures begin to increase, and occasionally exceed CCRWQCB water quality criteria for temperature in the summer, in the downstream portion of the middle reach, most likely as a result of limited riparian canopy cover in some areas and low instream flows. Sites adjacent to the town of Cambria had the least diverse assemblages of benthic macroinvertebrates and exhibit generally poor water quality as a result of increased levels of urban runoff, riprap, concrete, and trash. Water quality criteria for temperature and DO are frequently exceeded in the lagoon, in part as a result of low instream flows.

Sediment samples downstream of the Oceanic Mine on Curti Creek, including several in the lagoon, indicate elevated levels of mercury in the watershed (Section 2.8.3). Mercury is delivered to the watershed primarily from the erosion of mercury-laden waste rock at the former mill site by Curti Creek. No actions have been implemented to control this delivery or remediate the mine or former mill site. While additional study is necessary to determine the extent of mercury bioaccumulation in the aquatic food chain, moderately elevated levels of methylmercury—the bioavailable form of mercury—were recently measured in the Santa Rosa Creek lagoon.

2.11.3 Fine sediment in the lower reaches

Historically, fine sediment production rates likely increased substantially during the late 1800s and early 1900s when land clearing activities initiated (e.g., logging, ranching, and urbanization). Changes in the rainfall-runoff dynamics caused by this land clearing created a flashier system that more effectively eroded previously stored sediment on the hillslopes creating numerous erosional features (e.g., gullies and landslides), and led to channel incision throughout the watershed, particularly in the middle reaches of Santa Rosa Creek and the middle and upper reaches of Perry and Green Valley creeks. Over time, the channel incision eventually drove the mass instability of channel banks, another significant source of fine sediment. Together, this increase in hillslope and bank erosion rates led to proportionally higher rates of fine sediment delivery (as opposed to coarse sediment delivery) to stream channels in the watershed.

During the past half century, high fine sediment production rates have been reduced for the following reasons: (1) land use activities and vegetation coverage remained largely unchanged; and (2) the supply of sediments stored on hillslopes is less available after significant volumes were previously evacuated. The number and size of gully and landslide features present in the early 20th century have not changed considerably in recent decades, further indicating that land use-induced erosion of the landscape has stabilized. Additionally, and perhaps more importantly, stored sediment in the Santa Rosa Creek channel bed is predominantly coarse-grained (fine gravels to coarse cobbles), with few accumulations of fine sediment in the middle and upper reaches. This signifies that present-day fine sediment yields to the channel, which are assumed to be greater than pre-settlement rates, are not overwhelming the transport capacity of the channel under the current flow regime. This ability of the channel to self-maintain a predominantly coarse-grained bed helps to provide suitable instream habitat. However, occurrences of bank erosion exacerbated by incised channel morphology, altered watershed hydrology, and road runoff continue to represent a significant fine sediment source that can limit habitat quantity and quality at the reach scale.

The downstream, low-gradient reaches of Perry and Green Valley creeks are very fine-grained indicating that these major tributaries transport a high fine-sediment load to the lower reaches of Santa Rosa Creek. In addition, stormwater runoff-related erosion from Cambria neighborhood roads and home lots may also contribute to fine sediment in the lower reaches of Santa Rosa Creek. While the much of this input of fine sediment is conveyed with relative ease out of the watershed, the instream habitat quantity and quality of lower Perry and Green Valley creeks are limited by their fine-grained channels and enough remains in the lower reaches of Santa Rosa Creek to embed coarser substrates (see Section 3 for additional details).

2.11.4 In-channel infrastructure

Culvert on Curti Creek

Although the two downstream-most barriers to fish migration and movement (i.e., Burton Street Bridge and Ferrasci Road crossing) have been corrected, close to 20 man-made (i.e., bridges and culverts) barriers have been identified in the watershed. Barriers that may impede access to potential steelhead spawning and rearing areas include several stream crossings on Perry and lower Green Valley creeks.

Streambank rip-rap placement in the lower reaches of Santa Rosa Creek may cause flow to be deflected back across the channel resulting in further erosion downstream and threatening downstream land and infrastructure. If continued, extensive rip-rap placement could cause channel incision, more rapid flows, channel bed armoring (i.e., coarse bed surface layer), and reduced topographic complexity of the channel bed resulting in significant reductions in habitat suitability for native aquatic organisms including salmonids.

2.11.5 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. Several of these species are known predators of steelhead and other special-status aquatic species in the watershed, can alter and impair native habitat conditions, and/or have the ability to disperse and expand their distribution quickly. Relatively large infestations of some species, such as eucalyptus, cape ivy, crayfish, bullfrogs, and freshwater sunfishes, have already been reported. In addition, the currently limited distribution of some of the non-native invasive species documented in the watershed (e.g., arundo, pampas/jubata grass, and French broom) can quickly change since they are known to spread rapidly and can be difficult or problematic to control. For many non-native invasive species, early detection is important so that control measures can be undertaken before an infestation worsens and control becomes increasingly difficult.

2.11.6 Changes in land use

The subdivision of large parcels, population growth, and the proposed desalination plant all have important ramifications on the future condition of the Santa Rosa Creek watershed. In recent decades, fine sediment delivery to stream channels in the watershed has been reduced closer to pre-development levels primarily because land uses on high-yielding geomorphic landscape units have not changed over this time. The subdivision of large parcels is likely to result in land use changes in the smaller parcels. If these future land uses remove vegetation, change hillslope topography, or alter runoff patterns, there is the potential that gully and rill erosion could be reinitiated with a subsequent increase in fine sediment delivery to watershed stream channels. Retaining large parcels or otherwise conserving existing land uses, particularly in the upper watershed, could be a valuable tool in preventing the degradation of aquatic habitat throughout the watershed. In subdivided parcels, it will be important that land use changes are implemented in a way that reduces the potential for erosion and that associated increases in water demand are avoided.

The combination of San Luis Obispo County population growth and the proposed desalination plant to supplement the municipal water supply has the potential to increase the population and development in and around Cambria. This could further increase water demand and subsequently lead to impacts related to urban development that threaten aquatic habitat in the lower watershed (e.g., increased impervious surfaces, contaminated runoff, non-native invasive species introductions, and encroachment of floodplains and the riparian corridor). San Luis Obispo County's (2008) North Coast Plan restricts growth associated with any public works water supply project within the CCSD service area, stating: "[t]he maximum service capacity of the project will not induce growth inconsistent with the protection of coastal resources and public access and recreation opportunities," and that "[t]he project shall assure that CCSD water withdrawals from Santa Rosa and San Simeon Creeks will be sufficiently limited to protect: (1) adequate instream flows necessary to support sensitive species and other riparian/wetland habitats within the reach of the streams affected by CCSD pumping; (2) underlying groundwater aquifers; and (3) agricultural resources." Abiding by these restrictions by reducing groundwater pumping if the desalination plant is someday operational would minimize the potential effects of growth in Cambria on Santa Rosa Creek.

3 STEELHEAD LIMITING FACTORS ANALYSIS

The following limiting factors analysis describes seasonal and age class-specific habitat needs and discusses how habitat conditions in Santa Rosa Creek likely affect each steelhead freshwater life stage. The aim is to integrate 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 steelhead to determine mechanisms regulating population growth. Determining the relative effect of each life stage on overall population dynamics then allows for the identification of the factors most limiting steelhead production in the watershed (i.e., limiting factors) (Section 3.6) and specific actions that can be taken to address these factors (Section 4).

A species' life history and available habitat are among the many factors that can influence the growth or decline of a population (i.e., population dynamics) (Figure 3-1). Individual growth rate, survival, outmigration size, outmigration timing, ocean survival, upstream migration, and spawning success can all influence population dynamics of the Santa Rosa Creek steelhead population. Central to this analysis of limiting factors, which draws primarily upon the recent monitoring work of CDFG (Nelson 1994, Nelson et al. 2009) and D. W. Alley & Associates (2007 and 2008), is that steelhead population dynamics in Santa Rosa Creek are defined by two major characteristics: (1) patterns of habitat use between the upper and lower reaches, and (2) annual variation in flow. As to the first point, most of the successful spawning and rearing of steelhead in Santa Rosa Creek occurs in the upper reaches of the watershed (upstream of stream mile 8), although individual growth rates in the lower reaches (downstream of stream mile 8) appear to be high. Secondly, nearly every pattern of steelhead distribution, habitat use, abundance, density, or growth within the watershed is related to significant annual variation in instream flow conditions (as influenced primarily by precipitation). The sections below summarize the current understanding of the Santa Rosa Creek steelhead population based on the information gathered to date, and describe preliminary hypotheses of the primary factors likely limiting steelhead production in the watershed.

Ideally this understanding of steelhead and limiting factors hypotheses will be tested through the recommendations in Section 4, such that preliminary hypotheses are accepted, rejected, or refined, based on new understanding of the system, and as new uncertainties are identified. 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 steelhead.

3.1 Spawning Habitat

For anadromous steelhead populations (as well as other pacific salmon populations such as coho salmon), the average fecundity, the number of eggs in a female fish prior to spawning, is high relative to the amount of suitable juvenile rearing habitat usually available within a stream. Rather than being controlled by reproductive success, growth of anadromous populations tends to be limited by physical habitat constraints during the juvenile freshwater rearing stage. As described below this generally appears to be the case for Santa Rosa Creek as well, although spawning habitat quality in the lower reaches of Santa Rosa Creek, where fish can be restricted in dry winters, may become more limiting relative to juvenile habitat in some years.

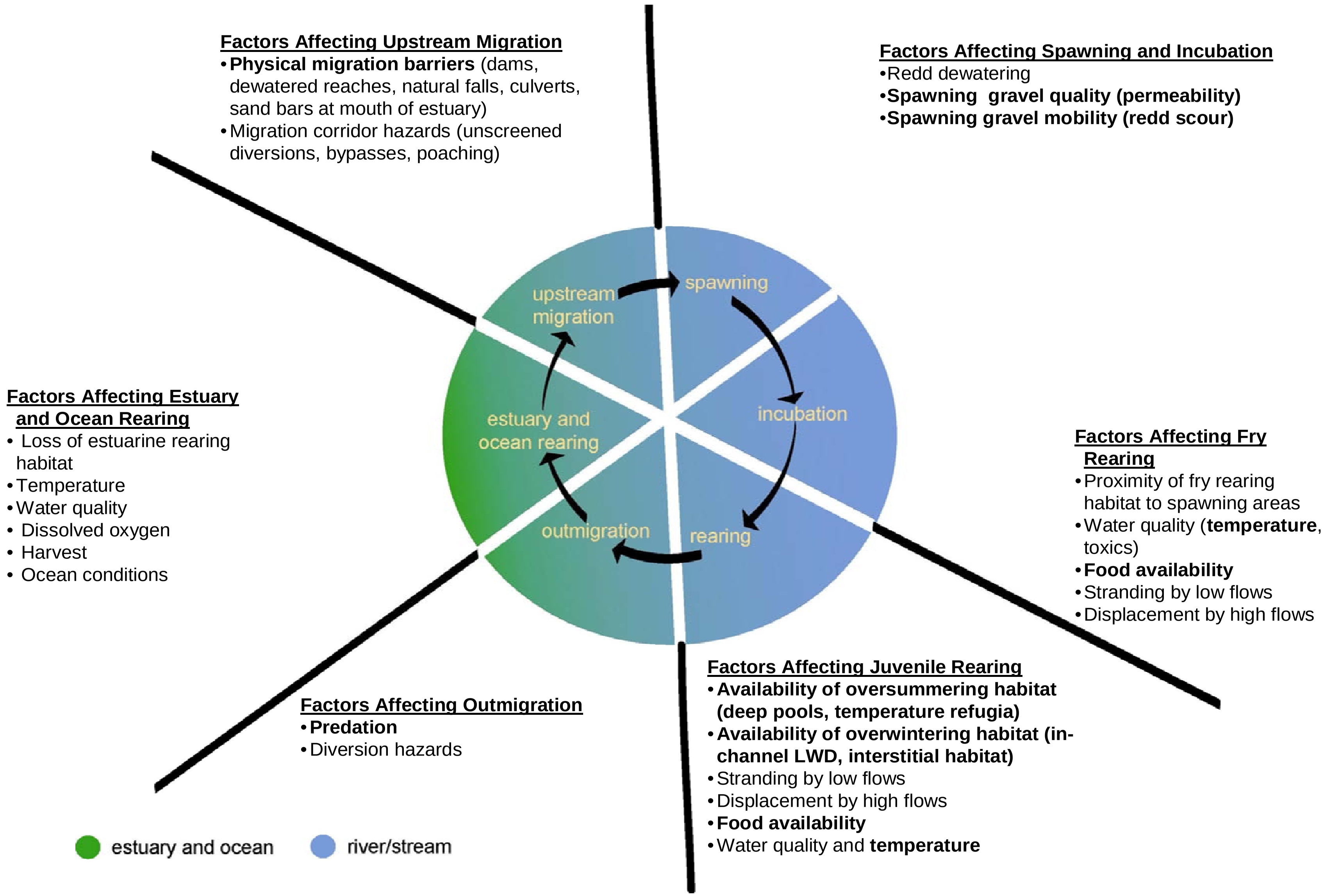

Figure 3-1. Steelhead life cycle with potential factors affecting each life stage.

3.1.1 Access to spawning habitat

CDFG surveys from the 1930s found no significant migration barriers to steelhead access in Santa Rosa Creek (Titus et al. 2006). Under current conditions several culverts and other man-made structures have been identified in the Santa Rosa Creek watershed that restrict the ability of migrating steelhead to access high quality upstream spawning habitat (see Section 2.7). Two of the furthest downstream barriers (Burton Street Bridge apron at stream mile 1.9 and Ferrasci Road crossing at stream mile 3.4) have recently been modified to allow fish passage under a wider range of flow conditions. Undersized and/or poorly placed culverts at road crossings likely limit steelhead access to potential spawning areas in Taylor and Curti creeks, and just as importantly, they disrupt the supply of coarse sediment and large woody debris that is necessary to create and maintain suitable rearing habitat (see Sections 3.2 and 3.3 below).

Nearly every road crossing in the Perry/Green Valley Creek sub-watershed has been identified as a potential fish passage barrier, but none have been assessed to determine if, why, or when a barrier to fish movement occurs (CalFish 2009; see Section 2.7). It is not known how often or in what capacity steelhead use reaches of the Perry/Green Valley Creek sub-watershed, or what condition those reaches are in (Nelson et al. 2009, Appendix A). Determining the potential for steelhead to access this sub-watershed would be an important first step towards understanding the relative importance of this sub-watershed for steelhead.

Low instream flows, which likely occurred naturally in drier years but are now exacerbated by groundwater pumping and water diversions, can also present barriers to fish movement on Santa Rosa Creek, particularly in the intermittent middle reaches (see Figure 2-8). Based on comparison of available flow data from the Main Street Bridge gauge (see Section 2.6) and steelhead passage requirements on lower Santa Rosa Creek (D. W. Alley & Associates 1993), it appears that when steelhead migration is initiated (as early as December) flows are typically adequate to allow migration, but that these flows are not continuously maintained throughout the entire upstream adult and downstream juvenile migration periods. It has also been suggested that in dry winters adult entrance into the lagoon and passage over shallow riffles can be constrained (Nelson 1994, Nelson et al. 2009, D. W. Alley & Associates 2007). Nelson et al. (2009) report that over one-half of the high-quality spawning locations are located upstream of stream mile 8, downstream of which the creek typically goes seasonally dry. During drier winters, this dry reach may significantly delay or prevent adult steelhead from accessing, and smolts from emigrating from, the upper reaches (Nelson et al. 2009).

Analyses of YOY steelhead capture data suggest that rainfall affects adult passage into the upper reaches of Santa Rosa Creek and drives the distribution of spawning and resulting YOY distribution (D. W. Alley & Associates 2007). Relative to the lower reaches, fall YOY densities were generally higher in the upper reaches in years with higher rainfall amounts during the previous year (D. W. Alley & Associates 2007, Nelson et al. 2009). Furthermore, the ratio of YOY steelhead densities in the upper reaches to lower reaches was positively correlated with rainfall in the preceding water year (Figure 3-2). These analyses suggest that during years with higher rainfall, such as 2005, a higher percentage of adults can migrate through the lagoon and lower reaches to access preferred spawning areas in the upper reaches (where greater numbers of YOY steelhead are produced), although the analyses did not specify whether this improved access is a result of longer sandbar breaching, the elimination of dry riffles, and/or improved flow conditions through or over structural barriers. A prolonged drought may prevent adult steelhead access to spawning grounds in the upper watershed for several consecutive years (Nelson et al. 2009).

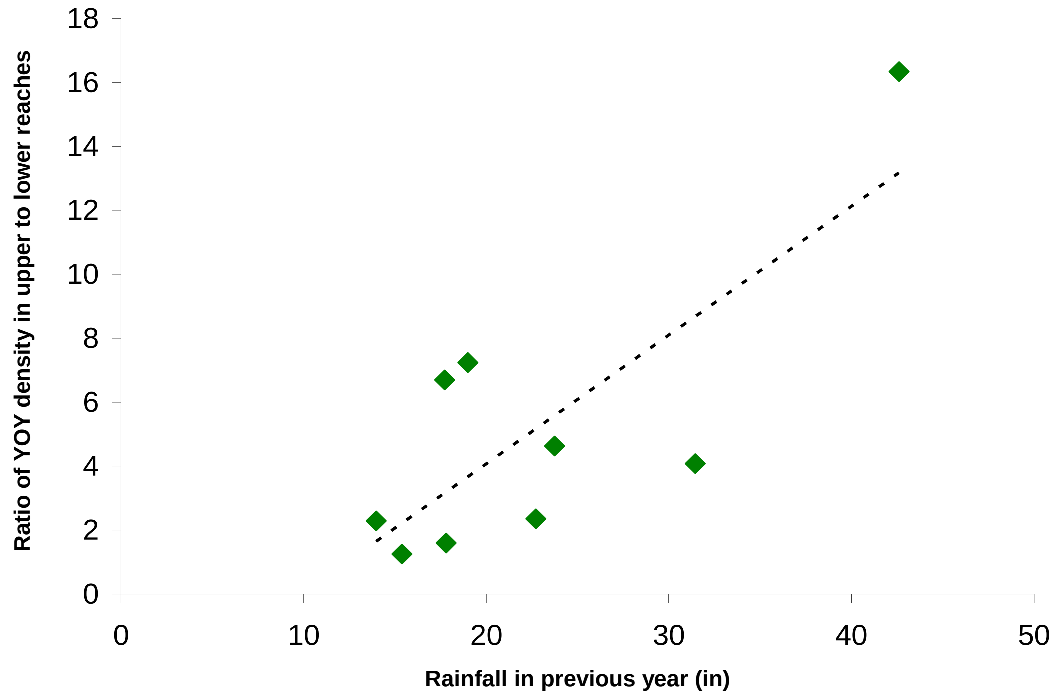

Figure 3-2. Ratio of YOY steelhead lineal density in upper to lower reaches versus rainfall in the previous water year (r^2 = 0.61; P = 0.0130; n = 9). Data sources: Nelson et al. (2009) and CCSD (http://www.cambriawqcp.org/).

In addition, lagoon sandbar formation and breaching patterns are speculated to affect adult steelhead migration in Santa Rosa Creek (D. W. Alley & Associates 2008, Nelson et al. 2009). In drier winters there can be insufficient instream flow to breach and/or maintain an open sandbar during adult migration, possibly preventing adults from entering the lagoon from the ocean, or resulting in a later or shorter run of steelhead (D. W. Alley & Associates 2008, Nelson et al. 2009). In addition, winter sandbar breaching can be influenced by ocean conditions. (Sandbar monitoring data for the Santa Rosa Creek lagoon were not available for this effort.)

In summary, structural and flow-related barriers to steelhead are likely a limiting factor for steelhead in dry years, when they may prevent steelhead from entering the lagoon and can restrict steelhead to the lower 3–7 mi (4–11 km) of the creek, where spawning and rearing habitat is of poorer quality (see discussions below).

3.1.2 Spawning habitat quantity

CDFG surveys from the 1930s described extensive steelhead spawning habitat in Santa Rosa Creek watershed (Titus et al. 2006). In 1960, CDFG noted that spawning areas were abundant and in good condition throughout the lower 7 mi (11 km) of the stream, and scattered in the next 4 mi (Titus et al. 2006). Recent surveys have also documented a substantial amount of steelhead spawning habitat throughout the watershed from stream mile 0.2–13 (Nelson et al. 2009, D. W. Alley & Associates 2008). Nelson et al. (2009) identified a total of 175 pool tail crests and 183 other potential spawning sites appropriate for steelhead spawning in the mainstem, and noted that suitable spawning habitat also likely exists in the lower, accessible reaches of Mora and Lehman Creeks and the East Fork of Santa Rosa Creek (see Figure 1-2). At this time it does not appear that spawning gravel quantity limits production of steelhead in the watershed.

3.1.3 Spawning habitat quality

On Santa Rosa Creek, spawning habitat quality is primarily controlled by the degree of spawning gravel embeddedness, since it appears that in most years flows are sufficient to prevent dewatering of redds during the incubation period and deliver adequate levels of dissolved oxygen to developing embryos (D. W. Alley & Associates 2008, Nelson et al. 2009). High levels of embeddedness, a measure of the degree to which cobbles and gravels are buried by fine sediments (i.e., silt and sand), reduces the ability of females to move cobble to construct redds, and the survival of developing eggs. The *California Salmonid Stream Habitat Restoration Manual* (Flosi et al. 2004) indicates that embeddedness of 25% or less is considered good spawning substrate for steelhead; however spawning habitat with embeddedness less than 50% is generally considered suitable (Nelson et al. 2009, NCRWQCB 2006). Excess fine sediments can also decrease egg-to-fry survival by filling interstitial spaces of the redd gravels and reducing oxygen delivery to developing embryos (Chapman 1988). Various studies indicate that as the percentage of fine sediments in spawning gravels exceeds 20–30%, dramatic reduction in embryo survival occurs (Chapman 1988, Reiser and White 1988, NCRWQCB 2006). Embeddedness values in Santa Rosa Creek range from 33–51% in runs (D. W. Alley & Associates 2008) to generally less than 25–50% in pool tail crests (Nelson et al. 2009)[11]. Spawning gravel embeddedness ratings higher than 50% are generally restricted to the lower reaches (Nelson et al. 2009).

Whereas spawning habitat appears to be suitable and not limiting production in the upper reach of Santa Rosa Creek, CDFG has identified a lack of suitable spawning substrates from excessive fine sediment deposition as one of the primary constraints to successful spawning in the lower reaches (Nelson 1994, Nelson et al. 2009). The lower reaches of a watershed are natural places for fine sediments to accumulate due to their lower gradients, and the Perry/Green Valley Creek sub-watershed, which joins Santa Rosa Creek at approximately stream mile 3, delivers a large supply of fine sediment directly to lower reaches of Santa Rosa Creek (see Section 2.5). Until 2011, the Ferrasci Road crossing may have, under a range of flow conditions, restricted spawning to the lower 3.5 mi (5.6 km) of the creek, while inadequate flows through the middle reaches may restrict spawning to the lower 7 mi (11 km) of the creek for a considerable portion of the spawning season during dry winters (Nelson et al. 2009). Under these circumstances, particularly if repeated over a number years, poor spawning habitat quality in the lower reaches likely limits the success of steelhead spawning and juvenile production. This is supported by the lower densities of fall YOY steelhead in the lower reaches when compared to the upper reaches (2-19), although it should be stressed that summer rearing habitat limitations may also be influencing this pattern. Notably, analysis of data from D. W. Alley & Associates (2007) indicated that YOY densities in the lower (stream miles 0–8) and upper (stream miles 8–13) reaches were not significantly correlated from 1998–2006, suggesting that YOY steelhead production—and the factors limiting it (e.g., spawning gravel quality)—differed between the upper and lower reaches within a given year.

Very little is known about the quality or access to spawning habitat in the Perry/Green Valley Creek sub-watershed. Presence of juvenile *O. mykiss* in Perry and Green Valley creeks (CDFG 2003b and USFS 1999, as cited in Becker and Reining 2008) indicates that at least some successful spawning occurred there, in spite of their apparently degraded condition (Yates and Van Konyenburg 1998, Appendix A), although it is not known if these juveniles were the progeny of anadromous steelhead or resident rainbow trout.

[11] It should be noted that a high degree of variability can result from embeddedness measures that are collected with different methods, calculations, or observers (Rowe et al. 2003).

3.2 Summer Rearing Habitat

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. Therefore, the number of YOY fish that a reach of stream can support is typically small relative to the average fecundity of an adult female steelhead.

The habitat requirements for different age classes of juvenile steelhead are relatively similar, except that as fish grow they require more space for foraging and cover. YOY steelhead can use shallower and slower habitat with finer substrates (e.g., gravels) to meet their energetic demands and escape predators than age 1+/2+ steelhead, which, because of their larger size, have higher energetic demands and require deeper, more complex pools, and coarser substrate or large woody debris for cover while feeding (Hartman 1965, Fontaine 1988, Spina 2003). Spina (2003) found that, in a short reach of Santa Rosa Creek near stream mile 11, most YOY steelhead used shallower water (<0.4 m) than age 1+/2+ steelhead (>0.4 m) and considerably greater availability of shallow habitat. Due to the greater frequency of shallow habitat and because YOY steelhead can generally utilize habitat suitable for age 1+/2+ steelhead, but age 1+/2+ steelhead can not use the shallower, finer substrate habitat suitable for YOY, a stream reach supports far fewer age 1+/2+ than YOY individuals during summer. Between 1998 and 2006 creek-wide densities of YOY steelhead in the fall were between 2.7 and 10.0 times higher than age 1+/2+ densities (D. W. Alley & Associates 2008) (Figure 3-3). For this reason, it is unlikely that YOY steelhead summer rearing habitat limits steelhead production. In support of this hypothesis, D. W. Alley & Associates (2008) reported that fall YOY densities in Santa Rosa Creek were the highest of nine streams surveyed on the Central California Coast in 2006. As such, the following sections generally focus on rearing conditions for age 1+/2+ steelhead.

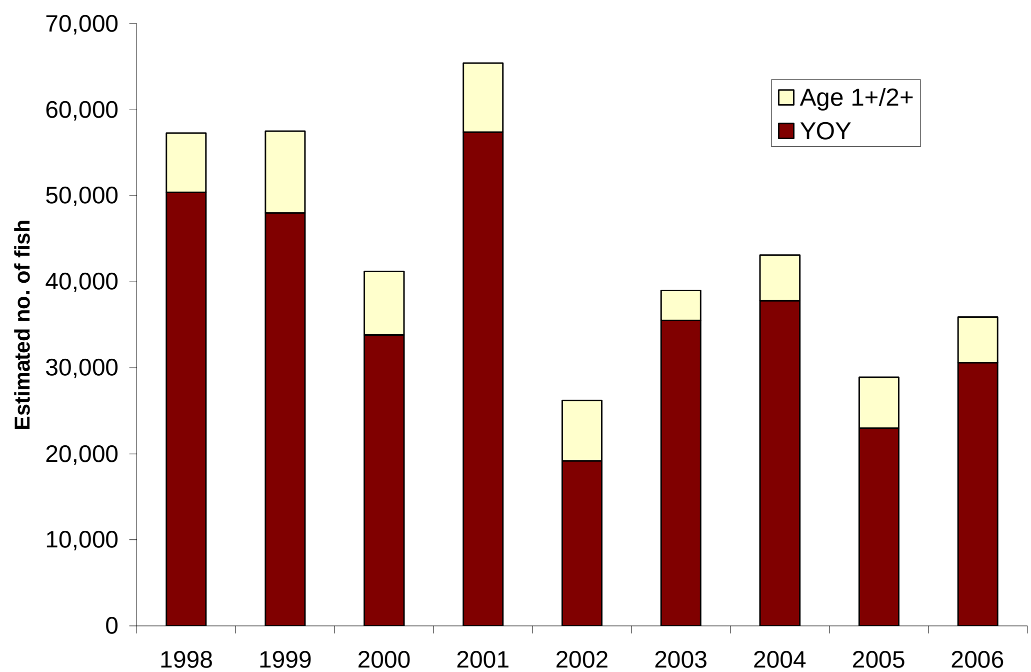

Figure 3-3. Creek-wide YOY and age 1+/2+ steelhead population estimates from 1998 to 2006. Data source: D. W. Alley & Associates (2007, Table 25a).

Juvenile steelhead carrying capacity is strongly influenced by instream flows during the summer, which influence overall rearing habitat area, the depth and volume of pool habitat, connectivity between habitat types, and water temperatures. Streamflow also dictates the quantity of drifting invertebrates that reach feeding steelhead, such that at higher summer flows steelhead can better maintain feeding rates that allow them to meet the metabolic demands of elevated summer water temperatures. Santa Rosa Creek likely experienced seasonally low flows, particularly during drought years, under natural conditions. However, due to groundwater pumping and water diversions, summer instream flows are chronically low compared to historic levels and are considered a critical factor limiting juvenile steelhead populations in Santa Rosa Creek (Yates and Van Konyenburg 1998, D. W. Alley & Associates 2008, Nelson et al. 2009). For example, in 2005, the wettest water year on record since 1998, discharge just downstream of Highway 1 was as low as 9 cfs by late May and was less than 2 cfs from late August until December (Nelson et al. 2009). During drier years, fall discharge measured by D. W. Alley & Associates (2008) was typically between 0.1 and 1 cfs at the downstream-most sampling site. While detailed analysis of how much flow is required to support steelhead summer rearing requirements (e.g., habitat connectivity, suitable stream temperatures, and invertebrate drift) in Santa Rosa Creek has not been conducted, it has been noted that instream flows are often inadequate to allow steelhead movement between habitat types in the late summer and fall (Rathbun et al. 1991, D. W. Alley & Associates 2007, Nelson et al. 2009). For example, flows in the mainstem Santa Rosa Creek go subsurface for approximately 0.5 mile (varying by year) near stream mile 7 during summer (D. W. Alley & Associates 2008, Nelson et al. 2009), eliminating rearing habitat and invertebrate drift in that reach and restricting it downstream.

In small coastal streams such as Santa Rosa Creek, pools are essential summer rearing habitat for age 1+/2+ juvenile steelhead (D. W. Alley & Associates 2008), although age 1+/2+ steelhead in Santa Rosa Creek have also been documented to utilize run habitat in the spring (Spina 2003). Pools must have sufficient depth, generally considered to be 2 ft (0.6 m), although this can depend on availability of escape cover and presence of predators and increases with fish size (Bjorrn and Reiser 1991, McEwan 2001, Spina 2003). In a 2,624-ft (800-m) reach of Santa Rosa Creek near stream mile 11, Spina (2003) documented age 1+/2+ individuals in water as shallow as 1 ft (0.4 m), but most individuals were in depths greater than 2 ft (0.6 m). Reductions in pool depth may adversely affect thermal and velocity refugia and reduce the potential to avoid predators. While recent surveys indicate pools comprise approximately one-third of habitat by stream length in the lower 13 mi (20 km) of Santa Rosa Creek, only about one-quarter were deep enough to be suitable rearing habitat for age 1+/2+ steelhead, and poor pool development has been cited as one of the primary limits on rearing habitat in Santa Rosa Creek (Rathbun et al. 1991; Nelson 1994; D. W. Alley & Associates 2007, 2008; Nelson et al. 2009). Substantially more pool habitat was located in the upper reaches above stream mile 8 than in the lower reaches from stream miles 0–8). Although pool filling as been attributed to fine sediment deposition (Nelson et al. 2009), the relatively high sediment-transporting capacity of the lower reaches of Santa Rosa Creek (see Section 2.5) suggests that poor pool development is likely due to the lack of large woody debris (see discussion below) and other elements that create and maintain pools (e.g., riparian tree roots), rather than solely infilling by fine sediment.

An important element of the pool habitat complexity required for juvenile steelhead rearing is escape cover. Also know as concealment cover or instream shelter, escape cover allows individuals to evade predators and, in the winter, to find refuge from high flows (Cunjak 1996, Spina 2003, D. W. Alley & Associates 2008). Escape cover in Santa Rosa Creek generally includes large, unembedded cobbles and boulders, undercut banks, large woody debris, and overhanging vegetation (D. W. Alley & Associates 2008, Nelson et al. 2009). Less than 20% of pools measured by Nelson et al. (2009) provided escape cover, and unembedded boulder/cobbles and large woody debris were in short supply. Large woody debris is a key habitat component for juvenile steelhead, not only because it provides escape cover, but because it increases overall habitat complexity, facilitates temporary sediment storage, and forms scour points that create and maintain the deeper pools needed by larger juvenile steelhead (Harmon et al. 1986). Both Nelson et al. (2009) and D. W. Alley & Associates (2008) report a paucity of large woody debris in Santa Rosa Creek, with large woody debris making up only about 3% of the cover. A lack of large woody debris is not uncommon in California Mediterranean-climate streams, where historical land clearing and development near streams has decreased the supply of large wood, and woody debris that does make it into the stream are frequently removed due to real and perceived threats to flood control and near-stream infrastructure (Opperman 2002). The lack of large woody debris in Santa Rosa Creek is speculated to restrict carrying capacity of oversummering age 1+/2+ steelhead, since it limits escape cover and prevents the scour formation and maintenance of deep pools (Nelson 1994, Spina 2003, D. W. Alley & Associates 2008, Nelson et al. 2009).

Based on the relatively high abundance of YOY steelhead in the fall, summer rearing habitat is not likely limiting this age class, which is supported by the fact that they can use shallower riffle and pool habitat than age 1+/2+. Based on low abundance of age 1+/2+ compared with YOY, infrequent pools, and groundwater extraction, physical rearing habitat required by age 1+/2+ (and larger YOY) steelhead is very likely limiting summer carrying capacity, and possibly smolt production, in Santa Rosa Creek. However, as discussed in detail below, limitations in winter habitat for age 0+ and age 1+ could also explain this pattern. In addition, the degree to which rearing habitat limits the population may be influenced by habitat conditions in the lagoon. In some cases, lagoons provide rearing habitat capable of supporting large numbers of juveniles that are likely in excess of the summer or winter carrying capacities of stream reaches (Smith 1990, Hayes et al. 2008, Sogar et al. 2009), although this has not been evaluated in the Santa Rosa watershed in recent years. As described in Section 3.5 below, in the 1970s, the juvenile steelhead population in the lagoon was quite large (Bailey 1973 and Puckett 1970, as cited in Rathbun et al. 1991), indicating that it was a suitable and significant rearing habitat for the steelhead population.

3.3 Overwintering Habitat

Overwintering steelhead may suffer elevated mortality when they are displaced (or “entrained”) by high winter flows. Discharge in the inherently flashy Santa Rosa Creek can range from 1 cfs to over 12,000 cfs (as in 1969 and 2005), with winter flood events over 5,500 cfs typically occurring once every five years (Appendix A). Refuge from such flood events requires that steelhead access deeper interstitial spaces in the substrate or other cover to avoid turbulent, high velocity conditions. In general, many of the habitat elements essential for successful summer rearing are also essential for winter rearing.

Because steelhead tend to spawn and rear in higher gradient stream reaches with more confined channels, they have less propensity than other species (e.g., coho salmon) for using off-channel slackwater habitat in winter, and a greater propensity for using in-channel cover provided by cobble and boulder substrates. As such, interstitial spaces in cobble or boulder substrate are considered to be the key attribute defining winter habitat suitability for juvenile steelhead (Hartman 1965, Chapman and Bjornn 1969, Meyer and Griffith 1997). Cobble-boulder rearing habitat is most likely to occur in step-pool channels of confined, higher gradient reaches (Montgomery and Buffington 1997). As described in Section 2.5, cobble-boulder dominated habitat is more common in the upper watershed, much of which is upstream of potential fish passage barriers, and median grain size decreases downstream in almost direct proportionality to drainage area.

Steelhead will use cover in the form of large woody debris or off-channel habitat when it is available, especially in low-gradient reaches where interstitial spaces among cobble and boulder are less abundant. Many of the stream surveys in the Santa Rosa Creek watershed indicate some level of substrate embeddedness by fine sediment (Rathbun et al. 1991, Nelson 1994, D. W. Alley & Associates 2008, Nelson et al. 2009). When embeddedness of cobbles and boulders is greater than about 25% it greatly restricts their utility as escape cover (D. W. Alley& Associates 2008). Nelson et al. (2009) reported that only 26% of pools in Santa Rosa Creek had small cobble, large cobble, or boulders as dominant substrate, with the remainder being comprised primarily of silt, sand, or gravel. Pool tail crest surveys indicated that most large cobbles and boulders were highly embedded, with only one of the 47 locations surveyed having an embeddedness value below 25%. Much of the geology underlying the watershed has moderate to very high erodibility (Section 2.4), 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 (Nelson et al. 2009, Appendix A). In particular, the Perry/Green Valley Creek sub-watershed delivers a large supply of fine sediment, with no corresponding coarse sediment component, directly to lower 3 m (5 km) of Santa Rosa Creek (see Section 2.5). In this case large woody debris may be more important as winter habitat than in a stream system with naturally available unembedded substrate. However, as described previously, recent stream surveys indicate a lack of large woody debris within the watershed (Nelson et al. 2009, D. W. Alley & Associates 2008).

As with summer habitat, a reach of stream will typically support far fewer age 1+/2+ than YOY steelhead in the winter because YOY are smaller and can utilize a wider range of substrate for refuge. For this reason, in the winter, habitat may often become unsuitable for age 1+/2+ steelhead at lower magnitudes of sedimentation than for YOY. Substrate will become less suitable for both summer and winter rearing at higher levels of embeddedness, but it will often be more limiting in winter because refuge from entrainment during winter freshets requires that steelhead hide deeper within the substrate. As a result, in many watersheds—even those containing poor summer habitat—it has been observed that winter rearing habitat limits steelhead populations in other central California coastal streams such as Lagunitas Creek (Stillwater Sciences 2008), San Gregorio Creek (Stillwater Sciences 2009), and Upper Penitencia Creek (Stillwater Sciences 2006b).

The relatively low abundance of age 1+/2 steelhead observed in fall suggests that either summer rearing habitat or winter rearing habitat is limiting smolt production in Santa Rosa Creek. However, in the absence of an assessment of the juvenile steelhead population in both the fall and the following spring, it is not possible to directly determine whether winter habitat is limiting. Based on the observed relatively low quantity of unembedded cobble-boulder habitat and a paucity of large woody debris (Nelson et al. 2009, D. W. Alley & Associates 2008, Appendix A) it is possible that winter habitat is limiting. Overall, winter habitat is expected to be less important than summer habitat in dry years that lack high flow events and have reduced summer flows. In these years, individuals are less susceptible to entrainment in the winter, while pool habitat and feeding opportunities are expected to be more restricted in the summer.

Juvenile steelhead

3.4 Bioenergetics

Numerous studies have examined the relationships between water temperature, growth, and survival of juvenile steelhead. Results of these studies vary between study populations. Recent studies of more southern populations of steelhead indicate that they can continue to grow at higher water temperatures (Spina 2007, D. W. Alley & Associates 2008, Sogard et al. 2009, Bell et al., in review) and will tolerate short periods of temperatures, up to approximately 81–84°F (27°–29°C) (depending on acclimation temperature), that were previously considered lethal (Myrick 1998).

Available data for Santa Rosa Creek indicate that, in most years, summer water temperatures are suitable for successful steelhead rearing in the majority of stream reaches. Maximum temperatures in the summer and fall of 2004–2006 rarely exceeded 69°F (21°C), particularly in the upper reaches above stream mile 8 (D. W. Alley & Associates 2008, Nelson et al. 2009). Temperature suitability for steelhead rearing may occasionally be exceeded in the lower reaches (below stream mile 8) in drier years (in the summer and fall of 2004–2006, maximum daily water temperatures commonly exceeded 75°F (24°C), but rarely exceeded 77°F (25°C) [D. W. Alley & Associates 2008, Nelson et al. 2009]), but there is still considerable uncertainty of what optimal temperatures for steelhead are in this region (A. Spina, pers. comm., 2010).

Available data suggests that despite periods of unsuitable water temperature in lower Santa Rosa Creek, steelhead continue to grow, and at rates reported to be higher than in nearby San Simeon Creek (D. W. Alley & Associates 2008, Sogard et al. 2009). Fulton condition factors for YOY and age 1+/2+ individuals captured in the fall of 2005 by Nelson et al. (2009) varied considerably, but, within size classes, were actually higher in the warmer lower reaches than cooler, upper reaches. In addition, both Nelson et al. (2009) and D. W. Alley & Associates (2008) found that the size of YOY fish increased steadily in the downstream direction. Although it is not certain whether YOY growth was higher in downstream reaches, if individuals emerged and begin feeding earlier in the spring there, or if larger individuals actively migrated downstream, together these results do suggest that water temperatures were not excessive and/or sufficient food was available in the lower 8 mi (13 km) of the creek during steelhead rearing. Age data from scale analysis and corresponding length data from 2006 (which had a relatively wet spring) support the finding that juvenile steelhead in the lower 8 mi (13 km) of Santa Rosa Creek generally have relatively high growth rates in their first year, with many individuals reaching 5–6 in (130–160 mm) fork length by fall (D. W. Alley & Associates 2008). Above stream mile 8 however, length frequency data of juvenile steelhead captured in October and November 2005 do show a large number of relatively small (2–3 in [50–80 mm] fork length) YOY fish (Nelson et al. 2009). The relatively lower condition factors and generally smaller fish captured above stream mile 8 suggests that food availability may be limiting growth in these reaches compared to the lower 8 mi (13 km).

Overall it appears that water temperature generally does not hinder juvenile growth in Santa Rosa Creek, likely because of mostly suitable water temperatures, natural adaptations to higher temperature, and possibly because of high food availability. However, there appears to be an inconsistency between the observed growth rates and the relatively small smolt sizes observed by the limited spring outmigrant trapping data in Santa Rosa Creek. Based on the size range of YOY observed in the lower reach (5–6 in [130–160 mm] fork length) in fall, most smolts would be expected to be greater than 7 in (170 mm) by spring. Instead, the majority of smolts captured during spring outmigrant trapping in 2005 averaged 6.5 in (165 mm) fork length (Nelson et al. 2009). Several studies have shown a strong relationship between the size at which a steelhead smolt migrates to the ocean and the probability that it will return to spawn (Kabel and German

1967, Hume and Parkinson 1988, Ward et al. 1989, Bond et al. 2008). In one the most focused studies on marine survival in a central California coastal watershed, Bond et al. (2008) found that, in Scott Creek in Santa Cruz County, few returning adults were smaller than 6 in (150 mm) at ocean entry and the majority were larger than 8 in (200 mm). Similarly, Ward et al. (1989) found that only smolts greater than 7 in (170 mm) typically experienced relatively high marine survival (>10%). Assuming that size-dependent survival and ocean conditions experienced by the Santa Rosa Creek populations are similar to these other populations, it is possible that in some years (e.g., 2005) most smolts from Santa Rosa Creek have poor ocean survival due to their small size. As a comparison to other southern California watersheds, in the Santa Clara River smolts in 2009 averaged 7 in (185 mm) fork length (S. Howard, pers. comm., 2010); in the Santa Clara and Santa Ynez estuaries most smolts in 2007/2008 were greater than 7 in (170 mm) fork length (Kelley 2008), and in Topanga Creek nearly all smolts captured during spring 2009 were greater than 7 in (170 mm) (Bell et al. in review). Based on the 2005 outmigrant trapping results, there is the potential that relatively small smolt sizes in Santa Rosa Creek (and therefore poor ocean survival) are a potential limiting factor for the population. However, since outmigrant trapping occurred at stream mile 0.3, and there were growth opportunities in the riverine and lagoon habitat downstream of the trap, it is not clear if captured individuals continued to rear and grow in the lagoon before leaving for the ocean, as observed in other systems (Smith 1990, Hayes et al. 2008). The extremely high growth of some YOY—as indicated by annual growth rings on their scales—collected just upstream of the lagoon (D. W. Alley & Associates 2008), suggests that food resources are likely high in lower Santa Rosa Creek. Clearly, additional outmigrant trapping data, and determining growth opportunities and residency within the lower creek and lagoon, is critical to assessing if smolt outmigrant size is a limiting factor in Santa Rosa Creek.

3.5 Lagoon Habitat

Coastal lagoons are fed mostly by freshwater streamflow and are generally separated from the sea by a sandbar, except when that sandbar is breached during high-flow events or when sea water overwashes the sandbar. Lagoon rearing has been demonstrated to be critically important for other central California coast steelhead populations, with significantly higher growth rates and ocean survival by steelhead that reared in lagoons, even with lagoon water temperatures as high as 75°F (24°C) (Smith 1990, Hayes et al. 2008, Bond et al. 2008). While no studies of lagoon rearing, growth, and survival have been carried out in Santa Rosa Creek, these findings from other central California coast watersheds highlight the potential importance of the Santa Rosa Creek lagoon for steelhead rearing. Since larger smolts tend to have higher ocean survival, growth during lagoon rearing may increase ocean survival of steelhead smolts. 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 (Smith 1990). This can potentially relax to some degree the density-dependent bottleneck occurring in stream habitat and provide a high growth environment and adjustment to a saline environment that improves ocean survival for both stream and lagoon reared fish. 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.

Full lagoon in winter

While very little historical or current data exist on the juvenile steelhead population in Santa Rosa Creek lagoon, what data are available suggests it has declined. In the 1970s, the juvenile steelhead population in the lagoon was estimated to be between 2,290 and 6,800 (Bailey 1973 and Puckett 1970, as cited in Rathbun et al. 1991), suggesting that it was a suitable and potentially important rearing habitat. By the 1980's it appears that little if any steelhead rearing occurred in the lagoon (Holland, unpubl. data, as cited in Rathbun et al. 1991). While ineffective at detecting juvenile steelhead, sampling for tidewater goby in the lagoon from 1993–2007 provides evidence that, in some years, both YOY and smolt-sized steelhead utilize the lagoon for rearing in the summer and fall. In summer and fall sampling in 2004, Alley and Sherman (2006) captured 101 and 69 juvenile steelhead, respectively between Shamel Park and the Windsor Bridge. No steelhead were captured in 2005, but visual observations of steelhead in the lagoon were made (Alley and Sherman 2006). Outmigrant trapping conducted in spring 2005 at stream mile 0.3 also suggests that a portion of the juvenile steelhead population likely migrates into the lagoon prior to smolting: numerous individuals measuring between 2 and 5 inches (50 and 140 mm) and having parr coloration were captured (Nelson et al. 2009). It is not clear whether these individuals were displaced due to limited carrying capacity in upstream reaches, or if they were preferentially exhibiting a lagoon rearing life history strategy.

It is unclear to what extent Santa Rosa Creek lagoon provides suitable conditions for juvenile rearing. While the lagoon may provide quality over-summering habitat in some years, it likely becomes too saline and warm for juvenile steelhead survival in others (D. W. Alley & Associates 2008). The quality of lagoon rearing habitat for steelhead is largely dependant on sandbar formation and maintenance, the amount of freshwater inflow, and water quality conditions. When sandbar breaching is delayed or cut short, either from inadequate instream flows or ocean conditions, adult steelhead are unable to enter the creek and spawn (they typically stray into other nearby creeks). The presence of smolt-sized individuals in Santa Rosa Creek lagoon after sandbar closure, suggests that outmigrating individuals may be "trapped" in the lagoon when the sandbar reforms early in the season (D. W. Alley & Associates 2006). Survival of smolts that rear in the lagoon is not known. Conversely, if the sandbar is breached artificially in the summer (natural breaching during the summer is rare), lagoon habitat can be rapidly reduced and become too saline for rearing steelhead. Fortunately, artificial breaching of the Santa Rosa Creek lagoon is not known to occur (M. Walgren, pers. comm., 2010).

Reduced instream flows limit the extent of lagoon habitat and 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 (Smith 1990, Capelli 1997). In some lower flow years such as 2003 and 2004, entire sections of the Santa Rosa Creek lagoon dried up, reducing the area of suitable steelhead rearing habitat (D. W. Alley & Associates 2008).

Water temperatures and DO levels in the lagoon, particularly at the bottom, can frequently exceed lethal limits for steelhead in the summer and fall (see Section 2.8.1). Although low DO may restrict the scope of steelhead activity in lagoon, D. W. Alley & Associates (2008) hypothesizes that low DO levels are less limiting than temperature to steelhead survival in the lagoon. The observed high water temperatures and low DO levels likely create seasonally unfavorable conditions for rearing steelhead and may limit smolt growth, survival, and production in the watershed in some years. Nonetheless, it is possible that the productive, food-rich lagoon allows juvenile steelhead to successfully rear in the lagoon, even when water temperatures reach moderately high levels for short periods. Overall, the lagoon habitat is predicted to be a crucial component of the life history of steelhead in Santa Rosa Creek and has the potential to increase the carrying capacity of the watershed, alleviating some of the limitations from poor habitat conditions in stream reaches and contributing to recovery of the population.

Although much of the above discussion describes stream and lagoon habitat separately, they are better viewed as connected 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, 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. For example, if it is initially assumed that winter or summer habitat conditions limit the carrying capacity of stream reaches, it would then be assumed 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.

Increasing winter carrying capacity for YOY steelhead may increase the abundance of juvenile fish until summer habitat for age 1+/2+ steelhead becomes limiting. After winters with high YOY survival, an age 1+/2+ summer habitat bottleneck may develop if pool habitat becomes limiting. However, behavioral emigration of "excess" age 1+/2+ steelhead surviving the winter could increase production if suitable habitat is available in the Santa Rosa Creek lagoon. Besides the ocean life stages, utilization of lagoon habitat is perhaps the least understood component of steelhead population dynamics and ecology in the watershed. For this reason, it is important to implement targeted studies describing the lagoon water quality and habitat conditions as they relate to juvenile steelhead use, growth, and survival.

3.6 Summary of Limiting Factors and Uncertainties

Based on historical evidence, the Santa Rosa Creek watershed supported a robust population of steelhead. There are many ecological characteristics of the watershed that continue to be relatively healthy compared to other streams in the region, and steelhead continue to persist in Santa Rosa Creek despite drastic declines in neighboring watersheds. These characteristics, including high quality habitat in the upper reaches (stream miles 8–13), moderate water temperatures, and an intact lagoon system, highlight the regional significance and potential of this watershed to protect and recover nearby steelhead populations.

A wide range of factors, however, affect the freshwater life stages of steelhead in Santa Rosa Creek. Rather than listing all elements that potentially influence the population (see D. W. Alley & Associates [2008] for a detailed discussion), the limiting factors analysis was used to generate the following hypotheses of the highest priority and most likely causes of the decline in steelhead abundance in the watershed. In turn, these hypotheses are the basis of several of the management and restoration recommendations in Section 4. Overall, the analysis results in the following hypotheses of high priority limiting factors in the watershed:

1. Restricted access to spawning habitat limits steelhead spawning and juvenile production. In dry water years the dry middle reaches can confine spawning adults to the lower reaches.
2. When confined to the lower reaches, steelhead spawning success is limited by poor quality spawning habitat. Potential spawning substrates in the lower reaches are embedded by fine sediment.

3. Low instream flows during the summer reduce summer rearing habitat for age 1+/2+ steelhead and limit the population, particularly during drier water years.
4. Inadequate large woody debris and to a lesser extent fine sediment filling of pools (primarily below Perry Creek), restrict formation and maintenance of complex summer rearing pool habitat for age 1+/2+ steelhead and limit the population.
5. Inadequate large woody debris, embeddedness of cobbles and boulders, and fine sediment filling of pools, limits the overwinter survival of YOY and age 1+/2+ steelhead, particularly during years with flood events.

In conducting the limiting factors analysis of steelhead in the Santa Rosa Creek several uncertainties and data gaps were identified. Filling these data gaps is fundamental to refining, and potentially eliminating, some of the limiting factor hypotheses posited above. These data gaps are the basis of several of the research recommendations in Section 4.

1. Given the uncertainty in recent escapement levels, adult trapping and/or detection in Santa Rosa Creek is needed to monitor annual population success and collect baseline data for the evaluation of population response to implemented restoration actions. Due to the difficulty in monitoring steelhead spawning in creeks with small steelhead populations and dispersed spawning habitat, CDFG recommends the use of traps, weirs, and/or video or sonar detection systems to provide an absolute count of migrating adults (Adams et al. 2011).
2. Juvenile population sampling (e.g., snorkel surveys) is needed in conjunction with fall sampling to differentiate overwinter from oversummer survival. This would need to be done over several years to help elucidate the dependence of winter and summer survival on variation in rainfall and stream flow.
3. A better understanding of residency timing, duration, and growth in the lagoon is needed to determine the suitability of the lagoon for rearing and the influence lagoon rearing has on smolt growth and ocean survival.

4 RECOMMENDATIONS

There are many ecological characteristics of the Santa Rosa Creek watershed that have not been as adversely impacted in terms of steelhead habitat requirements compared to other streams in the region—for example moderate stream temperatures and an intact lagoon system. However, based on the Watershed Synthesis, Steelhead Limiting Factors Analysis, Geomorphic Assessment (Appendix A), and benthic macroinvertebrate sampling (Appendix B), some watershed conditions have been degraded and will require restoration or enhancement to achieve significant protection and recovery of the steelhead population.

The primary objective of the recommendations provided in this section is to address the factors currently believed to be limiting the steelhead population. Additional objectives of these recommendations are to provide for the long-term protection of key ecosystem components that are intact, restore, or enhance ecosystem components that require it, and fill key gaps in the understanding of the watershed and steelhead population. Because there are a number of ways in which these objectives can be met, the recommendations have been organized based on their specific goal, resulting in eight categories. These goals are listed in order of their relative importance to steelhead habitat restoration:

- Increase Summer and Fall Instream Flows
- Restore the Riparian Corridor
- Reduce Fine Sediment Delivery to the Creek
- Conserve and Protect Open Spaces and Existing Land Uses
- Increase Woody Debris Supply and Retention
- Remove Barriers to Fish Passage
- Fill Key Data Gaps
- Reduce Mercury Supply

The recommendations serve as a guide to improving habitat conditions in the Santa Rosa Creek watershed for steelhead, based on identified limiting factors. If implemented, these actions will also benefit other aquatic and terrestrial species. In addition, they are compatible with current land uses in the watershed: reducing land erosion, maximizing efficient rural and urban water use, and conserving agricultural land use that has been part of this watershed for two centuries are compatible with many concerns voiced by stakeholders throughout the watershed planning process.

The recommendations have been developed to be implemented individually, although appropriate combinations and phasing are described, and on a voluntary basis, by or with the consent of willing landowners. They are not intended as prescriptions or requirements. Together, the full suite of recommendations presents multiple ways to address steelhead limiting factors and provides an integrated watershed management plan that will serve various local organizations and individuals for both the near- and long-term. As these are all voluntary actions, various funding sources are available to fund some or all of the recommendations described below (see Appendix D). One advantage of this plan is to serve as a document to support funding for restoration activities in the watershed.

4.1 Increase Summer and Fall Instream Flows

Insufficient instream flow during the summer and fall, as a result of groundwater extraction and riparian diversions, has been identified as the primary factor limiting summer rearing habitat and juvenile steelhead survival in the watershed (Rathbun et al. 1991, Nelson 1994, Yates and Van Konyenburg 1998, D. W. Alley & Associates 2008, Nelson et al. 2009). The recommendations below for increasing summer and fall instream flows include immediate actions, such as water conservation and constructing off-stream storage, as well as updating the water budget and identifying steelhead instream flow requirements, which are necessary to identify specific measures and locations that would be most effective in increasing summer and fall instream flows. These recommendations can be implemented to begin the process of reducing demand for surface and groundwater supplies in the summer and fall, and could also improve the quality and quantity of rearing habitat in the lagoon by increasing the amount and duration of freshwater inflow.

4.1.1 Implement water conservation and reuse strategies

To reduce the amount of water diverted from the stream and pumped from the groundwater basin, and potentially maintain summer and fall instream flows, it is recommended that municipal, domestic, agricultural, and recreational water conservation strategies, including water reuse, be implemented. It is further recommended that additional water conservation opportunities, such as using non-potable water for outdoor landscaping and irrigation, be pursued by CCSD. Per the San Luis Obispo County (2008) North Coast Area Plan, any new development resulting in increased water use should offset such an increase by retrofitting water fixtures, replacing irrigated landscaping with xeriscaping, or other verifiable actions to reduce water use. It is also recommended that water reuse, such as the direct reuse of sufficiently treated wastewater or groundwater replenishment with treated wastewater, be further evaluated in the Santa Rosa Creek watershed. A 2004 Recycled Water Master Plan prepared by CCSD estimated that approximately 50 acre-feet of water could potentially be provided through the use of recycled water, with no net increase in groundwater pumping (R. Gresens, pers. comm., 2012). Currently, Santa Rosa Creek watershed-derived municipal wastewater is treated and allowed to filter into the San Simeon Creek groundwater basin. Given the scarcity of water resources in the region, developing ways to retain and use this water in the watershed would be beneficial.

Local Resource Conservation District, Natural Resources Conservation Service, and Farm Bureau resources are available to assist rural residents and farmers in the watershed in implementing water conservation and reuse strategies. Examples of broad categories of voluntary on-farm and rural water conservation and reuse strategies include:

- Irrigation Management and Scheduling: The local Resource Conservation District's Mobile Irrigation Lab can provide on-site distribution uniformity evaluations of individual irrigation systems. Deciding when and how much water to apply to a field has a significant impact on the total amount of water used by the crop, water use efficiency, and irrigation efficiency. A number of different scheduling systems have been developed that can use either soil/plant- or atmosphere-based measurements to determine when to irrigate. Using a more scientific approach to irrigation scheduling has generally been shown to decrease the amount of water applied while improving yield.
- Tail Water Return Systems: To provide adequate water to the low end of the field, surface irrigation requires that a certain amount of water be spilled or drained off as tail water. Tail water return systems catch this runoff and pump the water back to the top of the field for reuse.

- Reduced Tillage and Cover Crops: The use of cover crops between crop rows or crop seasons and reducing soil tillage increases soil water storage capacity by capturing runoff and minimizing evaporation.
- Plant Species Options: Use drought tolerant forage and horticultural/landscaping plant species can help reduce water use.
- Keyline Design: Keyline design captures water at the highest possible elevation and spreads it outward toward drier ridges using plow lines and gravity, thereby reversing the natural concentration of water in valleys. Maximizing the distribution of water to drier ridges using precise plow lines that are slightly off-contour slows the movement of water and spreads it more uniformly, infiltrating it across the broadest possible area.

4.1.2 Construct off-stream closed water storage

Off-stream water storage of extracted groundwater and riparian diversions for domestic and agricultural uses, which would divert water during higher instream flow conditions in the winter and store it for use in the summer and fall, is one way of achieving additional instream flows for steelhead rearing and fall migration during dry water years. Water for off-stream storage would be diverted in winter only, with an elimination of spring, summer, and/or fall water rights. Off-stream closed water storage facilities (e.g., above-ground water tanks, cisterns, etc.) are maintained along several tributaries in the watershed; it is recommended that opportunities to increase their efficiency as well as to increase the number of facilities in strategic locations be pursued.

Storage tank in Santa Rosa Creek watershed

There have been several recent and successful efforts to increase summer and fall instream flows through water rights transfers and off-stream storage construction that may serve as a model for efforts in the Santa Rosa Creek watershed. In particular, the Mattole Headwaters Groundwater Management Plan 1.0 (Sanctuary Forest 2008) provides an example that, although from a northern California salmonid stream, is likely highly relevant to the Santa Rosa Creek watershed.

4.1.3 Purchase water rights from willing sellers for instream flows

California amended its Water Code in 1991 to allow for the purchase and transfer of water rights to instream flows. While water rights issues are technically and legally complex, and the effect of a single water rights claim on instream flows is typically not known, this could be a strategy for increasing summer and fall instream flows in Santa Rosa Creek. Water rights purchases would be based on willing sellers/donors. Purchased rights could be transferred to instream flows, with an entity such as CDFG or a land trust holding the right, or from a summer to winter diversion if off-stream storage is available (see recommendation above). Individual purchases and transfers will likely require significant research to understand the characteristics of the water right, assess second and third party impacts, and ensure the transfer is legitimate. If, based on this research, a purchase from a willing seller/donor is feasible and appropriate, an application for transfer would need to be prepared and finalized in accordance with SWRCB or governing agency specifications.

4.1.4 Conduct stream gauging and develop an updated water budget

Although Yates and Van Konyenburg (1998) provide insight into the effect of CCSD's municipal groundwater pumping and private groundwater pumping and water diversions on flow conditions in Santa Rosa Creek through the early 1990s, a more detailed and updated water budget is necessary to understand the effect of domestic and agricultural water extraction on instream flow levels, particularly during low-flow seasons. This level of understanding is important to identifying site-specific measures to increase instream flow levels and developing reasonable goals for minimum instream flow maintenance under a range of water-year types. Due to the technical and political complexities of developing an updated water budget, one option is that a sample set of private wells and surface water diversions be monitored and that the data be kept confidential. It is recommended that monitoring data be analyzed on an approximately annual basis to determine both the total amount of water pumped from the watershed and/or specific sub-watersheds during different water-year types and, in conjunction with instream flow measurements, the influence of groundwater pumping and surface water diversions on seasonal instream flow levels. An updated water budget would also contribute to the County's North Coast Area Plan requirement that any new development in Cambria not using a CCSD connection must assure no adverse impacts to Santa Rosa Creek (San Luis Obispo County 2008).

Currently there is no single consistent or accurate source of stream flow data in the watershed, which are necessary to provide useful and reliable data for an updated water budget. This is essential to understanding changes in watershed conditions, developing meaningful measures to increase instream flows, and monitoring the effectiveness of implemented actions. This could be done most efficiently by bringing the stream gauge at the Main Street Bridge up to current USGS-protocols for stream gauge operation and calibration. The primary requirement at present is for a campaign of flow measurements aimed at robustly calibrating the gauge during low and high flows. In addition to improving the gauge at Main Street Bridge, it is recommended that additional stream flow gauges be installed upstream of the lagoon to record flows that include all tributaries and in the vicinity of Mammoth Rock to record flows in the portion of the watershed with relatively consistent perennial flow.

4.1.5 Reduce future municipal groundwater pumping

Per the San Luis Obispo County (2008) North Coast Area Plan, if/when the proposed desalination plant is operational, it is recommended that CCSD water withdrawals from the Santa Rosa Creek aquifer be limited to help protect instream flows in the lower reaches of Santa Rosa Creek (i.e., those reaches affected by CCSD pumping), as well as the aquifer itself and agricultural resources. If planned and operated strategically, the proposed desalination plant could reduce the need for municipal groundwater pumping along Santa Rosa Creek and help to conserve instream flow in the summer and fall.

4.2 Restore the Riparian Corridor

Native riparian vegetation is fundamental to maintaining summer and winter rearing habitat elements that are likely limiting the steelhead population in Santa Rosa Creek. A functioning riparian corridor with overhanging vegetation moderates stream temperatures by shading the channel, provides a source of large woody debris and roots that interact with streamflows to force the development of pools for rearing habitat, and provides leaf litter for aquatic invertebrate, as well as terrestrial invertebrate, prey species. By providing these ecosystem benefits, riparian restoration will also improve steelhead rearing conditions in the lagoon by moderating water temperatures and contributing to the food supply. Riparian vegetation also reduces streambank erosion, filters fine sediment and nutrients from runoff, provides wildlife movement corridors, and prevents non-native invasive plant species from becoming established. The following recommendations to restore the riparian corridor, several of which overlap with previous recommendations by CDFG (Nelson 1994, Nelson et al. 2009), will enhance summer and winter steelhead rearing habitat elements, reduce streambank erosion and fine sediment supply, and help conserve more natural streambank conditions in the lower reaches.

4.2.1 Revegetate degraded streambanks

To facilitate and expedite the restoration of a dense, multi-storied riparian corridor that provides multiple ecosystem services and benefits, it is recommended that native riparian trees and shrubs be planted in suitable areas. Examples of suitable areas include reaches where cattle have been excluded or are otherwise unable to graze on revegetated plants, and in areas where natural recruitment of riparian vegetation is not expected to occur in the near-term, such as steeper streambanks, higher elevation benches, or in strategic locations in or around bank revetment. Active revegetation may also be suitable soon after non-native invasive plant removal efforts (see below) to quickly restore vegetative cover and minimize the potential for re-infestation.

Intact riparian vegetation in lower Santa Rosa Creek

While planting palettes need to be selected based on site-specific conditions (e.g., elevation above baseflow, soil type, and groundwater level), alder (*Alnus rubra*), willow (*Salix* spp.), cottonwood (*Populus* spp.), sycamore (*Platanus racemosa*), big-leaf maple (*Acer macrophyllum*), and mulefat (*Baccharis salicifolius*) are examples of native trees and shrubs that may be appropriate for revegetation on streambanks and in wetter areas. In some cases, such as in the middle reaches, steep streambanks may need to be graded before planting. In upland or drier areas, coast live oak (*Quercus agrifolia*), blue oak (*Q. douglasii*), madrone (*Arbutus menziesii*), manzanita (*Arctostaphylos* spp.), California sagebrush (*Artemisia californica*), sage (*Salvia* spp.), toyon (*Heteromeles arbutifolia*), and coyote bush (*Baccharis pilularis*) may be appropriate. To the greatest extent possible, planting stock should be collected from the Santa Rosa Creek watershed to maintain genetic integrity. Planting at the onset of the rainy season can greatly reduce and even eliminate the need for irrigation, particularly in areas where plant roots can be expected to reach groundwater quickly. The use of cuttings, particularly for willow, cottonwood, and mulefat, can be another way to reduce the cost of revegetation efforts.

4.2.2 Manage grazing to reduce impacts to the riparian corridor

Cattle currently graze on streambanks and access the stream channel in several reaches of Santa Rosa Creek, as well as throughout the lower Perry/Green Valley Creek sub-watershed (Nelson et al. 2009, Appendix A). Such grazing can have severe impacts on riparian and instream conditions, including denuded streambanks, increased water temperatures, increased streambank erosion, and water quality contamination (Armour et al. 1994, Belsky et al. 1999), to the extent that fish populations are impacted (Platts et al. 1985, Ohmart 1996). It is recommended that grazing in the Santa Rosa Creek watershed be managed to reduce impacts to the riparian corridor. This could include the installation of fencing to exclude cattle from streambanks and the channel, as previously recommended by CDFG (Nelson et al. 2009), or other practices to limit access and use of the riparian corridor by cattle, such as off-channel watering. Ideally these voluntary efforts would be focused on the denuded reaches of upper Santa Rosa Creek, the intermittent portion of the middle reach of Santa Rosa Creek, and in the Perry/Green Valley Creek sub-watershed. In the intermittent middle reach, where surface flow loss to groundwater may already limit the extent of riparian vegetation, cattle grazing is likely exacerbating streambank erosion and further preventing riparian vegetation to persist. In the Perry/Green Valley Creek sub-watershed, cattle grazing has denuded streambanks and is contributing to streambank erosion that supplies fine sediment to the lower reaches of Santa Rosa Creek.

4.2.3 Minimize the need for bank protection

While bank protection such as concrete, rip-rap, and gabion baskets can be necessary to protect infrastructure near the creek, particularly in emergency situations, it degrades riparian and instream habitat by precluding native vegetation and simplifying the channel, and, as observed on Santa Rosa Creek in the town of Cambria, often shifts the erosion upstream or downstream of the rip-rap or to the opposite bank (Nelson et al. 2009). Conserving and restoring streambanks and floodplains through the recommendations above will help minimize the need for bank protection by preventing development near the creek (that might subsequently require protection) and decreasing the erodibility of the banks. Where roads or buildings are threatened by streambank erosion, it is recommended that the potential to “train” the creek away from these areas be investigated as an alternative to hardened bank protection. For example, the bar opposite the eroding streambank could be manipulated (e.g., skimmed or cut) to direct flow closer to the middle of the channel and away from the eroding bank. The feasibility of such an approach is dependent upon site-specific conditions (e.g., access for heavy equipment, and the condition of upstream and downstream areas) and must be evaluated accordingly. However, it presents several significant benefits compared with hardened bank protection: it addresses the cause rather than just the symptom of bank erosion; and it conserves existing, and may even help improve, riparian and instream habitat conditions.

As previously recommended by CDFG, where bank protection is necessary, it is recommended that bio-engineering alternatives to rip-rap and other hard measures be implemented. Many of these alternatives are described in CDFG’s California Salmonid Stream Habitat Restoration Manual (Flosi et al. 2004). Streambank soil bioengineering, for example, typically includes installing large woody debris and/or boulder structures and planting interstitial (i.e., exposed) bank surfaces with quick growing vegetation, such as willows. The exposed large woody debris, boulders, and planted vegetation dissipates flow velocities against the bank toe and bank surface, and planted vegetation physically holds bank substrates (silts and sands) in place, thus increasing bank strength. Exposed large woody debris and planted vegetation will, in turn, also contribute to over-summer and over-winter habitat improvements for steelhead by scouring pools and providing cover. Separate or in combination with soil bioengineering, a bio-fabric can be applied across the bank surface to shield the bank high flow velocities and holds bank soils in place, and/or steep streambanks can be re-contoured (i.e., re-shaping) to create a more gently-sloping profile and increase resistance at the bank toe. A more gently-sloping bank has a lighter load above the bank failure plane and is, therefore, better able to withstand toe scour and/or undercutting than a vertical bank.

4.2.4 Treat non-native invasive species

As described in the Watershed Synthesis, a number of non-native invasive plant species that have the potential to degrade riparian habitat by replacing native species and altering physical conditions have been documented in the Santa Rosa Creek riparian corridor. Several of these species, including several large-scale infestations of cape-ivy, isolated occurrences of arundo, pampas/jubata grass, eucalyptus, and French/Scotch broom are priorities for treatment efforts to promote the natural regeneration and growth of native vegetation and prevent further infestations. Removal of large areas of non-native vegetation is generally done in conjunction with riparian restoration so as to prevent the re-colonization of the area by non-native species.

However, the vast majority of the remaining watershed area has not been surveyed for non-native invasive species, where infestations can easily expand to downhill or downstream locations. For example, ponds in the Perry/Green Valley sub-watershed, which is largely un-surveyed, are likely a major source of bullfrogs to lower Santa Rosa Creek. Identifying small or recently established populations early on is important, since these are easier to control and/or eradicate. In addition, understanding broader patterns of non-native invasive plant distribution is important to increase the effectiveness of treatment measures and reduce the potential for later or downstream re-infestations. Therefore, it is recommended that the locations and populations of persistent non-native, invasive species in the riparian corridor be mapped and described. The inventory needs to 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 need to 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.

4.3 Reduce Fine Sediment Delivery to the Creek

Summer and winter rearing habitat in the lower reaches (stream miles 0–3.5) of Santa Rosa Creek is partially degraded by excess fine sediment input. Fine sediment embeds larger substrates, limiting their use for spawning and as refuge from high flows, and can fill pool habitat that is used during both summer and winter rearing. The following recommendations focus on two of the most problematic sources of fine sediment identified in the Geomorphic Assessment (Appendix A): the Perry/Green Valley Creek sub-watershed and road-related streambank erosion. Fine sediment supply from excessive streambank erosion would be addressed through the riparian restoration recommendations made above. It is recommended that initial treatment of fine sediment sources, wherever they are conducted, be implemented as an adaptive management experiment, with monitoring to determine if treatments are effective at reducing substrate embeddedness and/or pool infilling.

In addition, it is recommended that fine sediment source treatments be conducted in coordination with other recommendations to improve winter rearing habitat in mainstem Santa Rosa Creek, further test the hypothesis that winter habitat is limiting steelhead production in the watershed, and assess the effectiveness of the actions. 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. Remediating sources of fine sediment, particularly in the Perry/Green Valley Creek sub-watershed is also likely to increase the extent of rearing habitat in the lagoon by reducing the amount of aggradation.

4.3.1 Maintain roads to decrease hillslope and streambank erosion

San Luis Obispo County is responsible for the maintenance of Santa Rosa Creek Road and others in the watershed. Road-related runoff is the cause of much of the hillside and streambank erosion that is frequently observed in the watershed. Often, improperly placed ditches and culverts (or a lack thereof) concentrate winter runoff from roads where it can actively erode hillslopes or streambanks. Such erosion currently threatens Santa Rosa Creek Road at several locations. Road maintenance actions taken by the County would correct drainage features that currently concentrate runoff to unsuitable locations. It is recommended that culvert or ditch improvement or relocation be considered by the County at several locations (particularly where the road base is threatened) in the short-term, while out-sloping of roads (to discourage the concentration of runoff) may be more appropriate in the long-term.

Erosion at Santa Rosa Creek Road

4.3.2 Reduce and/or retain fine sediment delivery from the Perry/Green Valley Creek sub-watershed

Sediment delivered from the Perry/Green Valley Creek sub-watershed consists almost entirely of fine sediment (Appendix A). This supply is almost certainly a significant contributor to the lower quality spawning and rearing habitat conditions in the lower reaches of Santa Rosa Creek. Based on the Geomorphic Assessment (Appendix A) a number of measures are potentially appropriate to reduce fine sediment to and from the Perry/Green Valley Creek sub-watershed, including exclusion of cattle from stream channels, riparian corridor restoration, gully maintenance, and road infrastructure improvements to reduce sediment-laden runoff from roads. However, as survey access has previously been limited in this sub-watershed, it is recommended that a focused survey be conducted to identify specific fine sediment supply areas and site-appropriate remediation measures. Ideally this survey would also be used to identify measures that may be appropriate to retain fine sediment from the sub-watershed before it enters Santa Rosa Creek.

4.3.3 Implement Cambria drainage study recommendations

Both the 1999 and 2004 drainage studies conducted in Cambria's residential neighborhoods indicated that storm water is not being adequately planned for or managed, and warned that storm water issues can be expected to worsen if development continues in the Cambria area, unless meaningful steps are taken to plan for and address road- and home lot-related storm water runoff (USDA NRCS 1999, RMC 2004). These studies include detailed maps of problem areas, and recommend projects to improve storm water runoff capture and conveyance. It is recommended that these recommendations be implemented on a voluntary basis by existing property owners, and be required for newly proposed developments, either by the developer or coordinating local entity. The USDA NRCS (1999) report and maps are available for review at the Greenspace office: 4251 Bridge St, Cambria, CA 93428. The San Luis Obispo County Flood Control and Water Conservation District report and maps (RMC 2004) are available on-line: http://www.slocountydrainagestudies.org/

4.4 Conserve and Protect Open Spaces and Existing Land Uses

Conserving existing open space and land uses in the watershed will help address one of the critical issues in the watershed: the threat of land use change on fine sediment production, water demand, and the deleterious effects of urban development (e.g., increased impervious surfaces, contaminated runoff, non-native invasive species introductions, and encroachment of floodplains and the riparian corridor). This can be done via conservation easement, in which the current landowner retains ownership but is compensated for potential restrictions on land use, or fee-title purchase. If property with water rights is purchased, then these recommendations can also serve to increase summer and fall instream flows. Two focal areas for conservation efforts, to best protect aquatic habitat conditions in the watershed, are described below. TLCSLOC (2010) provides additional details on the conservation easement and fee-title purchase options that are relevant to landowners in the watershed.

4.4.1 Conserve undeveloped floodplains

Development near rivers and streams necessitates or facilitates many of the elements that degrade the riparian corridor and aquatic ecosystem, such as polluted runoff, increased runoff and decreased percolation from paved surfaces, rip-rap and other bank protection measures, decreased riparian vegetation, invasion by non-native species, and frequently levees to protect developed areas from high flow events. Floodplains also provide important habitat for a number of terrestrial and semi-aquatic species, such as Pacific pond turtle, California red-legged frog, and two-striped garter snake. To prevent further degradation of the Santa Rosa Creek riparian corridor and aquatic ecosystem, it is recommended that undeveloped floodplains, particularly along the lower creek where few remain and the middle reaches where the floodplains are undeveloped, be conserved and floodplain-compatible land uses maintained. For example, the left-bank floodplain between the Burton Street Bridge and Highway 1 is currently undeveloped and supports hiking trails and related recreational activities. Keeping infrastructure and/or more developed land uses away from the creek in this area will help conserve existing floodplain conditions and service, likely contribute to restoration efforts, and prevent further constraints on riparian and aquatic conditions in the future.

4.4.2 Conserve land uses in the upper watershed

The subdivision of large parcels, which are generally located in the upper watershed, is likely to result in land use changes in the subsequent smaller parcels. If these future land uses remove vegetation (both upslope and riparian), change hillslope topography, or alter runoff patterns, there is the potential that gully and rill erosion could be reinitiated with a subsequent increase in fine sediment delivery to watershed stream channels. Retaining large parcels or otherwise conserving existing land uses in the upper watershed would help prevent the degradation of aquatic habitat throughout the watershed.

4.5 Increase Woody Debris Supply and Retention

Lack of available summer and winter habitat was identified as a factor limiting the population of steelhead. Summer habitat for steelhead has been degraded in part by a disruption of the channel forming processes that form pools, including, but no limited to, a lack of woody debris that typically forms pools where steelhead and other aquatic species can over-summer, provides instream cover and protection from predators, and contributes to the food supply. This lack of woody debris also contributes to the degradation of winter habitat for steelhead. In addition to finding refuge from high flows in the interstitial spaces among cobbles and boulders, steelhead depend on the slower-water refuge areas provided by large woody debris, boulders and other instream cover, and undercut banks during high flow events. In Mediterranean-climate watersheds, large woody debris, which is generally composed of hardwoods such as bay, alder, sycamore, and willow trees greater than six inches in diameter at breast height, is frequently lacking as a result of overall riparian vegetation loss and its removal when it does enter streams (Opperman 2002).

Recommendations to restore the riparian corridor (Section 4.2) will, over time, help to increase the supply of natural large woody debris to the watershed. In conjunction with riparian restoration, education efforts are recommended to help landowners develop a complete understanding of the role large woody debris plays in the riparian ecosystem, and the measures that can be taken to avoid conflicts between large woody debris recruitment and retention and adjacent land uses due to the real and perceived threats from large woody debris on streambank infrastructure and flood risk. The combination of increased large woody debris supply and retention in stream channels contributes to restoring natural ecosystem function and providing long-term and sustainable summer and winter habitat for steelhead.

Riparian restoration is a long term action that will take upwards of a decade before the large woody debris it supplies begins to contribute to the improvement of summer and winter habitat conditions for steelhead. Since the lack of both over-summer and over-winter habitat may be limiting the steelhead population in the Santa Rosa Creek watershed, it is highly recommended that large woody debris in the stream be left where it is found or to manipulate its orientation in its current location. In other cases, it may be appropriate for large woody debris structures to be incorporated into other types of instream projects, such as bank stabilization projects (see Section 4.2.3). Riparian tree species that are native to the watershed, such as alder, bay, sycamore, and willows are appropriate and have been documented, particularly when in multiple log configurations, to effectively form pool habitat and provide instream cover (Opperman 2002). Any project in the watershed that incorporates large woody debris structures needs to be carefully and strategically planned and implemented to minimize unintended consequences on adjacent and/or downstream property, maximize the sustainability and effectiveness of the project in providing winter and summer habitat, and be consistent with the type of woody debris that would occur naturally in Santa Rosa Creek.

4.6 Remove Barriers to Fish Passage

Physical fish passage barriers can restrict adult and juvenile steelhead to the poorer quality spawning and rearing habitats in the lower reaches of Santa Rosa Creek, and may limit the steelhead population if/when this occurs in successive years. Culverts at Taylor and Curti creeks, and elsewhere, not only impede steelhead access to these tributaries, but they interrupt the supply of coarse sediment and large woody debris which is essential to maintaining suitable winter and summer rearing habitat for steelhead. Removal or modification of these culverts is recommended if there is sufficient quantity and quality steelhead habitat upstream. In addition to improving fish passage, sediment and large woody debris transport would be improved under the full range of flow conditions. Recommendations to determine additional actions that could be taken to improve passage conditions in the middle reaches of Santa Rosa Creek, and to assess the severity of potential passage barriers in the Perry/Green Valley Creek sub-watershed are included in Section 4.7 below.

4.7 Fill Key Data Gaps

The Watershed Synthesis and Steelhead Limiting Factors Analysis identified a number of key data gaps that limit the understanding of watershed conditions and processes, the identification of factors potentially limiting steelhead, and the ability to develop effective actions to enhance watershed conditions and address steelhead limiting factors. Ideally the results of the investigations described below will be used to test the hypotheses of steelhead limiting factors, such that hypotheses are accepted, rejected, or refined, based on new understanding of the system.

4.7.1 Monitor adult steelhead population

Adult returns are usually considered the best indicator of population status. However, there are currently no robust estimates of adult abundance in Santa Rosa Creek. Due to the difficulty in monitoring steelhead spawning in creeks with small steelhead populations and dispersed spawning habitat, CDFG recommends the use of traps, weirs, and/or video or sonar detection systems to provide an absolute count of migrating adults (Adams et al. 2011).

4.7.2 Identify steelhead instream flow requirements

While the recommendations in Section 4.1 above will contribute to the maintenance of summer and fall instream flows, better understanding the site-specific instream flow requirements for key steelhead life history stages is essential for developing and planning specific actions. Therefore, an analysis of how much flow is required to maintain adequate summer and fall rearing habitat for age 1+/2+ steelhead (e.g., passage over shallow riffles and connectivity between pools, and suitable water temperatures) and summer invertebrate production is recommended. The results of this assessment would refine the understanding of the specific locations and ways that instream flows limit the steelhead population and can be used to identify minimum instream flow goals in specific parts of the watershed that can then guide the type and number of actions taken to maintain summer and fall instream flows. In addition, this survey, if conducted in the winter can be used to identify minimum flow needs to facilitate migration over shallow riffles. The flows needed for both adult and juvenile steelhead migration have been identified for lower Santa Rosa Creek (D. W. Alley & Associates 1993), but the previous study did not include the intermittent portion of the middle reach situated upstream of the Perry Creek confluence, or upstream of Mammoth Rock where the stream is perennial most years (Figure 2-8). It is recommended that any identification of instream flow requirements be accompanied by an analysis of available stream flow data in order to evaluate the extent to which instream flow requirements for fish passage and/or summer and fall rearing habitat are or are not being met.

4.7.3 Assess lagoon habitat quality and steelhead smolt growth in and outside the lagoon

The degree to which steelhead use the lagoon for rearing, and that the lagoon contributes to steelhead growth, is uncertain (Nelson et al. 2009). As stated previously by CDFG, it is recommended that studies be implemented to document juvenile steelhead use of the lagoon to better understand the link between juvenile steelhead production/carrying capacity in the creek and lagoon, and evaluate steelhead growth patterns under a range of water-year types. These surveys would ideally include the timing and extent of steelhead use of the lagoon, timing and duration of emigration/immigration as related to sandbar closure and instream flow, growth rates in and upstream of the lagoon, and population estimates. Combined with strategic monitoring of water temperature, DO, and salinity under varying flow conditions, these studies can be used to evaluate the suitability of the lagoon for rearing under different water-year types and identify specific actions for enhancing lagoon quality and optimizing steelhead lagoon rearing.

4.7.4 Assess flows through the middle reaches of Santa Rosa Creek

These reaches (approximately stream mile 6.5 to 8) generally run dry each summer, restricting connectivity between steelhead rearing habitat, and, in dry winters, are hypothesized to impede upstream migration of spawning steelhead (Nelson et al. 2009). Due to the low gradient and position in the watershed, these reaches are the natural depositional area for sediments transported from the upper watershed and, in combination with land use changes, result in a wide, undefined floodway and highly pervious substrates. Additional survey work and analysis are recommended to better understand the natural vs. human factors controlling instream flows through these reaches and determine what, if any, other actions would be appropriate to increase the capacity of these reaches to maintain minimum instream flows in the summer and improve upstream migration conditions during dry winters.

4.7.5 Estimate juvenile steelhead abundance

There are currently extensive data on fall abundance of juvenile steelhead in Santa Rosa Creek. While fall abundance data is useful for understanding annual abundance trends, it does not allow the direct assessment of summer habitat limitations, which is a key step in understanding factors limiting the steelhead population in the watershed. Developing reach-specific abundance estimates in the early summer, in addition to the fall, would allow evaluation of both over-winter and over-summer survival of both YOY and older juveniles, and potentially help identify over-winter and/or over-summer habitat limiting factors that may be addressed through restoration. Ideally this would be conducted for several years to help understand the dependence of winter and summer survival on variations in water quantity and flow dynamics. It is recommended that any juvenile monitoring be done according to the protocols described in CDFG's recent California Coastal Salmonid Population Monitoring Strategy, Design, and Methods report (Adams et al. 2011).

4.7.6 Assess mercury uptake in the aquatic food chain

It is unknown to what extent or even if the high levels of mercury that have been detected in sediments in Curti and Santa Rosa creeks are accumulating in the aquatic food chain and/or potentially affecting steelhead populations. To better understand the degree of mercury contamination in the watershed and potentially garner funding for remediation efforts, it is recommended that a focused study of mercury be conducted in the watershed. A well designed study would include sites upstream of, at, and downstream of the mercury mine former mill site off of Curti Creek, as well as other known mercury mine locations in the watershed, to determine natural background levels of mercury and patterns of mercury contamination downstream. Such a study would also include water, sediment, and resident aquatic organism (e.g., benthic invertebrates and/or small resident fish) samples that are tested for total mercury and methylmercury.

4.7.7 Assess the Perry/Green Valley Creek sub-watershed

It is unknown if the Perry/Green Valley Creek sub-watershed is accessed or used by steelhead, or what the aquatic habitat conditions are like. Given the size of this sub-watershed and the potential for steelhead habitat, it is recommended that the assessment include, but not be limited to, geomorphic, hydrologic, and biological (e.g., aquatic habitat conditions, fish passage, and steelhead use) surveys. Knowing the limiting factors potential for steelhead in this sub-watershed would be an important first step towards understanding the relative importance of this sub-watershed for steelhead.

4.7.8 Continue and expand citizen water quality monitoring

The benthic macroinvertebrate and first flush sampling, which was done in coordination with the broader Monterey Bay Sanctuary Citizen Watershed Monitoring Network, conducted for the development of this Watershed Management Plan help characterize just one year of water quality conditions in lower Santa Rosa Creek. Multiple, and ideally continuous, years of sampling and additional sampling sites in the upper watershed, are needed to better understand temporal and spatial trends in water quality conditions. If and when temporal and spatial trends are recognized, these can be used to help identify emerging risks to water quality and aquatic species, pollutant sources, and, subsequently, appropriate best management practices to minimize or prevent pollutants from entering waterways.

4.8 Reduce Mercury Supply

Due to the high potential for mercury to affect human health and aquatic organisms and the fact that methlymercury—the most bio-available form of mercury—has been detected in the Santa Rosa Creek lagoon, it has been previously recommended that efforts be made to control known sources of mercury in the watershed. These recommendations include erosion control along Curti Creek to prevent mercury-laden sediment from being delivered to the creek and creation of treatment wetlands to retain and accumulate existing mercury in the system, need to be implemented to prevent further mercury contamination.

4.9 Summary of Recommendations

Table 4-1 summarizes the recommendations described above and the primary reason for their inclusion in the Watershed Management Plan (e.g., near-term steelhead habitat restoration, long-term watershed enhancement, etc.). The recommendations are listed in order of their relative importance to steelhead habitat restoration, but this ranking is not intended to limit the implementation of any recommendation. Appendix D describes a variety of sources of potential funding for implementation of the plan recommendations.

Table 4-1. Summary of recommendations.

Recommendation (Bolded text indicates actions that are of higher priority for steelhead habitat restoration)		Included to Address: Near-term steelhead habitat restoration	Long-term watershed enhancement	Key uncertainties
4.1.1	**Implement water conservation and reuse strategies**	•	•	
4.1.2	**Construct off-stream closed water storage**	•	•	
4.1.3	**Purchase water rights from willing sellers for instream flows**	•	•	
4.1.4	**Conduct stream gauging and develop an updated water budget**		•	•
4.1.5	Reduce future municipal groundwater pumping			
4.2.2	**Revegetate degraded streambanks**		•	
4.2.1	**Manage grazing to reduce impacts to the riparian corridor**		•	
4.2.3	**Minimize the need for bank protection**		•	
4.2.4	Treat non-native invasive species		•	
4.3.1	**Maintain roads to decrease hillslope and streambank erosion**		•	
4.3.2	**Reduce and/or retain fine sediment delivery from the Perry/Green Valley Creek sub-watershed**		•	
4.3.3	Implement Cambria drainage study recommendations		•	
4.4.1	**Conserve undeveloped floodplains**		•	
4.4.2	**Conserve land uses in the upper watershed**			
4.5	**Increase woody debris supply and retention**	•	•	
4.6	**Remove barriers to fish passage**		•	
4.7.1	**Monitor adult steelhead population**			•
4.7.2	**Identify steelhead instream flow requirements**		•	•
4.7.3	**Assess lagoon habitat quality and steelhead smolt growth in and outside the lagoon**	•		•
4.7.4	Assess flows through the middle reaches of Santa Rosa Creek	•	•	
4.7.5	Estimate juvenile steelhead abundance			•
4.7.6	Assess mercury uptake in the aquatic food chain			•
4.7.7	Assess the Perry/Green Valley Creek sub-watershed			•
4.7.8	Continue and expand citizen water quality monitoring			•
4.8	Reduce mercury supply		•	

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JoEllen Butler *Friends of Fiscalini Ranch*	Scooter Rhodes *Property Owner*	Steve Soto *Property Owner*
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Appendices

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Appendix A

Geomorphic Assessment of Santa Rosa Creek Watershed

(provided as separate document)

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Santa Rosa Creek
Watershed Geomorphology Assessment,
San Luis Obispo County, CA

FINAL TECHNICAL REPORT
May 2010

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Cover photography (from top to bottom):

1. Westward (downstream-facing) view of the Santa Rosa Creek watershed, July 2009. Photograph by R. Hawley/Greenspace – The Cambria Land Trust.
2. Eroding hillslopes in the Curti Creek subwatershed of Santa Rosa Creek watershed, July 2009. Photograph by Stillwater Sciences.
3. Santa Rosa Creek channel, view east (upstream), July 2009. Photograph by Stillwater Sciences.
4. Santa Rosa Creek lagoon at Moonstone Beach, view west (downstream), June 2009. Photograph by Stillwater Sciences.

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1 INTRODUCTION

1.1 Project Overview

Santa Rosa Creek in northern San Luis Obispo County once supported one of the largest populations of southern steelhead trout (*Oncorhynchus mykiss*) along the central California coast south of San Francisco (Titus et al. 2006). Perennial flow, suitable instream habitat conditions (e.g., riparian cover and spawning substrate), and few physical barriers contributed to the success of this species in the watershed. However, recent fish studies have determined that the population has dropped significantly below historic levels, driven by a number of probable factors including land uses, road building, and groundwater pumping (e.g., Nelson 1994, D. W. Alley & Associates 2007, Nelson et al. 2009). In response to the concerns over the existing habitat conditions of the threatened steelhead trout, several state and local advocacy groups have begun to identify limiting factors for steelhead trout habitat in the watershed (D. W. Alley & Associates 2008; TLCSLOC 2008), although these limiting factors have not been prioritized. These studies have focused on many of the geomorphic controls on habitat at the reach scale of Santa Rosa Creek, but prioritization requires a more comprehensive assessment of geomorphic factors at the watershed scale. Therefore, a watershed-wide evaluation of geomorphic conditions and processes that potentially contribute to aquatic habitat quantity and quality must be considered to successfully identify appropriate management solutions for Santa Rosa Creek.

An assessment of the geomorphic controls on steelhead trout habitat requires a study of hillslope and channel processes in the watershed from a historic and present-day perspective. Greenspace – The Cambria Land Trust (Greenspace) received grant funding from the California Department of Fish and Game (CDFG) to investigate the watershed's geomorphology—the scientific study of landforms and the processes that shape them—and synthesize the study's findings with existing steelhead trout habitat and other pertinent stream ecology information into a watershed management plan. Stillwater Sciences was tasked to conduct the watershed geomorphic assessment of Santa Rosa Creek, which entails the following:

- Compile and review existing information relating to hillslope and channel geomorphic processes
- Characterize hillslope geomorphic processes in the watershed and resulting sediment delivery into the mainstem Santa Rosa Creek
- Characterize sediment transport and channel dynamics in the mainstem of Santa Rosa Creek to understand how these processes affect channel morphology

This technical report examines geomorphic processes across the Santa Rosa Creek watershed at scales ranging from the site to the entire watershed. At the hillslope scale, field observations (including air viewpoints and accessible ground locations) combined with information contained in published literature were utilized to understand sediment production and delivery to the channel network. This approach integrates the effects of climate, precipitation, topography, tectonic activity, underlying rock types and geologic structure, vegetation coverage, and land uses throughout the watershed. Within the mainstem channel, contemporary conditions were assessed using reconnaissance surveys of channel morphology and data collected at accessible field locations including sediment-size distributions and observed sediment delivery from eroding banks and tributaries. Sediment transport characteristics were evaluated using these field data coupled with historical flow frequency and duration data. Evolution of the channel over the past 70 years was assessed using historic and current aerial photography and topography.

The results of these studies have been synthesized to produce a baseline geomorphic assessment, and characterization of geomorphic processes in the watershed that affect aquatic habitat conditions, particularly those for steelhead trout. In support of the watershed management plan, this technical report presents the following:

- Summary of historical changes
- Prediction of hillslope and tributary sediment production and identification of production zone locations and delivery pathways
- Estimation of reach-scale differences in channel form and processes, and sediment transport dynamics within Santa Rosa Creek
- Categorization of the channel network into zones of sediment production, transfer, and storage.

1.2 Regional Setting

The morphology of the central California coast, and in turn the Santa Rosa Creek watershed and its supported aquatic habitats, is controlled by both natural and anthropogenic (human-induced) forces. This section briefly introduces these forces to the extent they relate to the subject area.

1.2.1 Watershed characteristics

Santa Rosa Creek watershed lies within the southern portion of the California Coast Range—a northwest-trending series of mountains and basins along the coast from Santa Barbara north to the Oregon border (Figure 1-1). The 123 km^2 (48 mi^2) watershed is bounded to the east by the Santa Lucia Mountains and the west by the Pacific Ocean. Bordering the watershed are the similarly sized watersheds of San Simeon Creek to the north, Adelaida Creek to the northeast, Paso Robles Creek to the east, and Villa Creek to the south. Santa Rosa Creek and its tributaries flow mostly unobstructed down steep hillslopes mantled with shallow soils and sparse shrub vegetation, and through agricultural areas and the small town of Cambria before reaching the Pacific Ocean. Santa Rosa Creek travels 25 km (16 mi) from its headwaters, following a sinuous course to the west through a confined canyon that opens up into a relatively long, broad valley floor. The town of Cambria sits near the mouth of Santa Rosa Creek, below the confluence with Perry Creek—the largest tributary in the watershed. Only four creeks have been named on topographic maps of the U.S. Geological Survey (USGS)—Santa Rosa, Perry, Green Valley, and Fiscalini creeks (USGS 1979a, 1979b)—while an additional 6 streams have been unofficially designated as derived from past or current property owner names (e.g., D. W. Alley & Associates 2008). These tributaries are referenced throughout this report, as summarized below in Table 1-1 and shown in Figure 1-2.

The watershed exhibits an unusual drainage pattern as it is effectively split in two primary halves: Santa Rosa Creek represents the northern half and Perry Creek, along with Green Valley Creek, represents the southern half. In effect, the watershed supports two main stream branches. Both subwatersheds exhibit similar drainage patterns with longer tributaries flowing from the north and down south-facing slopes to their individual confluences. This pattern gives the valleys of Santa Rosa, Green Valley, and upper Perry Creek an asymmetrical form when viewed looking downstream. This form is clearly exhibited by the position of the three mainstem channels flowing much closer to the southern divide of their respective subwatersheds. The two primary streams and their tributaries flow across various geologic rock units, including shales, sandstones, and volcanics, but they primarily cross rocks of the tectonically sheared Franciscan Complex (see Section 1.2.2). The topographic relief is typical of the southern Coast Range terrain, with steep upland areas and low-gradient valley bottoms bordering the lower reaches of Santa Rosa, Green Valley, and Perry creeks (Figure 1-2). Relatively higher elevations are present in the Santa Rosa Creek subwatershed, which peaks at Cypress Mountain with an elevation of 894 m (2,933 ft). In comparison, the highest point in the Perry Creek subwatershed (NE corner of the Green Valley subwatershed) reaches an elevation of 433 m (1,419 ft). At its lowest elevation, Santa Rosa Creek flows through a lagoon contained by an annually formed sandbar at Moonstone Beach that re-opens when streamflow begins to rise in late fall (see Section 4.5 – Lagoon Morphology and Dynamics).

Table 1-1. Santa Rosa Creek watershed and subwatershed areas, stream lengths, and maximum relief.

Subwatershed	Area [A]		Stream length [B]		Maximum relief [C]	
	km^2	mi^2	km	mi	m	ft
Total Santa Rosa Creek Watershed [D]	**123**	**47.5**	**25.4**	**15.8**	**894**	**2,933**
Santa Rosa Creek [D, E, F]	63.6	24.6	25.4	15.8	894	2,933
Taylor Creek [G]	*3.8*	*2.4*	*3.8*	*2.4*	*200*	*658*
Curti Creek [G]	*5.5*	*2.1*	*3.5*	*2.2*	*596*	*1,957*
Lehman Creek [G]	*6.5*	*2.5*	*4.1*	*2.6*	*774*	*2540*
East Fork Santa Rosa Creek [G]	*4.9*	*1.9*	*4.7*	*2.9*	*527*	*1,730*
North Fork Santa Rosa Creek [G]	*5.6*	*2.2*	*4.2*	*2.6*	*534*	*1,752*
Mora Creek [G]	*6.8*	*2.6*	*4.8*	*3.0*	*680*	*2,230*
Perry Creek [E]	59.3	22.9	15.6	9.7	245	804
Fiscalini Creek [E]	6.7	2.6	2.3	1.4	188	617
Green Valley Creek [E]	31.5	12.2	12.8	7.9	405	1,330

[A] Subwatershed area derived in a GIS using a USGS 10m Digital Elevation Model (DEM).
[B] Stream length derived in a GIS using a USGS 10m DEM-generated stream network with a contributing area threshold of 0.04 km^2.
[C] Minimum and maximum elevations of subwatershed derived in a GIS using a USGS 10m DEM
[D] Santa Rosa Creek mainstem continues along "East Fork Santa Rosa Creek" per the USGS name designation (USGS 1979b)
[E] USGS stream name designation (USGS 1979a, 1979b)
[F] Excludes Perry Creek subwatershed
[G] Unofficial tributary name (D. W. Alley & Associates 2008)

Figure 1-1. Santa Rosa Creek watershed and vicinity map.

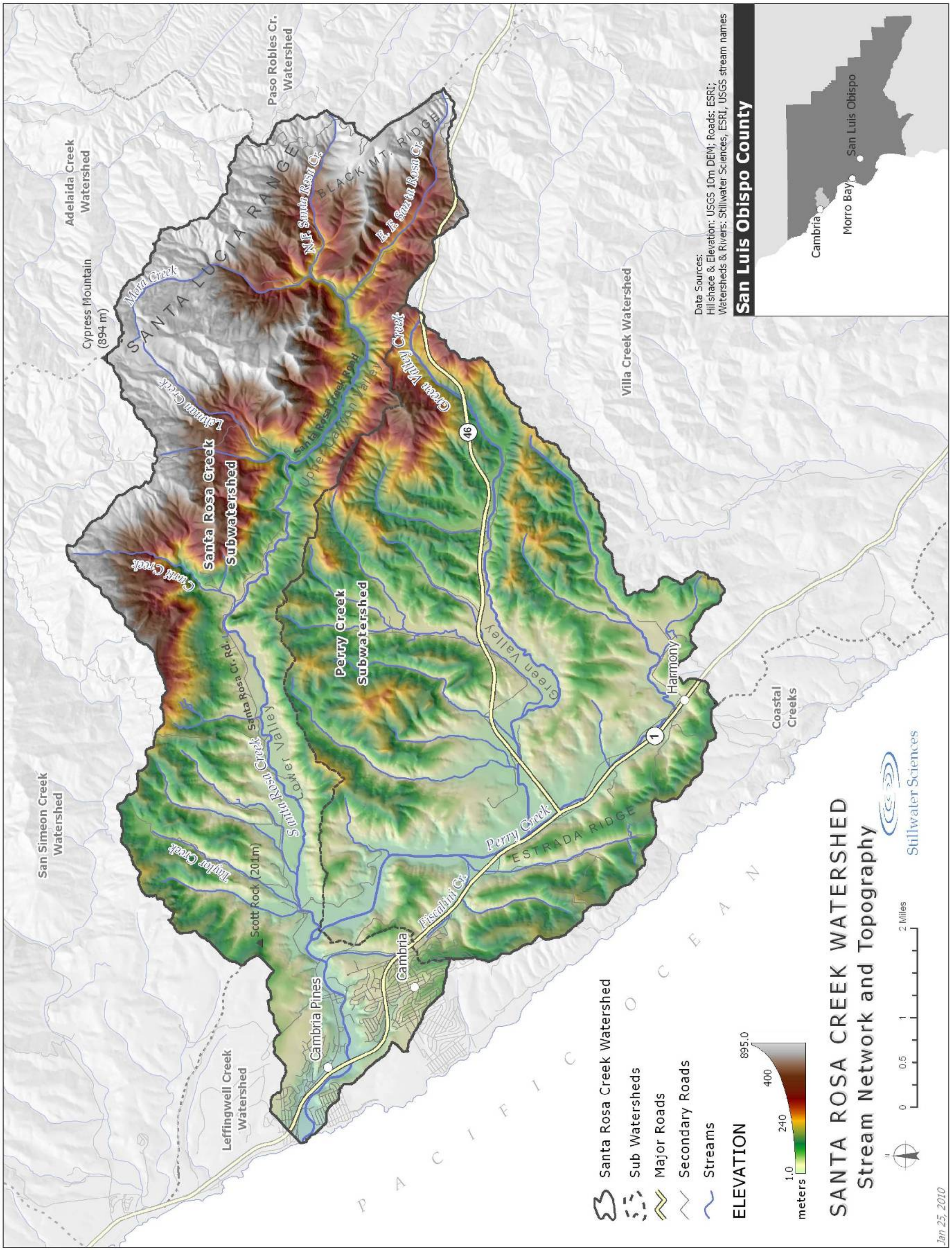


Figure 1-2. Santa Rosa Creek watershed stream network and topography.

1.2.2 Geology

The Santa Rosa Creek watershed lies along the Santa Lucia Mountain range near the southern end of the geologically distinctive Coast Range geomorphic province. Orientated with the overall NW–SE trending grain of the California topography, the Santa Lucia range follows the southern Coast Range for 150 km (93 mi) between Monterey Bay to the north and the San Rafael Mountains to the south near Santa Barbara. The province resides within a tectonically active zone composed primarily of right-lateral strike-slip (horizontal sliding motion) faults separating the Pacific and North American plates. At the axis of this zone is the 1,000-km-long (600-mile-long) San Andreas Fault, which lies 60 km (37 mi) to the east of the Santa Rosa Creek watershed. Overall, this tectonically and geomorphically active province exhibits intermittent seismicity and asymmetrical drainages offset by faulting. Geologic mapping utilized for this study and presented in Figure 1-3 were based primarily on maps produced by Dibblee (2007a, 2007b), with supplemental information drawn from maps produced by Hall et al. (1979) and Lettis et al. (2004).

The geologic history of the Coast Range province formation that is relevant to this geomorphic study begins about 150 million years ago (Ma), before the formation of the San Andreas Fault and during a period when the dense oceanic Farallon Plate moved east and slid beneath the less dense continental North American Plate. This process, referred to as subduction, formed a deep, marine trench along the ancestral California coastline at the western base of the Sierras. A portion of the sediments and volcanic flows composing the eastward-moving seafloor were scraped off during the subduction process and, along with sediments transported downstream from the Sierras, accumulated within the trench. These accreted materials are preserved today as the Mesozoic (200 to 100 Ma) rocks of the Franciscan Complex and early Cenozoic (65 to 25 Ma) sedimentary rocks that together make up much of the Coast Range province (Chipping 1987, Dibblee 2007a, 2007b). Rock types contained within the Franciscan include chert, graywacke (argillaceous sandstone), greenstone (altered basalt), and serpentinite—the state rock of California. Non-marine rock units formed during the early Cenozoic era include the Lospe Formation sandstones. Today, the majority of the Santa Rosa Creek watershed is predominately composed of Franciscan mélange: a mix of hard graywacke (sandstone) and sheared argillite (silt/claystone). Sandstones of the Lospe Formation are exposed along the hilltops near lower Perry and Green Valley creeks.

Following the complete subduction of the Farallon Plate, the eventual transition to a transform (strike-slip) plate boundary began about 25 Ma with the gradual contact between the northwest-moving Pacific Plate and the southeast-moving North American Plate (Atwater and Molnar 1973). This transition marked a geologically brief period of coastal volcanism which locally produced the Cambria Felsite rocks of Oligocene age (27 Ma), as seen today at Scott Rock located east of Cambria near Taylor Creek (Dibblee 2007a). Sedimentary rocks subsequently formed in offshore basins developed during early San Andreas Fault activity, which included Vaqueros Formation sandstones and Rincon Formation shales. Both of these units presently occur adjacent to the Lopse Formation sandstones in the uplands of the lower watershed. A second brief period of volcanism occurred underwater along the proto-coastline about 16 Ma (early Miocene) and locally created the basalts and tuffs of the Obispo Formation (Hall 2007). These now highly weathered basalts and hardened tuffs (solidified volcanic ash) lie unconformably upon the Franciscan mélange rocks along a northwest-trending band in the upper watershed. Erosion-resistant Obispo tuffs are presently exposed at the Black Mountain ridge near the headwaters of Santa Rosa Creek. The submarine volcanic activity was followed in the upper Miocene and lower Pliocene epochs (12 to 3 Ma) by continued offshore sediment deposition resulting in the Monterey Formation—one of the thickest and most widespread sedimentary units in the Coast Range—and the Pismo Formation. In the Santa Rosa Creek watershed, both of these units are dominated by thin-bedded, silica-rich shales, siltstones, and claystones, with some sandstones present in the lower Pismo Formation member (Chipping 1987).

The Coast Range orogeny, or mountain-building process, began during the late Pliocene and Pleistocene epochs ($\leq$4 Ma) and continues today. Regional uplift has been driven by crustal convergence that occurs where subtle NW–SE trending bends along the active transform fault zones force earth materials in between the larger faults to “pile up”, thereby creating the upland areas of the watershed. Obvious evidence of geologically recent uplift activity is the existence of Pleistocene marine terraces situated along the coastline and the lower watershed. Tectonic movement here may explain the watershed’s unusual drainage pattern of being split in two primary halves—Santa Rosa Creek and Perry Creek subwatersheds—where Perry and Green Valley creeks may have once flowed directly to the coast but were eventually “captured” by Santa Rosa Creek as uplift and transverse migration of the elevated landscape re-directed Perry and Green Valley creeks northward. Additional evidence of this event is the presence of a broad, flat expanse along lower Perry Creek where, prior to European settlement, flow and sediment conveyed by Perry Creek collected in the basin to form a perennial lagoon. Additional details on the lagoon are discussed in Chapter 4.

Since the last 10,000 years, active faults traversing and/or bordering the watershed exhibit a general stick-slip motion, whereby movement is episodic and expressed as earthquakes. The largest of these faults in the vicinity of the watershed is the San Simeon-Hosgi Fault Zone located offshore and estimated to have a late Quaternary (since 1.8 Ma) slip rate of 1–3 mm a^{-1} (Lettis et al. 2004). In December 2003, a 6.5-magnitude earthquake occurred about 17 km (10 mi) north of Cambria near the Oceanic Fault, which also traverses the headwaters of Santa Rosa Creek (USGS 2004). Properties in both Cambria and Paso Robles were damaged during this event, as were Highway 46 and Santa Rosa Creek Road.

Coincident with the Coast Range uplift period, the valley floors along Santa Rosa, Perry, and Green Valley creeks have accumulated unconsolidated alluvial and stream-terrace deposits. It is within these sediments that the watershed’s groundwater basins have developed, which currently serve as a primary water supply source to urban areas and land use activities in the watershed (see Section 1.2.4 below). The bulk of the water-bearing units are along the lower valley reach of Santa Rosa Creek, below a geologic constriction composed of hard Franciscan greenstone called Mammoth Rock (see Figure 1-5 in Section 1.2.3 below). The groundwater storage capacity in the basin has been estimated at 24,700 acre-feet (CDWR 1975).

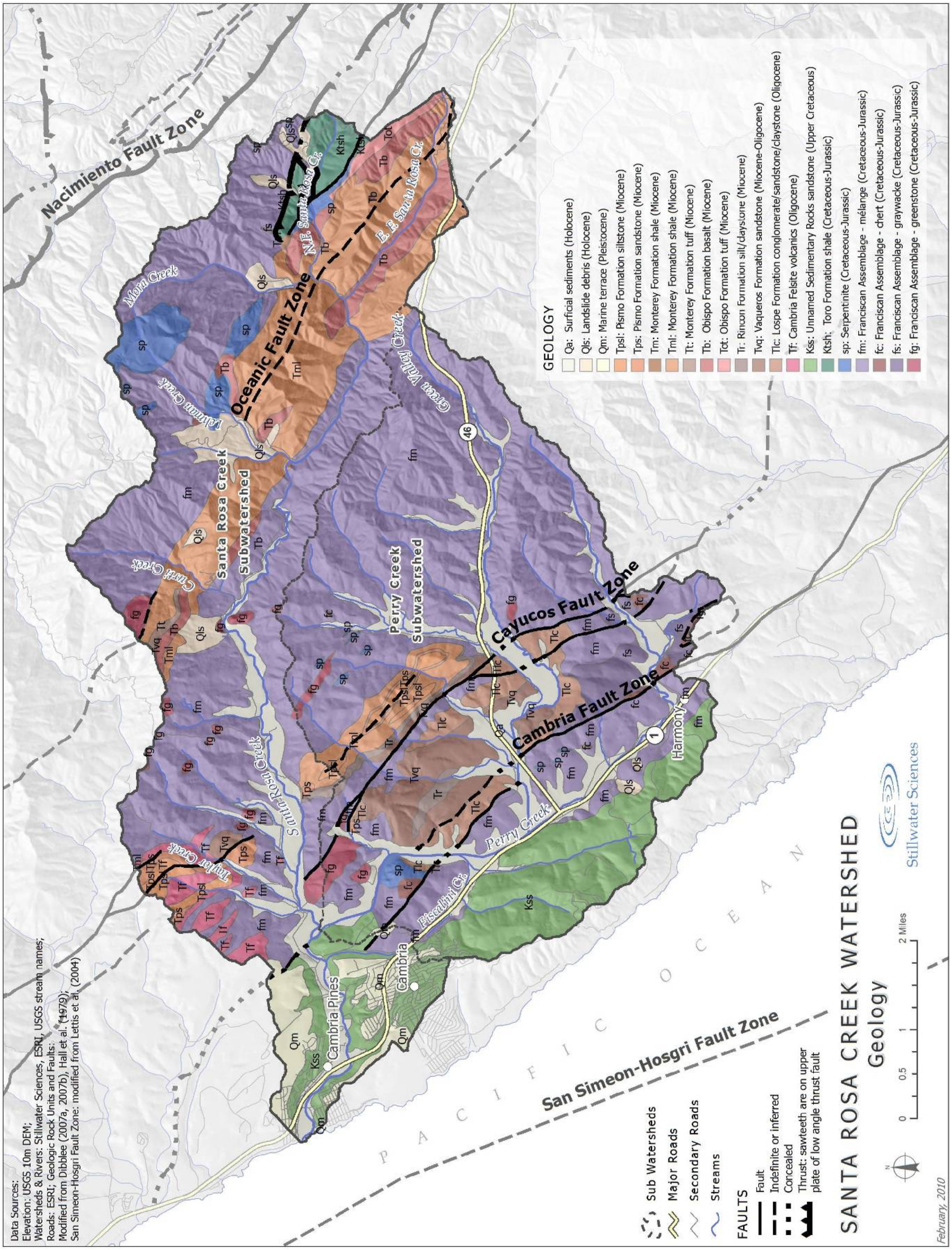


Figure 1-3. Santa Rosa Creek watershed geology.

1.2.3 Climate and hydrology

Coastal watersheds along the west side of the Coast Range province experience a two-season Mediterranean-type climate, with wet cool winters and dry warm summers. The regional climate is controlled by the North Pacific High, a high pressure system resting over cold upwelling waters of the eastern Pacific, while the local climate is controlled by the watershed's topography and proximity to the ocean (Carle 2006). The Pacific High system deflects storms from reaching the California coast during summer months, resulting in dry westerly winds blowing over cold ocean water and often producing fog. In the Santa Rosa Creek watershed, this fog belt typically extends inland just past Cambria. During winter, the Pacific High retreats to the south resulting in high rainfall in California concentrated between November and April. Overall, the California coast experiences highly variable annual rainfall depending on each storm's frequency and magnitude and on the landscape relief. Mean annual rainfall across the watershed varies between 53 and 94 cm (21 and 37 in), as reported by the U.S. Department of Agriculture (1971–2000) and San Luis Obispo County Division of Public Works (1954–2008) (Figure 1-4). A clear pattern of increased rainfall with elevation is expressed across the watershed, as the lowlands near Cambria, including much of Perry and Green Valley creeks, receive nearly half the rainfall received in the headwaters of Santa Rosa Creek.

Periodicity in the pattern of the wet/dry years in California is correlated to the El Niño–Southern Oscillation (ENSO) climatic phenomenon. ENSO is characterized by warming and cooling cycles (oscillations) in the waters of the eastern equatorial Pacific Ocean. Specifically, El Niño episodes are initially driven by abnormally low atmospheric pressures in the eastern Pacific, resulting in lower upwelling rates of cold ocean waters and, therefore, a persistence of warmer surface water temperatures (Kousky and Bell 2000). Ultimately, the warmer waters lead to increased precipitation along the eastern Pacific, extending up to California. ENSO cycles typically have a 1–1.5 year duration and 3–8 year recurrence interval. ENSO-induced climate change occurs on a multi-decadal time scale that is consistent with the recent shift from a relatively drier climate (averaged over the period 1944–1968) to a relatively wetter climate (averaged over the period 1969–1995) in North American's Pacific region (Inman and Jenkins 1999). The most recent El Niño event (although weak) occurred in water year 2007, and another event is underway in water year 2010 (NOAA 2009a).

The climatic and hydrologic characteristics of the watershed produce a perennial flow regime along the majority of Santa Rosa Creek, while most tributaries, including Perry and Green Valley creeks, experience intermittent flows (Figure 1-5). Similar to other Coast Range basins, flood flows in Santa Rosa Creek typically increase, peak, and subside rapidly in response to high intensity rainfall. This hydrologic attribute is characteristic of a "flashy" hydrograph, whereby a rapid increase in discharge occurs over a relatively short time period with a quickly developed peak discharge in relation to normal baseflow (Ward 1978). Since 1958, large flood events have occurred in 1967, 1969, 1973, 1978, 1986, 1993, 1995, and 2005, frequently (but not always) corresponding with ENSO years (NOAA 2009b), which is consistent with an understanding that ENSO years in the Coast Ranges, especially south of 35ºN, are characterized by relatively high rainfall intensities, with rivers and streams exhibiting higher annual peak flows than they do in non-ENSO years (Cayan et al. 1999, Andrews et al. 2004). Additional details on the discharge dynamics in the watershed are presented below in Chapter 4.

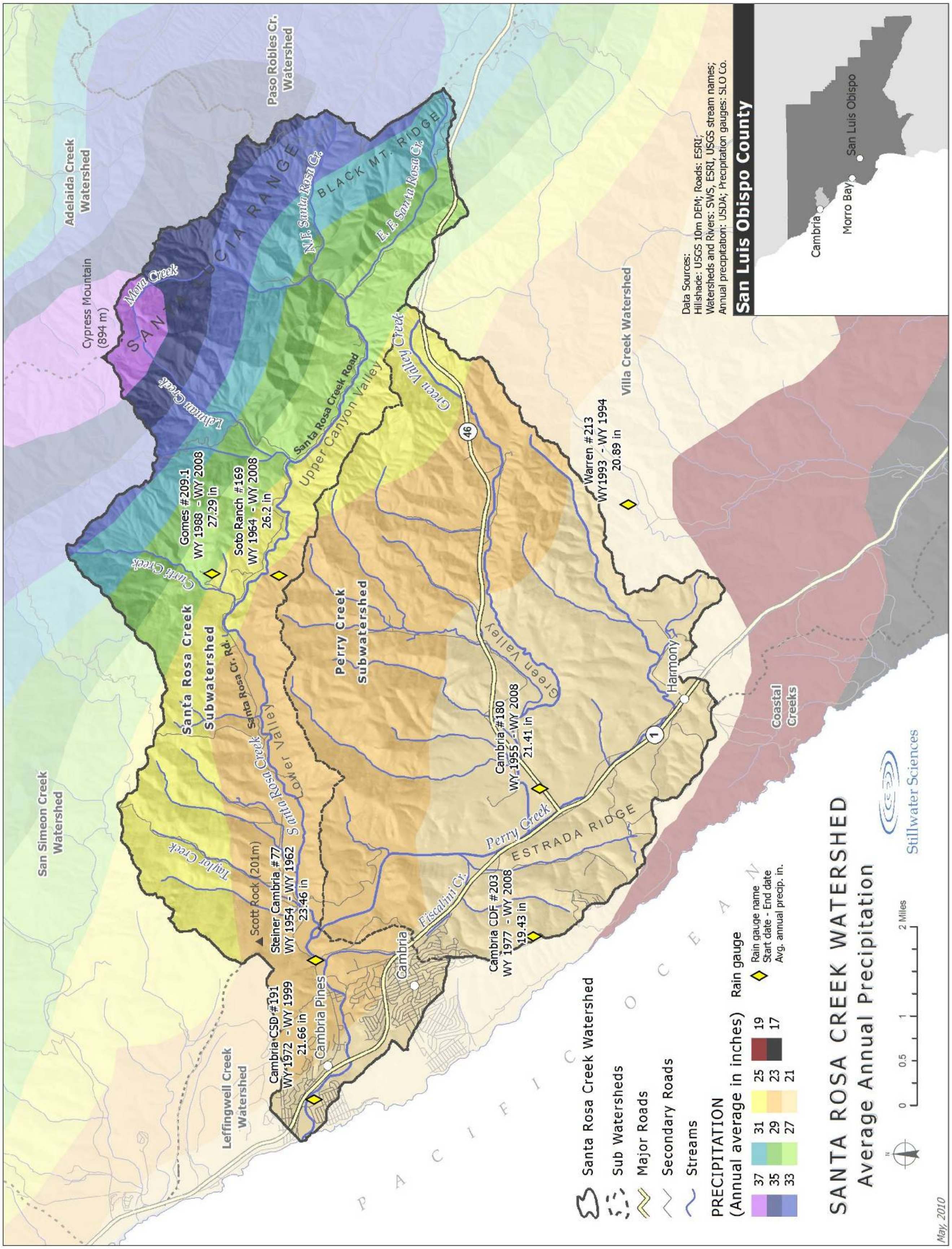


Figure 1-4. Distribution of average annual precipitation in the Santa Rosa Creek watershed. Precipitation contours represent the period of 1960 – 2001. Rain gauge stations representing various years of data shown for reference.

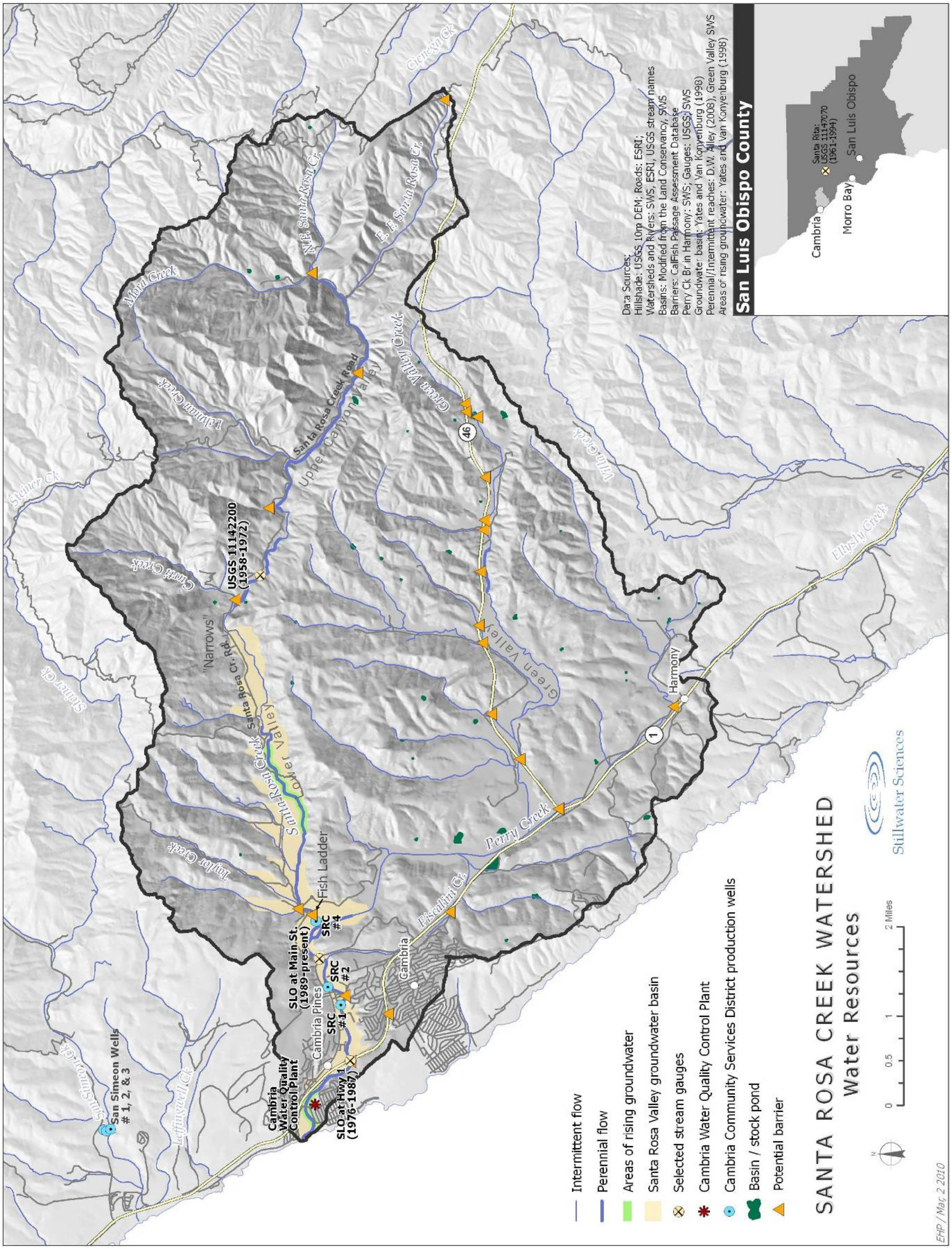


Figure 1-5. Water resources in the Santa Rosa Creek watershed. Perennial and intermittent streams, groundwater basin, and stream gauge locations are shown.

1.2.4 Land use/Land cover

The majority of Santa Rosa Creek watershed is sparsely populated, with urban development concentrated downstream at the town of Cambria (Figure 1-6). As of 2009, the town supported a population of 6,624 (Cambria Chamber of Commerce, pers. comm., 2009). The remainder of the watershed is almost entirely under agriculture, with primary activities consisting of cattle ranching, dairying, and crop cultivation, all of which require some level of irrigation, primarily obtained via groundwater pumping. In Cambria, developments consist of a business district, which closely borders the lower 4.5 km (2.8 mi) of Santa Rosa Creek from Main Street bridge to the lagoon area, and residential neighborhoods that extend to the north and south upon the adjacent hillsides. Tourism, primarily catered towards visitors traveling to Hearst Castle in nearby San Simeon, is the chief industry of Cambria. As of 2001, developed areas in total account for approximately 8% of the watershed area according to data contained within the National Land Cover Database (Homer et al. 2004). Besides the town of Cambria, the only other significant elements of infrastructure in the watershed include three roadways: Highway 1, Highway 46, and Santa Rosa Creek Road. The roadways closely follow and occasionally cross, via bridge or culvert, portions of Santa Rosa, Perry, and Green Valley creeks (see Figure 1-5).

Land cover in the remainder of the watershed is dominated (63% of watershed total) by grassland/herbaceous cover related to lands used for cattle ranching and dairy cattle pasture (Homer et al. 2004) (see Figure 1-6). Valley bottoms along Santa Rosa and Green Valley creeks support the majority of cultivated crops grown in the watershed. The steeper uplands support scrub/scrub, or chaparral, cover with some forest cover. Higher density vegetation cover and larger trees generally concentrate on north-facing slopes, higher elevations, and/or adjacent to perennial streams, particularly near the headwaters of Santa Rosa Creek. Native vegetation community types typically include mixed-hardwood forest (e.g., California bay tree [*Umbellularia californica*]) in riparian areas, chaparral (e.g., chamise [*Adenostoma fasciculatum*]) and oak woodland (e.g., coast live oak [*Quercus agrifolia*]) upon ungrazed hillslopes farther up in the watershed, and some remnant stands of conifers (e.g., Monterey pine [*Pinus radiata*]) near Cambria. Aquatic vegetation communities present in the watershed are limited to the lagoon. In the areas of denser vegetation cover (i.e., chaparral and forest), surface erosion is effectively hindered as the vegetation provides: (1) a continuous surface cover that intercepts rainfall and prevents rainsplash erosion, and (2) roughness to the landscape surface that divide and slow sheetflow upon the land surface. Changes to these land cover types over time are discussed in greater detail below in Chapter 2.

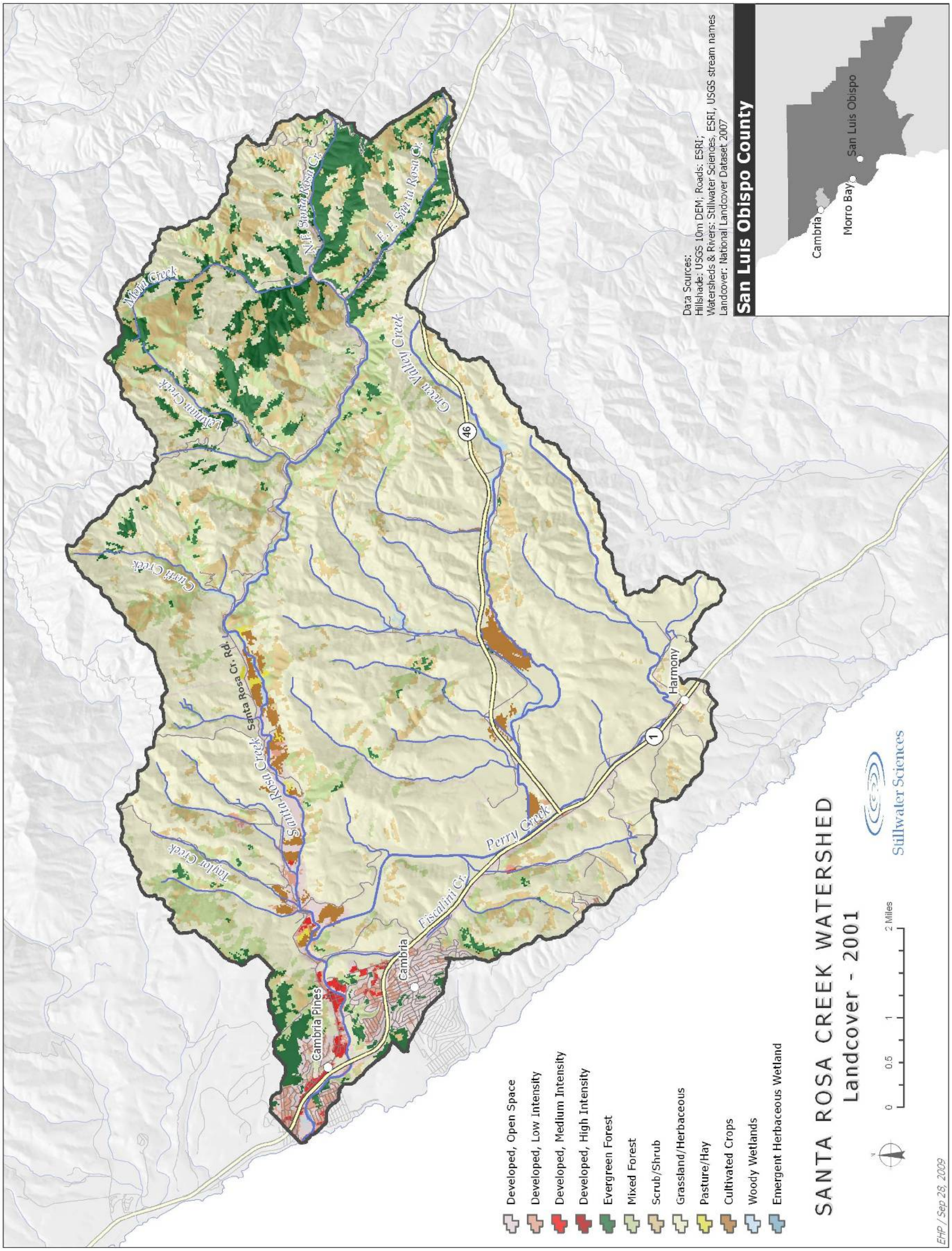


Figure 1-6. Land cover present in 2001 within the Santa Rosa Creek watershed (after Homer et al. 2004).

2 IMPACT OF HISTORICAL WATERSHED CHANGES ON GEOMORPHIC PROCESSES

Understanding the historical conditions of the Santa Rosa Creek watershed relative to present-day conditions is necessary in order to answer the following questions: (1) "what did the watershed look like in the past?"; (2) "what geomorphic processes were active?"; (3) "how has the watershed changed over time?"; and (4) "what were the factors that contributed to those changes?" In effect, looking at the watershed's past provides insight into the natural geomorphic trends in addition to the identification of any human-induced changes over time. An informed forecast of future watershed conditions can therefore be made when synthesizing our understanding of past and present conditions. The information presented here summarizes general historical conditions in the watershed dating back to pre-European settlement in an attempt to answer the questions posed above. A synthesis of this information with the results of contemporary hillslope and fluvial processes (see Chapters 3 and 4, respectively) are presented in Chapter 5.

2.1 Chronology of Watershed Changes

The history of development and land use changes in the Santa Rosa Creek watershed has been documented by several authors (e.g., Angel 1883, Hamilton 1974), whose main focus has been on the town of Cambria and other nearby coastal settlements rather than on the watershed or stream channels. Specific details on the geomorphic conditions of the watershed have been interpreted from maps, aerial photographs, and reports, such as those published by the CDFG and USGS. Overall, very little historical information has been published on the geomorphic or ecologic conditions of Santa Rosa Creek or its watershed. The primary sources of historical information used in this study are listed in Table 2-1. Information from these sources has been distilled here as a narrative summary to illuminate the historical (both natural and human-induced) events that may have had an effect on water and sediment discharge in the watershed, and so have influenced geomorphic processes and channel morphological responses within the mainstem stream corridor (Figure 2-1). Figure 2-1 and Appendix A present more detailed information chronicling the history of potential watershed impacts.

Table 2-1. Primary historical information sources for the Santa Rosa Creek watershed.

Data	Source	Dates	Notes
Aerial photography	UC Santa Barbara (UCSB), USGS, others	1937 to present	Watershed-wide coverage, with variable resolution depending on year
Geography / Topography	Map: R. R. Harris. 1874. Map of the County of San Luis Obispo.	1874	County-wide coverage of geographical elements: cities/towns, land ownership, stream/rivers, and roads. Oldest map of the County. Includes inset map of Cambria.
	Map: USGS. 1919. Topographic map of the San Simeon quadrangle. Scale 1:62,500.	1919	Detailed geographic and elevation maps (50-ft contours)
	Map: USGS. 1932. Topographic map of the Adalaida quadrangle. Scale 1:62,500.	1932	

Data	Source	Dates	Notes
Geography / Topography (cont.)	Map: USGS. Topographic map of the Cambria quadrangle. Scale 1:24,000.	1959, 1989	Detailed geographic and elevation maps (40-ft contours)
	Map: USGS. Topographic map of the Cypress Mountain quadrangle. Scale 1:24,000.	1948, 1979	Detailed geographic and elevation maps (20-ft contours)
Hydrology: Precipitation	San Luis Obispo (SLO) County	1870 to present	Long-term rainfall record from City of San Luis Obispo rain gauge.
	SLO County	1950s to present	Various local rainfall data from Santa Rosa Creek watershed rain gauges.
	U.S. Department of Agriculture (USDA)	1960 to 2001	Spatially averaged rainfall data for SLO County.
Hydrology: Stream flow	USGS	1957 to 1972	Daily stream flow data (upstream of Mammoth Rock)
	SLO County	1976 to 1992	Daily stream flow data (at Highway 1)
	SLO County	1989 to present	Daily stream flow data (at Main Street)
Land cover	Vegetation Type Mapping (VTM) project and NLCD	1930 to 2001	Detailed land cover (i.e., vegetation types) maps for whole watershed
Land use	California Department of Water Resources (CDWR)	1959 to 1996	Land use maps for watershed, primarily focused in urban and valley areas
Panoramic ground-based illustrations and imagery	Book: Myron Angel. 1883. History of San Luis Obispo County.	Late 1800s	Illustrations of farms in the watershed; also showing valleys and hillslopes
	VTM project http://vtm.berkeley.edu/	1930	Panoramic photos of hillslopes in the Santa Rosa and San Simeon watersheds
Population	San Luis Obispo County Historical Society (SLOCHS)	1860s to 1960s	Population estimates for Cambria as reported in document sources archived by the SLOCHS
Roads	California Highways http://www.cahighways.org/	1930s to present	Maps and summary accounts of the history of Santa Rosa Creek Road and Highways 1 and 46 through the watershed.
Textural accounts	Book: Myron Angel. 1883. History of San Luis Obispo County.	1700s to 1880s	Summaries of the history of the Cambria area. Includes some accounts of the watershed's historical condition.
	Book: Geneva Hamilton. 1974. Where the highway ends – Cambria, San Simeon and the Ranchos.	1700s to 1970s	
Verbal accounts	Personal communications: Dawn Dunlap, Santa Rosa Creek watershed resident and amateur historian	1800s to present	Source of additional information related to populations, flood damage, and land use changes, etc.

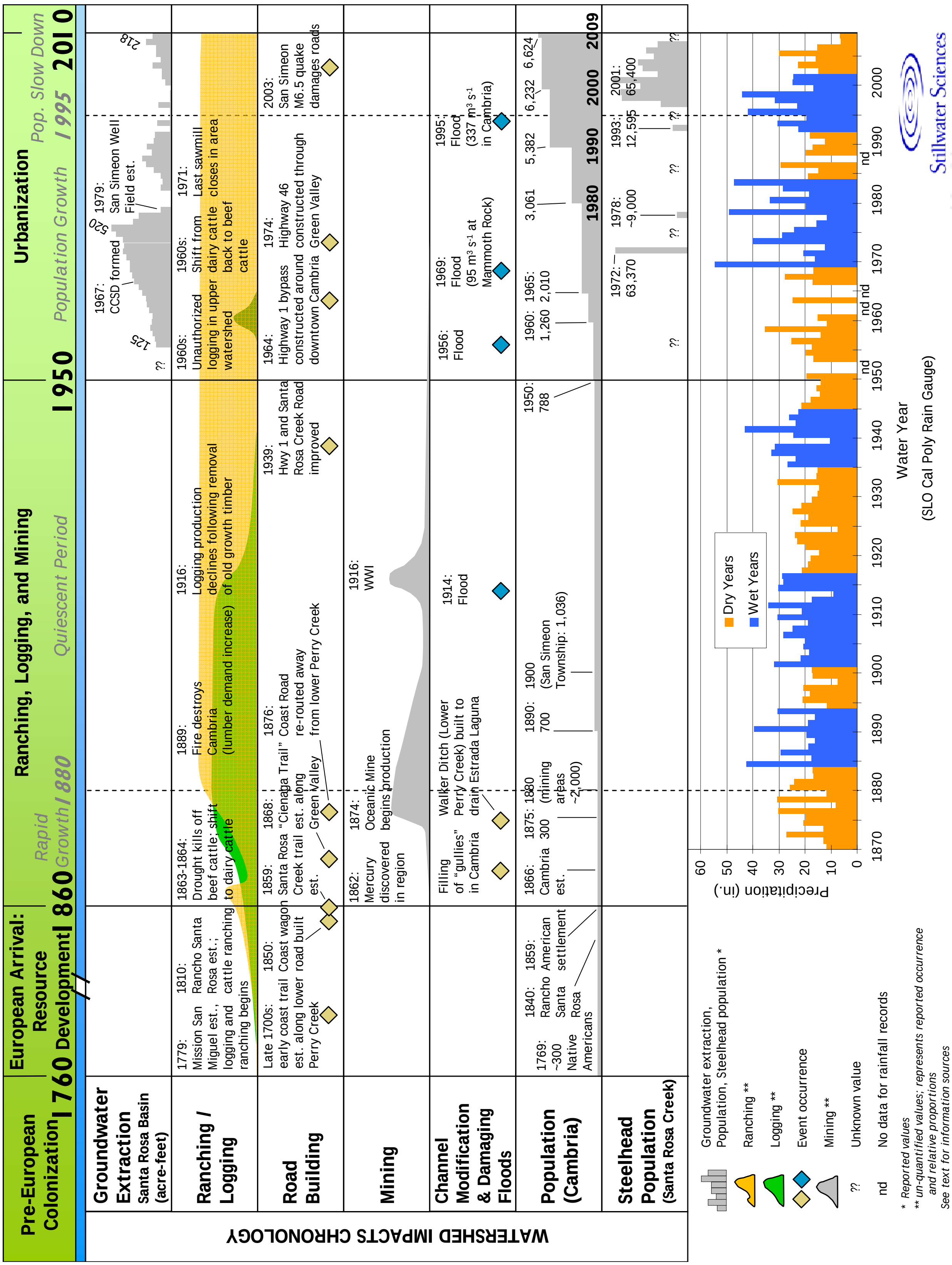


Figure 2-1. Chronology of potential watershed impacts and events. Precipitation records indicate periods of cumulatively wetter (blue) and drier (orange) periods in the watershed. Most very wet years in the watershed are also years with large floods.

Prior to European settlement along the California coast, the watershed is assumed to have been in a relatively undisturbed condition, responding only to fluctuating flood, drought, earthquake, and fire sequences, and with relatively minor impacts associated with the agricultural practices of the local indigenous peoples. The first recorded accounts of Santa Rosa Creek valley are those made during the Portola Expedition where, in September 1769, the party encountered a "canyon… and arroyo surrounded with hills of pine" (Hamilton 1974). The Spanish word of "arroyo", as used in this account, translates to mean a small creek and not one that is necessarily incised, which is unlike the contemporary use of the word in the English language to mean an incised creek, typically those found in the American southwest. On numerous instances, the expedition party noted observing flowing streams, both along what is now known as the mainstem Santa Rosa Creek and from many of its "springs", or tributaries (Hamilton 1974). Few other records of this area's natural resources were made for several decades despite the establishment of Mission San Miguel (1779) near present-day Paso Robles and the growing use of the Santa Rosa and San Simeon watershed areas for timber and wild game to support the growing Spanish population throughout the southern Coast Range region.

In 1841, Don Julian Estrada was granted possession of Rancho Santa Rosa—a 13,200 acre (53 km^2) land holding encompassing much of the western half of the watershed (Angel 1883, Hamilton 1974) (Figure A-1). Estrada drafted an illustration of his land in that year that depicts several notable features of the historical landscape, including Santa Rosa and San Simeon creeks draining to the ocean from steep upland areas, continuous pine forests upon hillsides surrounding lower Santa Rosa Creek near the area of present-day Cambria, a coastal trail parallel to the coastline, and, perhaps most interestingly, a "laguna", or lagoon along the narrow valley of lower Perry Creek (Figure A-2). This inland lagoon is further described in Hamilton (1974) as a "shallow, broad lake… clogged with tules" fed by both Perry and Green Valley creeks, and bordered along its eastern shore by a coastal trail linking San Luis Obispo with San Simeon. The exact location of this lagoon is not precisely known, but it has been estimated to have formerly extended from the Perry and Green Valley creeks confluence north towards Santa Rosa Creek (Hamilton 1974, D. Dunlap, pers. comm., 2009). The lagoon was eventually drained by "Walker Ditch" in the early 1870s under the order of property owner George Hearst for the purpose of converting the wetland area to agricultural land (Hamilton 1974, D. Dunlap, pers. comm., 2009). The first official survey map of San Luis Obispo County published in 1874 does not depict the lagoon, indicating that it had been drained already when the survey was conducted, and instead shows a stream channel that generally follows the present-day stream course of lower Perry Creek (Harris 1874) (Figure A-1). Today, this artificial stream course of lower Perry Creek stands out from all other stream courses in the watershed as it follows long, straight segments connected by right-angle turns along the valley floor and north towards its confluence with Santa Rosa Creek. The lake likely functioned as a settling basin for sediment delivered by tributaries of Perry Creek, and effectively served historically to separate the Perry Creek subwatershed from the Santa Rosa Creek subwatershed in terms of sediment delivery, especially of coarse sediments.

Starting in the late 1700s, clearing of the land in support of agricultural activities—cattle ranching, crop cultivation, and logging—likely caused significant changes to rainfall-runoff relationships as trees, shrubs, and deep-rooted native perennial grasses in the valleys and hillslopes were degraded and replaced by shallow-rooted, non-native annual grass species that less effectively protect soil against erosion. Initially, cattle herds from Mission San Miguel were occasionally moved into the Santa Rosa Creek watershed because of ample sources of water and foraging vegetation even during the dry seasons (Hamilton 1974). Following California statehood in 1850, Americans quickly settled the watershed and greatly increased the pace of land clearing, which was reportedly achieved by cutting and/or burning the native vegetation (Coffman 1995, D. Dunlap, pers. comm., 2009). Historical accounts from across the coastal region tell of coordinated efforts by land owners to clear valley-bottom forests along major rivers (Boughton et al. 2006), which was likely practiced along Santa Rosa, Perry, and Green Valley creek valleys as very little forest cover remains but for some riparian stands closely bordering the stream channels (see Section 2.2). Overall, these land uses coupled with episodic storm events resulted in several significant changes in the watershed, namely: (1) greater volumes of hillslope runoff generated per unit rainfall, with far greater volumes of fine sediment production throughout the watershed and increased gullying and shallow landslide potential on the steeper hillslopes; and (2) incision of the mainstem stream channels due to decreased stream bank stability and increased stream power allowing high flows to entrench the channel. Prior to incision, the Santa Rosa, Perry, and Green Valley creek channels would have supported higher groundwater elevations and more frequent inundation under lower flows, which supported the valley forests.

Between 1860 and 1880 marked a period of unprecedented population growth and land development as the watershed became more settled. Despite a die-off of beef cattle during the intense 1863–1864 drought, a shift to dairy farming, continued logging, and mining of mercury in the region maintained a steady rate of landscape alteration over the next two decades. Urban development and road building began the process of filling in small stream channels, especially those situated where Cambria was to be established (Hamilton 1974). By 1880, the landscape had been radically changed from its pre-European settlement condition and appeared very similar to present-day conditions, as represented in several illuminating sketches made during the 1870s (Angel 1883) that show grass-covered hillslopes and valley floors used for pasture with some relict patches of native riparian vegetation remaining near stream channels (Figures A-3, A-4, and A-5). Another notable feature depicted in two of these illustrations (Figures A-3 and A-5) is active hillslope erosion in the form of gullies, which remains a ubiquitous feature of the present-day landscape (see Figure 3-1 in Section 3). As discussed in further detail in Section 3, gullies and shallow landslides form between ridges in concave depressions, or swales, that are filled with sediment, or colluvium, over time and become the primary focus of erosion when changes to the rainfall-runoff relationship (i.e., vegetation clearing) has occurred (Reneau et al. 1990).

Specific impacts to hillslope and stream morphology from the Oceanic Mine operations situated in the middle of the Curti Creek subwatershed are not well known. Available information, however, both from this mine and others located in neighboring watersheds (e.g., Klau/Buena Vista mines) suggest that land clearing and road building were conducted to access the numerous mine adits while excavation and processing of rock materials led to runoff of toxic water and an increase of fine sediment delivery into the stream channel (CCRWQCB 1999 as cited in CCRWQCB 1998, CDPH 2009). The mining production slowly declined over time but experienced a second peak around 1916 in support of World War I efforts (Hamilton 1974, Baker 2003).

Between the 1880s and 1950s, the rate of new land development leveled off as mining and logging operations declined, along with the transient population that supported those industries. These trends were driven, respectively, by falling mercury prices and by the near-depleted stock of old growth pine trees (Hamilton 1974). Through this period, dairy farming and crop cultivation continued, but likely did not increase in areal extent. In general, the landscape condition present during this period appeared very similar to the present-day condition, as is clearly represented in photographs taken in similar (yet not exact) locations of lower Santa Rosa Creek valley in 1930 and 2009 (Figure A-6). Visible in both photographs are south-facing, pine tree-rimmed hillslopes mostly covered with a mix of scrub/shrub and grass vegetation, and farms situated at the base of the hillslopes upon the valley floor. However, despite these seemingly unchanged conditions in many areas of the watershed, significant changes to specific areas did occur after this relatively quiescent period in the watershed's post-settlement history.

Starting in 1950 and extending through to the mid-1990s, the town of Cambria experienced a steady increase in population and, correspondingly, an increase in urban development in the form of new housing, commercial, and some industrial developments as driven by their tourism industry (see land use / land cover comparisons over time in Section 2.2). According to County and US Census data, Cambria's population (excluding the remainder of the watershed) increased from 788 to 5,382 between 1950 and 1990, representing 6.8-fold increase, while California as a whole experienced only a 2.8-fold increase. Recent population growth in Cambria since 2000, however, dropped considerably to only a 1.1-fold increase, which is below the state growth rate during the past decade (A. Ochs, pers. comm., 2009, US Census Bureau 2003, US Census Bureau 2009). This population growth slowdown period signifies stabilization not only of the Cambria population but also of future development activity that may act to expand the town's urban footprint in the watershed.

The urbanization time period between 1950 and the 1990s also represents an expansion of groundwater pumping to irrigate crops and provide drinking water to Cambria, which has reduced base flows in Santa Rosa Creek. The amount of groundwater and surface water extracted by private entities for agricultural purposes is not well known but was estimated by Yates and Van Konyenburg (1998) in 1988–1989 to total approximately 3.5 times the amount pumped by the Cambria Community Services District (CCSD) for municipal uses. The present-day amounts of urban and agricultural groundwater extraction are approximately equal (815 acre-feet per year [AFY] for urban, 830 AFY for agricultural) in the Cambria Water Planning Area, which includes Santa Rosa Creek, San Simeon Creek, Leffingwell Creek, and Villa Creek watersheds (ESA 2010). Until the San Simeon well field was established to supplement municipal water demands in Cambria, the peak of groundwater extraction by CCSD in the Santa Rosa Creek watershed occurred in 1976 and totaled 520 acre-feet (CCSD 2009), or 3.6 times the total annual streamflow measured at the Highway 1 bridge stream gauge (annual flow in 1976= 144 acre feet).

The likely impact of groundwater extraction has been an overall reduction in baseflow within Santa Rosa Creek, and potentially within Perry and Green Valley creeks, depending on the amount of groundwater pumped by private wells in those basins. A lowered groundwater table has led to subsidence in areas of the lower Santa Rosa Creek valley, which was observed in Cambria during 1976—the year with the highest municipal groundwater extraction (Yates and Van Konyenburg 1998). Groundwater lowering may have led to further degradation of mature riparian vegetation (in areas where riparian vegetation was not replaced by crops), which is reliant primarily on groundwater during summer dry season. Large floodplain areas with extensive riparian vegetation may have attenuated floods within Santa Rosa Creek; the removal and degradation of large riparian stands would have therefore increased the "flashy" nature of the stream to flood events. Indeed, large floods in 1914, 1956, 1969, and 1995 have damaged properties situated upon floodplain areas (Hamilton 1974, D. Dunlap, pers. comm., 2009). As a result, bank revetments, or riprap, were subsequently installed along some reaches of Santa Rosa Creek near Cambria to protect floodplain developments from future flood-induced bank erosion. To date, however, no levees have been constructed along the creek or its tributaries, with the exception of Highway 1, which serves as a low-lying berm to the west of downtown Cambria.

A final and potentially very significant impact to the watershed from 1950 to the 1990s is the construction of roads, namely Highways 1 and 46, and Santa Rosa Creek Road, because each of these have altered runoff patterns as they traverse the landscape. The first trails and roads in the watershed closely followed the contours of the natural terrain as large-scale excavations of hillsides and bridge building were infeasible. Their impact was likely limited only to vegetation removal and fine-sediment run-off. The present-day path of Santa Rosa Creek Road mostly follows the original trail path from Cambria and east towards Paso Robles (Harris 1874, Hamilton 1974) and has since been paved, thereby limiting fine-sediment runoff from road surfaces. Further, a comparison of aerial photographs taken in 1937 and 2009 reveals that the road exactly follows the same path in both time periods. The route taken today by Highway 1 differs slightly from that traced by the original "coast road" (Harris 1874, Hamilton 1974) and, similar to Santa Rosa Creek Road, the current route of Highway 1 was cut into hillslopes and laid across small streams channels with culverts.

Completed in 1974, Highway 46 travels through Green Valley and is the most recent and substantial roadway constructed in the watershed, involving relatively large cut and fill sections that allow for a nearly straight path through the varied topography. As a result, upper Green Valley Creek and numerous small streams have been virtually cut-off from the reaches of lower Green Valley Creek, but for the presence of some culverts. Figure 1-5 shows potential barriers throughout the watershed that are mostly road culverts (CalFish 2009). Under normal circumstances, water may be conveyed completely through these culverts, but coarse sediment and large woody debris deposited at the culvert entrance during high flows causes blockages that deny the replenishment of gravel and cobble substrates and woody debris in the lower reaches. This adversely affects not only the channel morphology of Santa Rosa Creek but also the availability and complexity of steelhead trout habitat (D. W. Alley & Associates 2007, Nelson et al. 2009). An additional negative of all three major roadways in the watershed has been their effect on erosion associated with concentrating runoff towards the downslope side of the roads (see Figure 3-1 in Section 3.2 – Hillslope Processes).

As stated above, the most recent time period between the mid-1990s and present day is generally characterized by a population growth slowdown and, accordingly, a reduction in additional urban developments that would act to further alter the landscape and the rainfall-runoff relationship in the watershed. This period also marks the initiation of several endeavors to restore ecologic and geomorphic function in Santa Rosa Creek, including the removal of certain fish barriers: a former channel weir beneath Burton Bridge and the planned removal of the Ferrasci Road fish ladder. Also, bank-repair projects recently implemented along Santa Rosa Creek have attempted to minimize their impacts to geomorphic and ecologic conditions through implementation of flood storage features (e.g., setback bank protection) and biotechnical elements (riparian plantings).

2.2 Measurements of Watershed-wide Changes in Land Use and Land Cover

During the recent population boom in the watershed since 1950, improvements to infrastructure have been made to support the growing tourism industry, namely more homes, commercial and industrial buildings, roads, and groundwater extraction. Overall, Cambria's urban footprint within the watershed has grown significantly, as is apparent when comparing acreages of land uses presented in 1959 and 1996 maps compiled by the California Department of Water Resources (CDWR) (Figures A-7 and A-8). It is important to note that these maps primarily focused on agricultural and urban areas situated in the valley lowlands, and they do not delineate land uses or native vegetation cover in non-valley areas (e.g., open grazing upon hillslopes) as they typically have not required a significant irrigation supply and therefore are not a primary concern of CDWR. Values presented in Table 2-2 reveal that agricultural types have changed over the 37-year time period with a general decrease in non-ranching agricultural land uses, while the urban footprint of Cambria has increased by almost 4-fold.

Table 2-2. Land use coverage and relative changes in the Santa Rosa Creek watershed between 1959 and 1996. [A]

Land use type [B]	1959 (acres)	1996 (acres)	% Change
Pasture	547	66	-88%
Grain and hay crops; rice crops	531	320	-40%
Field crops; truck, nursery, and berry crops	19	596	3,079%
Semi-agricultural and incidental to agriculture	123	19	-84%
Citrus and subtropical; deciduous fruits and nuts	0	130	+
Total agricultural-related land use (non-grazing)	***1,220***	***1,131***	***-7%***
Barren and wasteland	16	15	-6%
Urban	411	1,553	278%

[A] Source: CDWR 1959, 1996
[B] Remainder of watershed was depicted in CDWR maps as blank areas, which included “riparian vegetation”, “native vegetation”, “unimproved grazing land”, or “unclassified” (see Figures A-7 and A-8).

Changes to land cover throughout the entire watershed between 1930 and 2001 were also evaluated here to illustrate how primary vegetation cover types have changed over time (Figures A-9 and 1-6). Results presented in Table 2-3 reveal several changes to the dominant land cover types over the evaluated time period; specifically, evergreen forest (e.g., pine trees) and scrub/shrub (e.g., chamise) acreages have increased while mixed forest (e.g., oaks and manzanita) acreage has decreased. It is important to note that because the land cover mapping efforts of 1930 and 2001 followed slightly different cover identification methodologies, an unquantifiable degree of error exists and therefore the values presented in Table 2-3 are useful only in demonstrating trends of land cover changes, not definitive values. Furthermore, the absence of a “developed”, or urban, land cover category in the 1930 maps is slightly erroneous as the town of Cambria did exist during this time.

Table 2-3. Land cover and relative changes in the Santa Rosa Creek watershed between 1930 and 2001. [A]

Land cover type	1930 (acres)	2001 (acres)	% Change
Pasture/hay [B]	0	34	+
Cultivated crops	2,571	362	-86%
Total agricultural-related land use (non-grazing)	***2,571***	***396***	***-85%***
Grassland/herbaceous (grazing)	19,640	19,156	-2%
Evergreen forest	1,414	1,954	38%
Mixed forest	4,152	2,930	-29%
Scrub/shrub	2,597	3,290	27%
Woody wetlands [B]	0	157	+
Emergent herbaceous wetlands [B]	0	4	+
Barren/beaches [C]	14	0	-
Developed [B]	0	2,505	+

[A] Source: Weislander 1930a, 1930b, Homer et al. 2004. Land cover categories used in the 1930 maps were converted to those categories used in the 2001 land cover map.
[B] Categories not distinctly represented in the 1930 land cover maps. Developed category also not represented in 1930 land cover maps, however, the town of Cambria, Santa Rosa Creek Road, and coastal road were present during this time (see Figures A-9 and 1-6).
[C] Barren category in 1930 land cover maps represented Moonstone Beach, which still remained in 2001 but was not distinctly represented in the 2001 land cover map.

Overall, information gleaned from the land use maps of 1956 and 1996 and the land cover maps of 1930 and 2001 indicate the following trends that are relevant to evaluating impacts to the watershed morphology: (1) the amount of developed/urban areas has increased with the growth of Cambria and construction of new roads (e.g., Highway 46); (2) the total amount of evergreen and mixed forest has decreased, likely as a result of continued logging and/or some additional land clearing by ranchers in the early half of the last century; (3) the amount of scrub/shrub cover has increased, suggesting either a re-establishment of vegetation at this stage of plant succession upon formerly cleared areas or the conversion of forested terrain to scrub/shrub-covered terrain due to logging; (4) the amount of agricultural land not used for grazing (i.e., cropland) has decreased, either due to urban encroachment or a return to scrub/shrub vegetation cover; and (5) the amount of grassland, which is primarily used for cattle grazing, has remained nearly unchanged.

2.3 Summary of Watershed Changes

Returning to the questions posed at the start of this chapter, the following draws upon the above summary of the watershed's history to briefly answer those questions. Prior to European settlement, the watershed supported a widespread vegetation cover throughout the valleys and hillslopes that acted to stabilize land surfaces, dampen floods, maintain perennial streamflow, and enable a near-equilibrium exchange of sediment through the watershed (i.e., sediment delivery to Santa Rosa Creek more closely equaled the sediment yield at the creek's mouth). Processes occurring during this period would have been the same as those occurring today (see Chapters 3 and 4); however, the frequency and magnitude of those processes would likely have been significantly lower, such as streambank erosion, channel incision, gullying, and landslides, due to the lack of human-induced perturbations.

Overall, the greatest impact to the watershed over the past 150 years has been the alteration of land cover, primarily during the relatively intense change periods of 1860 to 1880 and 1950 to the 1990s, which resulted in the modification of the rainfall-runoff relationship and has, accordingly, led to a flashier system with higher fine sediment production. Lesser but still significant impacts also include reduced baseflows due to groundwater pumping and channel modifications in lowland areas (e.g., draining of Estrada lagoon on lower Perry Creek and riprapping Santa Rosa Creek streambanks near Cambria).

The remaining chapters in this report further investigate the geomorphic understanding of the Santa Rosa Creek watershed following almost two centuries of land use changes and direct modification of water flow, sediment discharges, and channel morphology in the watershed. Note that overall change is cumulative over time and so difficult to quantify: we therefore draw on numerous sources both quantitative and qualitative, and from within the watershed and from the local region where appropriate, to understand the evolutionary trajectory of Santa Rosa Creek and its watershed. Also, sediment transport and morphological changes in Santa Rosa Creek occur only in brief periods during flood events, and frequently when flood events follow large land cover changes (e.g., fires, logging, or conversion of forest to grazing land). As such, there are both natural components and human aspects to channel morphology changes: disentangling human impacts from natural events is one of the most challenging arenas in geomorphology.

3 HILLSLOPE PROCESSES AND THE PRODUCTION AND DELIVERY OF SEDIMENT

3.1 Overview

This section evaluates the hillslope processes that control the production of sediment across the watershed and the subsequent delivery of that sediment into the channel network. Overall, rates of hillslope sediment production in the Santa Rosa Creek watershed are driven by tectonics, geology, climate, and land uses. At a finer scale, sediment is released from hillsides via several discrete processes, including soil creep, gullying, and landsliding. Methods used here to evaluate the active processes occurring in the watershed included field observations, analysis of aerial photographs, and literature review of applicable studies. Quantification of sediment production and delivery rates was beyond the scope of this project due to the lack of available watershed-specific data that could enable such a calculation (e.g., hillslope erosion studies or sediment discharge records at the Santa Rosa Creek stream gauge). However, an attempt has been made here to estimate sediment production and delivery rates using values calculated in similar watersheds in the southern Coast Range region.

3.2 Hillslope Processes

Evaluation of active hillslope processes in the watershed was accomplished by conducting field surveys and analyzing aerial photographs. For the field approach, viewpoints of the watershed hillslopes were made from both the ground (foot and road surveys) and the air (low-elevation airplane flight). This approach was used to identify and characterize active geomorphic processes in viewable and/or accessible areas, with a focus on areas representative of general landscape types (e.g., consisting of distinct combinations of geology, land cover, and hillslope gradient) (see Section 3.4). Ground-based reconnaissance surveys in accessible locations were supplemented with aerial reconnaissance in order to view the majority of the watershed, albeit at a coarser scale. Another benefit of the airplane flight was to view the landscape from an oblique angle, whereby discrete hillslope processes could be seen more directly upon steep slopes, a benefit not afforded by a standard aerial photograph analysis that can only view the landscape at a fixed angle directly overhead.

Active hillslope processes in the watershed, as identified during the field surveys, airplane flight, and/or the airphoto analysis, are summarized in Table 3-1.

Table 3-1. Active hillslope processes in the Santa Rosa Creek watershed.

Category [A]	Hillslope process	Process description [B]
Natural processes		
Sediment production	Conversion of bedrock to soil mantle	Physical, chemical, and biotic-breakdown of bedrock material into friable weathered rock and then physically disrupted into soil. [a]
	Rockfall	Mass failure of mostly rock that has separated from its parent bedrock surface (typically along vertical cliff). [a]

Category [A]	Hillslope process	Process description [B]
Mass-wasting processes	Soil creep	Slow, often un-observable down-slope movement of surface soils or rock debris. [a]
	Biogenic transport	Exhumation and down-slope transport of soil and rock fragments by biological forces, including tree-throw and burrowing animals. [a]
	Dry ravel	Downslope transport of individual particles under power of gravity (or bioturbation) rather than water; mostly occurring where vegetation cover is non-existent. [b]
	Shallow landsliding	Mass failures that have a composition mostly of colluvial sediments, a failure plane above the soil-bedrock interface, and a relatively long travel distance through the low order channel network. [c]
	Deep-seated landsliding	Mass failures that have a composition mostly of bedrock (parent material), a failure plane below the soil-bedrock interface, and a surface area >0.1 km^2. [d]
Overland flow erosion	Sheetwash	Downslope transport of fine particles (<2 mm) driven by concentrated surface runoff. [a]
	Rilling	Formation of generally discontinuous, small channels less than several cm deep and wide that develop on slopes composed of fine-grained sediments where surface runoff has concentrated. Typically occurs in areas of land disturbance and/or vegetation clearing. [a]
Tributary connection with hillslope processes	Gullying	Formation often driven by the coalescence of several rills into an enlarged master rill, which can further extend the drainage network upslope. Often occurs in areas of land disturbance and/or vegetation clearing. [a]
	Channel head advance	Upslope migration of a stream channel into hillslope colluvium, usually due to gully incision and/or channel head-cutting. [a]
Human disturbances		
Agriculture and rangeland	Surface wash, rilling, and gullying	(see description above)
	Shallow landsliding	(see description above)
Road-related	Cut and fill failures	Erosion by sheetwash, rilling, gullying, or shallow landslides into road cuts or road fill material. [e]
	Surface erosion	Erosion of fine sediments from unpaved road surfaces. [e]
	Gully formation associated with inboard ditch relief	Occurs when road runoff concentrates into an inboard ditch that then incises the ditch and/or adjacent surfaces where the routed flows have been discharged. [e]
	Gully formation and mass failure on the outboard side	Occurs when road runoff concentrates on the outboard side of the road and erodes/destabilizes road fill material and/or hillside soils. [e]
Urban	Construction phase sediment pulse	Release of fine sediment downslope and into the drainage network during the disturbance of the landscape.
	Slope destabilization	Surface erosion and mass failures can occur on slopes that have been over steepened and/or undercut.

[A] With the exception of road-related erosion, human disturbances affect the geomorphic processes already identified as natural and, therefore, require efforts to separate the relative influence of natural and human factors.

[B] Sources: [a] Selby 1993 ; [b] Gabet 2003; [c] Roering et al. 2003 ; [d] Roering et al. 2005 ; [e] Reid and Dunne 1984

The analysis of aerial photographs performed for this study enabled the evaluation and measurement (area) of active erosion processes throughout the majority of the watershed area. The analysis consisted of digitally analyzing recent aerial photographs taken for the National Agriculture Imagery Program (NAIP) in 2005 and 2007 at a constant elevation over the watershed. An inventory of several erosion feature types using the 2007 aerial photographs had been previously created by The Land Conservancy of San Luis Obispo County (TLCSLOC 2008) and was reviewed and subsequently updated through consolidation of some categories and addition of new feature categories (e.g., landslides) identified during a review of the aerial photographs. Some features identified during our field survey and airplane flight were also added to the inventory, provided that they could also be viewed in the aerial photographs taken during either 2005 or 2007. The inventory, however, does not fully identify all erosion processes active in the watershed, nor does it chronicle every erosion feature in the watershed for two reasons: (1) the resolution of the aerial photographs generally prevents the identification of discrete features less than 1–2 m in width, thereby overlooking small-scale erosion processes such as rilling, soil creep, and dry ravel; and (2) obfuscation of the ground surface caused by vegetation severely restricts the identification of erosion features under tree cover. Therefore, these aerial photograph-identified features are considered herein as "macro-scale" erosion features, whereas features too small to be viewed in the aerial photographs, such as soil creep, dry ravel, and rilling, are considered as "micro-scale" erosion features.

The erosion feature inventory, as updated for this study, considered four feature types that all may potentially contribute sediment to the stream network (Figure 3-1). These features include gullies, landslides, and road-related erosion. An additional feature type considered, referred to as "other erosion", includes those erosion processes that were not identified as either a gully, landslide, or road-related erosion but still exhibited signs of surface erosion. For example, one such feature identified in the aerial photographs and subsequently confirmed in the field exhibited a widespread and deeply incised rilling pattern typical of a badlands terrain. A separate "rilling" category was not created to accommodate this specific feature because the majority of rill features in the watershed, as observed in the field, were too numerous to completely record and were too fine to be identified in the aerial photograph analysis and, thus, could not be easily included in the inventory. Overall, the feature having the greatest number of occurrences and, accordingly, the greatest area represented in the watershed are gullies, accounting for two-thirds of the total area of erosion features contained in the inventory (Table 3-2). Road erosion features accounted for 21% of the total area of erosion-related features, while landslides accounted for only 3%.

An estimate of the volumetric contribution of sediment from each hillslope erosion-related feature was made based on general field observations and select field measurements of feature depths (Table 3-2). The total amount of sediment eroded from gullies, landslides, road-related erosion features, and "other" erosion features is estimated to be approximately 2.5 Mt. If we assume that initial destabilization of the hillslopes initiated approximately at the time of Euro-American settlement of the watershed (i.e., ~150 years ago: 1860–2010), then an annual average sediment-production rate estimate of 17,000 tonnes per annum ($t\ a^{-1}$) for these "macro-scale" hillslope erosion features can be made. The sediment-production rate per unit area would equate to 140 $t\ km^{-2}\ a^{-1}$ across the hillslopes of the watershed. It is important to note that these coarse estimates do not account for sediment produced from "micro-scale" hillslope erosion features (e.g., soil creep, dry ravel, and rilling) or channel-related erosion features (e.g., bank and bed erosion).

Estimated sediment yields for the watershed as inferred from other studies in the region are presented below in Section 3.3. A comparison of the sediment-production rate estimated for these "macro-scale" hillslope erosion features and sediment production estimates from other studies is presented below in Section 3.4.3.

Table 3-2. Erosion-related feature types and estimated amount of eroded sediment in the Santa Rosa Creek watershed identified using recent aerial photographs. [A]

Erosion-related feature	Number of features	% of total area of erosion-related features	Estimated amount of sediment eroded [B]	
			volume (m^3)	mass (tonnes)
Gully	1,068	72%	1,306,000	2,089,600
Landslide	17	3%	61,000	97,600
Road erosion	253	22%	199,000	318,400
Other erosion	6	3%	24,000	38,400
Total	**1,344**	**100%**	**1,590,000**	**2,544,000**

[A] Source: updated from TLCSLOC (2008) erosion inventory using aerial photograph and field data.
[B] Based on general field observations and select field measurements, the assumed average depth of gully and landslide features was 1 m while the assumed average depth of road and other erosion features was 0.5 m. Assumed bulk density of eroded sediment was 1.6 t m^{-3}.

Water basins were also identified in the aerial photograph analysis; however, these features are considered to promote sediment deposition rather than erosion. The basin feature included mostly cattle stock ponds along with some water supply ponds for crop irrigation. A total of 41 basins were identified to be present throughout the watershed (Table 3-3). Less than five basins identified related to depressions in lowland areas where rain waters collect (visible in the 2005 aerial photographs), specifically near the former Estrada lagoon along lower Perry Creek. Most basins are situated in small first-order tributaries; no basins are present on the mainstem Santa Rosa or Perry creeks, but two relatively large basins, or reservoirs, are present on the upper reach of Green Valley Creek (Figure 3-2). In total, the area of the landscape that drains to these basins was found to equal 10.1 km^2 (2,500 acres), or 8.1% of the total watershed area. Consideration of these basins is important as large basins have the potential to trap sediment transporting down-gradient before reaching the larger stream channels. The trap efficiency of these basins is difficult to estimate, but based on the relatively small storage capacity of each basin (500–5,000 m^3 [0.5–3.5 acre-feet]) it is likely that only the coarse fraction of the sediment load—gravel-size or bigger (>2 mm in diameter)—gets trapped in the basins, while the fine sediment load transporting as suspended or wash load likely flows over the basin retaining wall. Occasional maintenance of the basins by their owners may involve the removal of accumulated sediment in order to maintain storage capacity of the basins over time. Overall, these basins likely represent a coarse-sediment sink within the watershed—a potentially adverse effect on mainstem morphology as coarse sediment serves to stabilize the channel bed elevation (i.e., more stream power is needed to scour down into coarser bed material) and offer suitable steelhead spawning conditions for the construction of their redds.

Table 3-3. Deposition-related feature types in the Santa Rosa Creek watershed identified using 2005 and 2007 aerial photographs. [A]

Deposition-related feature	Number of features	Total area of landscape contributing to the features (km^2) [B]	% of the total contributing area in watershed
Basin	41	10.1	8.1%

[A] Source: updated from TLCSLOC (2008) erosion inventory using aerial photograph and field data.
[B] All precipitation falling upstream of the feature drains down to the basin.

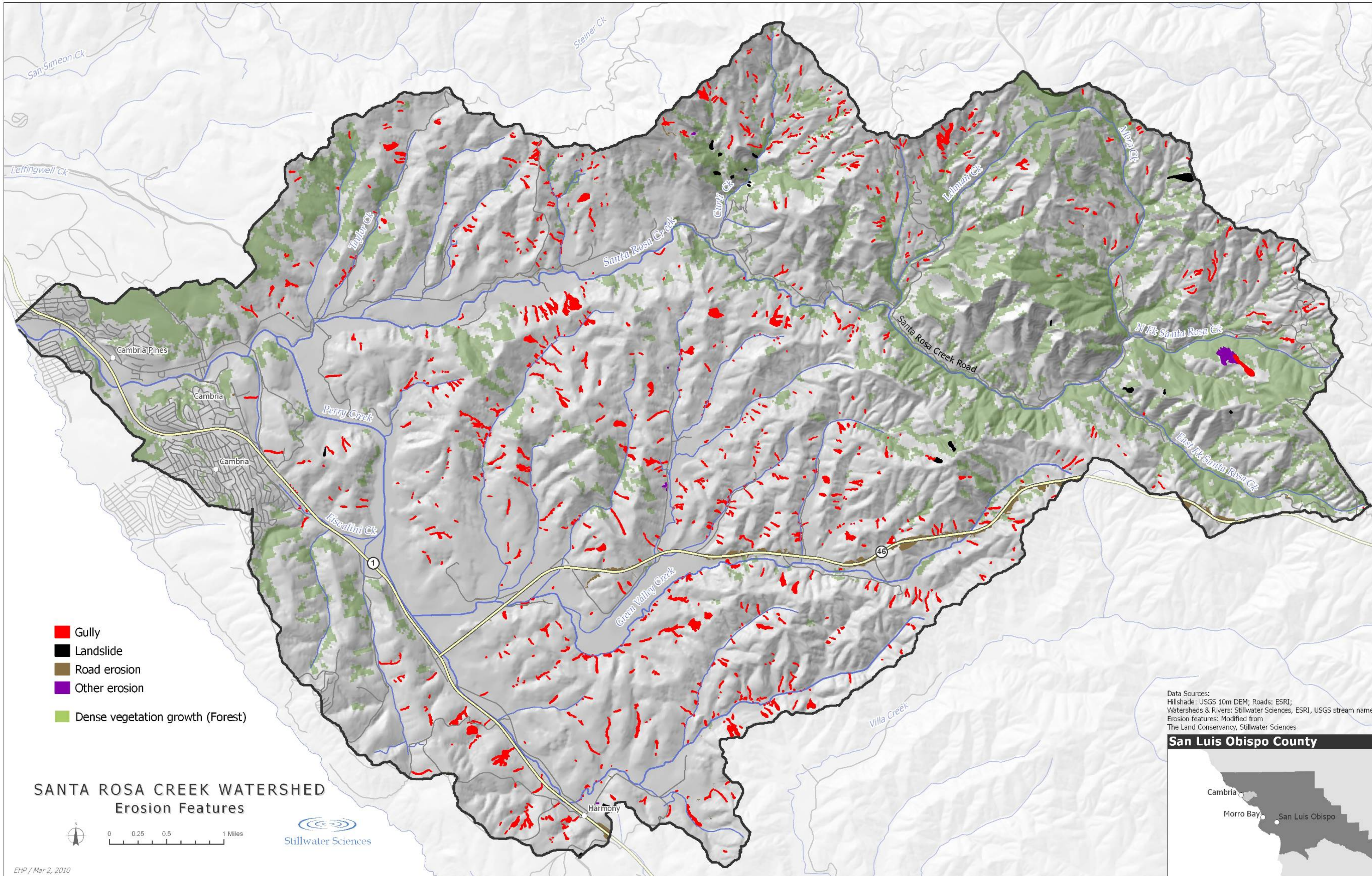


Figure 3-1. Hillslope erosion inventory (2005 and 2007) of the Santa Rosa Creek watershed. Updated from TLCSLOC (2008). Dense vegetation (forest land cover) shown to highlight areas not clearly visible in analysis of aerial photographs.

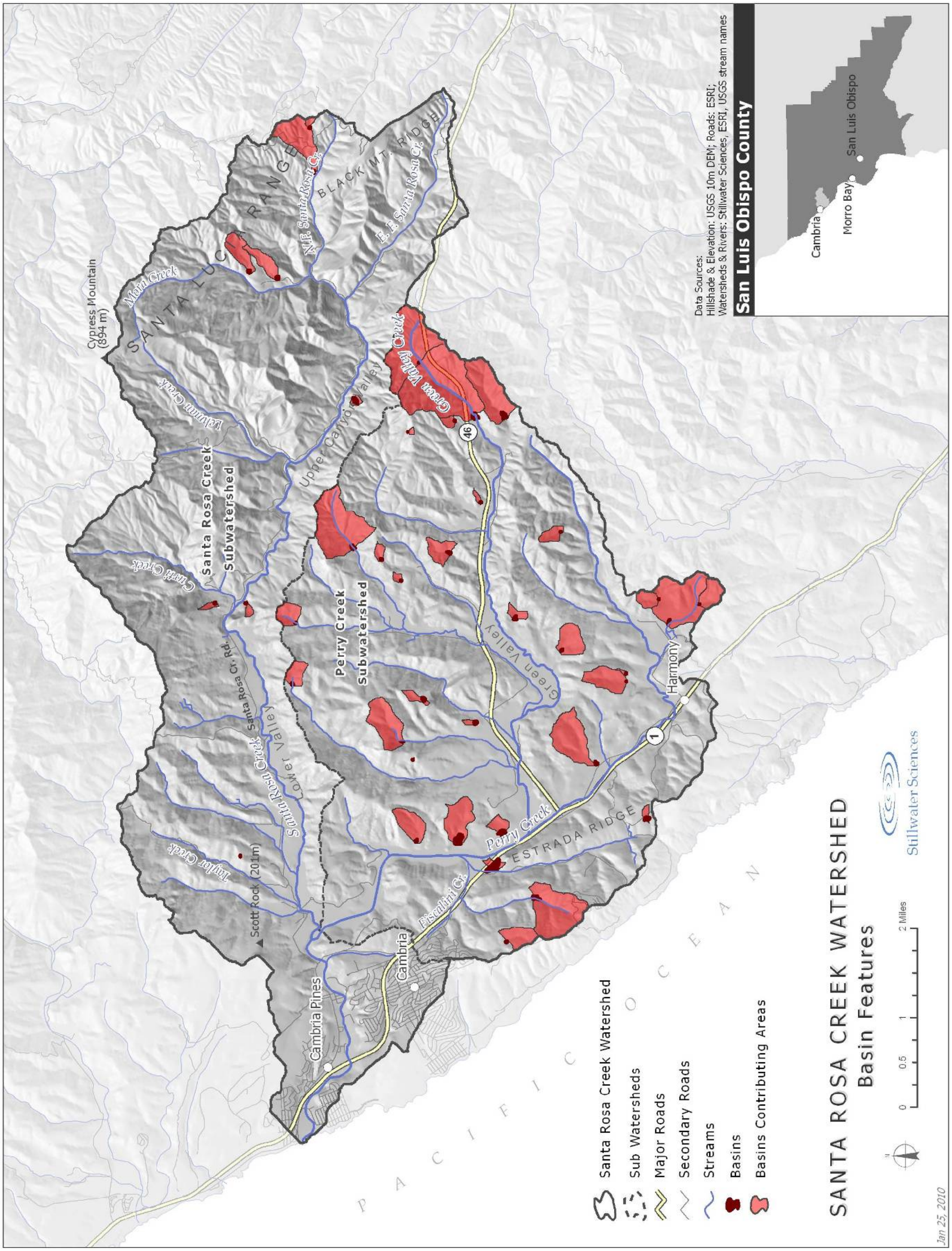


Figure 3-2. Basin features and their upstream contributing areas within the Santa Rosa Creek watershed.

As described in greater detail below in Section 3.3 – Sediment Production, a landscape's erosion potential can be defined by its combination of geology, land cover (e.g., vegetation), and hillslope gradient. Understanding the occurrence of the mapped erosion features with these landscape elements, or units, is necessary in order to estimate relative rates of sediment production and to identify those areas with the potential for future erosion. An overlay of the mapped gullies, landslides, road erosion, and "other erosion" features onto the underlying geology, land cover, and hillslope gradient produced the results presented in Table 3-4.

The vast number of erosion features was found to occur in landscapes that are underlain by rock composed of the highly sheared and fractured Franciscan mélange, covered with herbaceous vegetation, and characterized by moderately steep slopes (10-40%). This relationship is mostly related to the fact that the watershed is predominately composed of these three landscape units and, therefore, erosion features are more likely to occur there. After normalizing the occurrence of the erosion features in a given landscape unit by the proportion of the unit within the entire watershed, we find a slightly different relationship between the total area of an erosion feature within a given landscape unit (Table 3-4). All erosion features were found to be primarily concentrated in terrains underlain by either Monterey Formation shale or Franciscan mélange. Gullies are primarily concentrated in areas underlain by four geologic units: Quaternary landslide debris, Lopse Formation sandstone, Franciscan mélange (graywacke and argillite), and Franciscan graywacke. Landslides occur more upon surfaces underlain by Monterey Formation shales, weathered Obispo Formation basalts, and Franciscan mélange. "Other erosion" features are predominantly underlain by Obispo Formation tuff and serpentinite. Road-related erosion features were found to occur mostly in areas underlain by Monterey Formation tuff; however, this result is likely incorrect as the road-related erosion mostly occurred within imported road fill material based on field and aerial photographic evidence.

Gullies are concentrated within grassland/herbaceous areas, which typically represents those areas used for grazing. Landslides and "other erosion" occur more often in mixed forest and scrub/shrub land cover types. Road erosion is concentrated in developed areas, which is an obvious outcome because roadway areas were categorized as developed areas in the National Land Cover Database (Homer et al. 2004) used in this analysis. In the evaluation of hillslope gradient, the slope distribution was generalized into three classes (see Section 3.4) and it was found that the greatest concentration of erosion features occurred upon hillslopes steeper than 10%. Gullies and road-related erosion features occur more within moderately steep slopes (10–40%), while landslides and "other erosion" features occur more within the steepest landscapes (>40%). For landslides, this is an expected outcome as they develop as a function of the hillslope gradient, soil properties (i.e., cohesiveness), mass of material, and degree of saturation.

Table 3-4. Proportion of erosion features within distinct landscape units of the Santa Rosa Creek watershed.

Landscape unit	Erosion feature (% of feature area within landscape unit, normalized by the proportion of the unit in the total watershed area)			
	Gully (1.3 km^2)	Landslide (0.06 km^2)	Road erosion (0.4 km^2)	Other erosion (0.05 km^2)
Geology (mapping symbol)				
Alluvial sediments (Qa)	3	0	8	<1
Landslide debris (Qls)	11	0	4	0
Marine terrace (Qm)	<1	0	2	0

Landscape unit	Erosion feature (% of feature area within landscape unit, normalized by the proportion of the unit in the total watershed area)			
	Gully ($1.3\ km^2$)	Landslide ($0.06\ km^2$)	Road erosion ($0.4\ km^2$)	Other erosion ($0.05\ km^2$)
Pismo Fm. siltstone (Tpsl)	1	0	0	0
Pismo Fm. sandstone (Tps)	6	0	1	0
Monterey Fm. shale (Tm)	0	0	0	0
Monterey Fm. shale (Tml)	2	44	6	<1
Monterey Fm. tuff (Tt)	1	0	35	0
Obispo Fm. basalt (Tb)	<1	32	2	0
Obispo Fm. tuff (Tot)	<1	0	<1	38
Rincon Fm. siltstone (Tr)	1	0	0	0
Vaqueros Fm. sandstone (Tvq)	6	0	1	0
Lospe Fm. sandstone (Tlc)	17	0	19	0
Cambria felsite (volcanic) (Tf)	6	0	0	0
Unnamed sandstone (Kss)	3	0	1	0
Toro Fm. shale (Ktsh)	4	0	6	0
Serpentinite (sp)	6	0	0	61
Franciscan mélange (fm)	10	24	10	<1
Franciscan chert (fc)	7	0	5	0
Franciscan graywacke (fs)	11	0	<1	0
Franciscan greenstone (fg)	5	0	<1	0
Land cover				
Developed, open space	8	<1	63	<1
Developed, low intensity	<1	0	20	0
Developed, medium intensity	0	0	1	0
Developed, high intensity	0	0	0	0
Evergreen forest	<1	2	<1	10
Mixed forest	3	52	<1	12
Scrub/shrub	19	41	8	77
Grassland/herbaceous	47	5	3	1
Pasture/hay	5	0	0	0
Cultivated crops	8	0	0	0
Woody wetlands	9	0	3	0
Emergent herbaceous wetland	0	0	0	0
Hillslope gradient (generalized)				
0–10%	25	<1	28	1
10–40%	47	31	45	36
>40%	28	69	27	63

3.3 Sediment Production and Delivery

At a watershed scale, soil production and hillslope sediment transport are difficult to quantify because they are driven by the episodic and commonly transient effects of rainstorms, windstorms, fires, earthquakes, and human and other disturbances (Benda and Dunne 1997, Gabet and Dunne 2003). The inherently episodic nature of erosional processes results in substantial year-to-year variability and makes any assessment of sediment-transport rates sensitive to the timescales over which they are averaged (Kirchner et al. 2001). Although long-term averages cannot predict the sediment load for any given year, they nevertheless can be useful in assessing the long-term consequences of alternative management actions, especially those concerned with impacts to aquatic habitats. To understand and estimate the magnitude of sediment flux down Santa Rosa Creek, we evaluate the production and delivery of hillslope sediment using a combination of field observations, available data specific to the watershed, and estimated values from similar watershed in the southern Coast Range region. Using a combination of methods is important because cross-comparison provides the basis for a more robust and reliable estimate than from any single method.

3.3.1 Lithology, erosion, and channel sediment

With continuous landscape uplift to drive hillslope processes and large areas of highly sheared metamorphic and sedimentary rock units now hundreds of meters above the valley bottoms, the Santa Rosa Creek watershed has geologic characteristics commonly associated with high rates of erosion. The eroded sediment is derived from three distinctly different sources (Figure 3-3), which are categorized as follows:

1. Fine-grained, weak – Easily eroded siltstone and mudstone of the Pismo (shale member), Monterey, Rincon, and Toro formations, found traversing the watershed close to the two primary fault traces (Figure 1-3);
2. Coarse-grained, weak – Moderately erodible and highly sheared/fractured rocks that erode into abundant sand and gravel-sized clasts, primarily the Franciscan mélange unit that is found throughout the majority of the watershed; and
3. Coarse-grained, competent – Relatively durable and moderately fractured sandstone and volcanics of the Pismo, Obispo (volcanic member), Vaqueros, Lospe, Cambria, and Franciscan greenstone units, found traversing the lower watershed paralleling the Cambria and Cayucos faults.

This three-part division into relative grain size and erodibility components is central in understanding the present behavior, and predicting the future behavior, of stream channels such as Santa Rosa Creek. By analogy to other rivers world-wide, the fine-grained load (<2 mm) represents the majority of sediment that is delivered by hillslopes into the channel, and that is subsequently transported by the channel to the ocean. Field observations indicate that areas displaying relatively high hillslope erosion are chiefly underlain by siltstone and shale (e.g., Monterey Formation [Tml]) and fractured graywacke/argillite (i.e., Franciscan mélange) (see Table 3-4).

Delivery of coarse-grained sandstones, weathered basalts, and volcanic tuffs from hillslopes to channels is also important. The clasts from these units are generally more resistant to mechanical breakdown during fluvial transport; although they become rounded within a short distance from their initial entry into the channel network, they persist throughout their passage down the network, which in many cases requires many tens of kilometers of transport. Schmidt and Reid (2007) found wide variability in the relative strength of dominant rock types present in the southern Coast Range. Specifically, they found that serpentine and argillite-dominant Franciscan complex rocks were the weakest rocks, while Pismo Formation sandstones and Franciscan greenstone and graywacke were the stronger rocks. Their findings extended to include a positive correlation between the occurrence of weak rocks and landslide density along their study area of the Monterey County coast, which concurs with our findings that landslides were associated with the weaker rocks of the watershed (Franciscan mélange and Monterey shale) (see Table 3-4). Persistence and dominance of sandstone-derived gravel and boulders in the coarse fraction of bedload sediment in Santa Rosa Creek indicates that the channel morphology is largely determined by the delivery, transport, and floodplain deposition of these erosion-resistant (typically sandstone) clasts. The presence or absence of this sediment in the channel also determines whether any given reach will be alluvial (i.e., flowing over loose bed sediment) or non-alluvial with a scoured channel bottom that exposes the underlying bedrock.

Consequently, the processes and rates by which sediment is eroded off of hillslopes, and subsequently delivered to the channel network, vary substantially across the watershed. Given the profound differences in mechanical properties of the shale, sandstone, and volcanic bedrock, the processes affecting each must be considered distinctly.

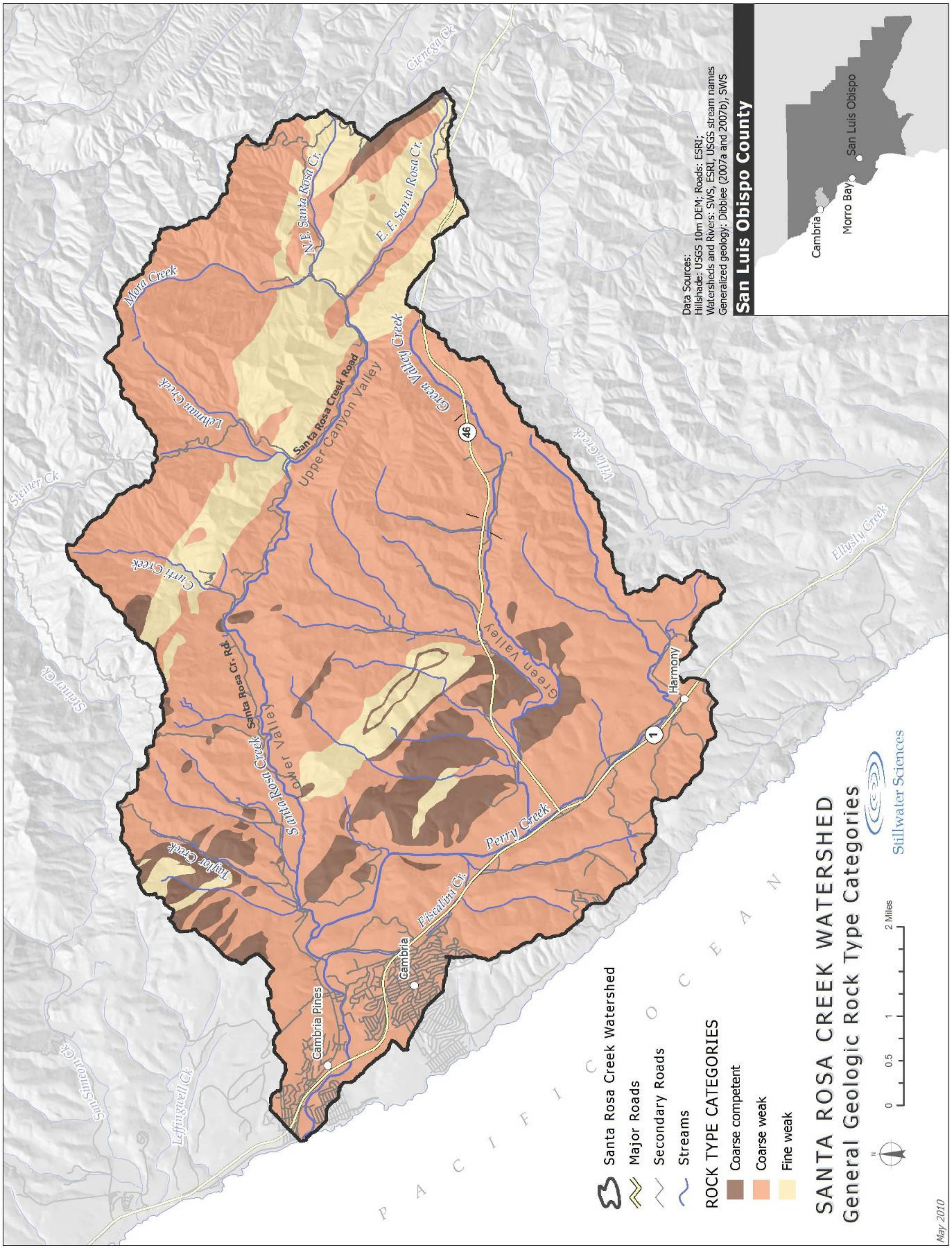


Figure 3-3. Generalized geologic rock unit categories used for the GLU analysis.

3.3.1.1 Fine sediment

The most highly erosive rocks and, therefore, the largest contributors of fine sediment (less than sand, <0.0625 mm) in the watershed are assumed here to comprise siltstone/claystone and thin-bedded shaley rock units, particularly in the Pismo (siltstone member), Monterey, Rincon, and Toro formations (Figure 3-4). In total, these “weak” rock units make up 14% of the watershed area and lie entirely adjacent to the two main fault traces that cross the watershed near the headwaters of Santa Rosa Creek (Oceanic Fault) and near the lower portions of Santa Rosa, Perry, and Green Valley creeks (Cambria-Cayucos faults) (Figure 1-3). These rocks either interbed or occur adjacent to coarser and/or more competent rocks in the watershed, namely the coarser Franciscan mélange graywacke, which structurally support them and, thus, effectively mute their otherwise high erosion rates. In other words, these weaker, fine-grained rocks would likely erode faster as a whole if they occurred across a broader and more continuous area without structural support from harder or coarser rock units. An example of such a terrain is exhibited clearly in the Santa Clara River watershed of southern California where entire mountain ranges composed of weak rock units exhibit active, widespread erosion (Stillwater Sciences 2007a).

It is important to note that all rock units in the watershed produce some fraction of fine-grained sediments, although their relative proportion of fine to coarse particle sizes depend on the specific material properties and the local conditions (e.g., vegetation cover, land uses, and hillslope gradient). Coarse-bearing bedrock can produce fine-grained sediments when the rock already contains a fine matrix component or when biotic (e.g., tree throw or gopher burrowing) or abiotic (e.g., bedrock dissolution or abrasion during transport) processes occur. Fine sediment production from predominately coarse-bearing bedrock is evident by the presence of a mixed-size soil mantle throughout the watershed, not just in those areas underlain by fine-grained rock units. The relatively erodible, yet mostly coarse-bearing Franciscan mélange graywacke unit that accounts for the majority of the total watershed area likely produces a significant portion of fine sediment, which is viewable where gullies have eroded through accumulated colluvium comprised of mixed sediment sizes.

Overall, the fine-grained rocks are generally very susceptible to erosion, especially in the absence of vegetation. By analogy to other studies, rates of fine sediment delivery from these rocks should vary most directly with hillslope gradient and vegetation cover (Reid and Dunne 1996). Observations throughout the Santa Rosa Creek watershed affirm this principle, recognizing that vegetation cover is both a cause and an effect of relative hillslope stability. Lack of vegetation cover enhances the rate of sediment delivery; but where the ground is unstable or eroding rapidly, vegetation does not grow well. Gradients in the watershed are generally moderate to high in areas underlain by these rocks, which is due to two factors: (1) continued uplift of the region does not allow for an equilibrium condition whereby weaker rocks should erode to lower slopes over time (e.g., Gilbert 1877, Schmidt and Montgomery 1995); and (2) the rocks are closely interbedded, underlain, and/or bordered by harder or coarser rocks that structurally support them.

Figure 3-4. An exposure of fine-grained, weak shale of the Monterey Formation in the Curti Creek subwatershed (note person in foreground for scale).

3.3.1.2 Coarse sediment

The most widely occurring rock unit is graywacke (sandstone and argillite) of the Mesozoic-age Franciscan mélange, underlying almost half of the watershed area. In total, all coarse-sediment bearing rocks account for 86% of the watershed. These units include sandstone, volcanic rocks, and young alluvium that are the primary source of coarse-grained sediments to Santa Rosa Creek and its tributaries. Areas underlain by these lithologies display characteristic modes of hillslope erosion and channel delivery that are very different from those of the fine-grained deposits. These rocks are more resistant to surface erosion due the degree of particle cementation (or welding for tuffs); however, many of these units are moderately to severely sheared and/or fractured which decreases their overall net strength. Therefore, two categories of coarse-sediment bearing rock units have been used here to distinguish those units that are more or less erosion-resistant—"coarse weak" and "coarse competent". Examples of a coarse weak rock unit is the highly sheared/fractured Franciscan mélange (Figure 3-5) and a coarse competent rock unit is the volcanic tuff of the Obispo Formation, which forms the backbone of Black Mountain in the headwaters of Santa Rosa Creek (Figure 3-6). Steep bluffs of all coarse-bearing units are prone to rockfalls. Accumulations of talus at the base of these slopes are susceptible to mass transport or gulling; the nearby stream channels are often chocked with coarse, subangular blocks. These coarse-grained rock fragments eventual transport downstream, abrading into cobbles, gravels, and eventually sands and silts. The delivery of these coarse-grained sediments is particularly important to stabilizing channel bed morphology and, thus, supporting steelhead habitat conditions.

Figure 3-5. An exposure of coarse-grained, weak graywacke of the Franciscan mélange along Santa Rosa Creek Road. Large fractured blocks of the rock unit lie upon the top of the outcrop.

Figure 3-6. An exposure of coarse-grained, competent volcanic tuff of the Obispo Formation along Black Mountain.

3.3.2 Relative rates of sediment production - geomorphic landscape units

Relative rates of sediment production and delivery are controlled by vegetation cover, rainfall, and the physical properties of the landscape itself. These conditions, however, can be relatively steady through time, or they can be highly variable. As a result, some delivery processes have fairly constant rates (such as soil creep), but many are unpredictably episodic (such as debris flows or rockfalls). In this section, we discuss estimates of sediment production for the watershed using several approaches to estimate the watershed sediment yield—that is, the amount of sediment per unit area removed from a watershed by flowing water during a given time period.

Although the conditions and events that affect hillslope sediment production and subsequent delivery to the channel network vary greatly over time, different parts of the landscape can be readily identified as to their relative sediment production and delivery potential. Based on available landscape data (both previously available landcover data and recently collected field observations), we can estimate relative production rates for the watershed. We divided these identified factors into discrete categories to define "geomorphic landscape units" (GLUs) across the watershed that, together, influence sediment yields from a particular unit (Reid and Dunne 1996, Montgomery 1999). We assigned relative, qualitative rates of sediment production to each of these GLUs ("High", "Medium", and "Low", commonly abbreviated H, M, and L throughout this report) based on field observations and the inventory of erosion features presented in Figure 3-1. This approach ultimately aids in the identification of these portions of the watershed having relatively high, medium, or low sediment production potential, which can be used to guide future management options. Based in part on field observations in this watershed and on prior studies in southern California (e.g., Stillwater Sciences 2007b, 2008) we have assumed here that sediment-production rates for each category vary by *up to* an order of magnitude. Despite the lack of sediment accumulation and sediment discharge data in the watershed, we can apply estimated sediment yield values from other watersheds in the vicinity to the Santa Rosa Creek watershed and apportion out these yield estimates to each GLU category on an annual unit-area basis (see Section 3.5.2).

Recognizing that many factors can determine sediment-production rates from hillslopes, this study focused on three that were judged to impose the greatest range of variability over the Santa Rosa Creek watershed: rock type, vegetation cover, and hillslope gradient. Overall, those areas of the watershed displaying a combination of erosion-resistant bedrock, dense vegetation cover, and low slopes and correlated with a near absence of observed erosion features (both macro- and micro-scale) were assumed to have a low sediment production potential. In contrast, those areas displaying a combination of weak lithology, minimal vegetation cover, and steep slopes and correlated with numerous observed erosion features were assumed to have a high sediment production potential. Data sources for each landscape category were compiled in a GIS for the entire watershed at a resolution determined by the coarsest dataset (i.e., 30 m). The following describes the methods used in our analysis; tables and figures presenting more detailed information in support of the GLU analysis are presented in Appendix B.

Rock types were derived from the 1:24,000-scale geologic maps of Dibblee (2007a, 2007b; Figure 1-3). Mapped units were grouped into categories of fine weak (siltstone/claystone and shale units), coarse weak (highly fractured coarse sandstone/graywacke and basalt), and coarse competent (less fractured/sheared sandstone, conglomerate, volcanics, and greenstone) (Figure 3-3). Unconsolidated Quaternary deposits, exclusively modern river gravels, paleo-landslides, and uplifted marine terraces were considered "coarse weak" for purposes of this division, reflecting observed abundance of gravels and cobbles in these poorly lithified units. Qualitatively, those units identified as "fine weak" displayed greater erosivity than those identified as "coarse weak", and in turn the "coarse weak" units displayed greater erosivity than those identified as "coarse competent". The relative proportions of the geology GLU categories are summarized in Table 3-5.

Table 3-5. Geology GLU categories within the Santa Rosa Creek watershed.

GLU category [A]	% of Watershed area [B]
Coarse competent	8.2%
Coarse weak	77.8%
Fine weak	14.0%

[A] GLU category based on literature information and field observations.
[B] Proportion of geology GLU category within the total watershed area determined in GIS.

Land cover was based on a data contained within the National Land Cover Database of 2001 (Homer et al. 2004) at 30-m resolution (Figure 1-6). By an automated classification system, four grouped categories were identified; they largely correspond to vegetation covers of forest, scrub/shrub, agriculture/grassland, and developed land (Figure 3-7). The relative proportions of the land cover GLU categories are summarized in Tables 3-6. For this analysis, areas having greater vegetation cover (i.e., forest) are assumed to have lower sediment-production rates, while those areas having lower cover (i.e., agriculture/grassland) have higher sediment-production rates for the following reasons: (1) plant roots physically hold soils in place; (2) organic barriers (e.g., tree trunks, stems, downed branches, and litter) diffuse the erosive force of overland flow and trap sediments transporting down-gradient towards stream channels by acting as physical barriers; and (3) vegetation canopy mutes the otherwise erosive effects of rain splash erosion by intercepting precipitation.

Table 3-6. Land cover GLU categories within the Santa Rosa Creek watershed.

GLU category [A]	% of Watershed area [B]
Forest	16.0%
Scrub/shrub	11.1%
Agriculture/grassland	64.7%
Developed	8.2%

[A] GLU category based on literature information and field observations.
[B] Proportion of land cover GLU category within the total watershed area determined in GIS.

Lastly, hillslope gradients were generated directly from the digital elevation model (DEM), which in turn was based on a USGS 10m DEM. Based on the distribution of slopes and on observed ranges of relative erosion and slope instability, the continuous range of hillslope gradients was categorized into three groups: 0–10%, 10–40%, and steeper than 40% (Figure 3-8). The majority of hillslope gradients fall within the "moderately steep" category of 10–40% (Table 3-7). Greater hillslope gradients have a greater erosion potential and are more likely to deliver eroded sediment downslope towards a stream channel.

Table 3-7. Hillslope gradient GLU categories within the Santa Rosa Creek watershed.

GLU category [A]	% of Watershed area [B]
0–10%	15.3%
10–40%	60.1%
>40%	24.6%

[A] GLU category based on distribution histogram statistics and field observations.
[B] Proportion of hillslope gradient GLU category within the total watershed area determined in GIS.

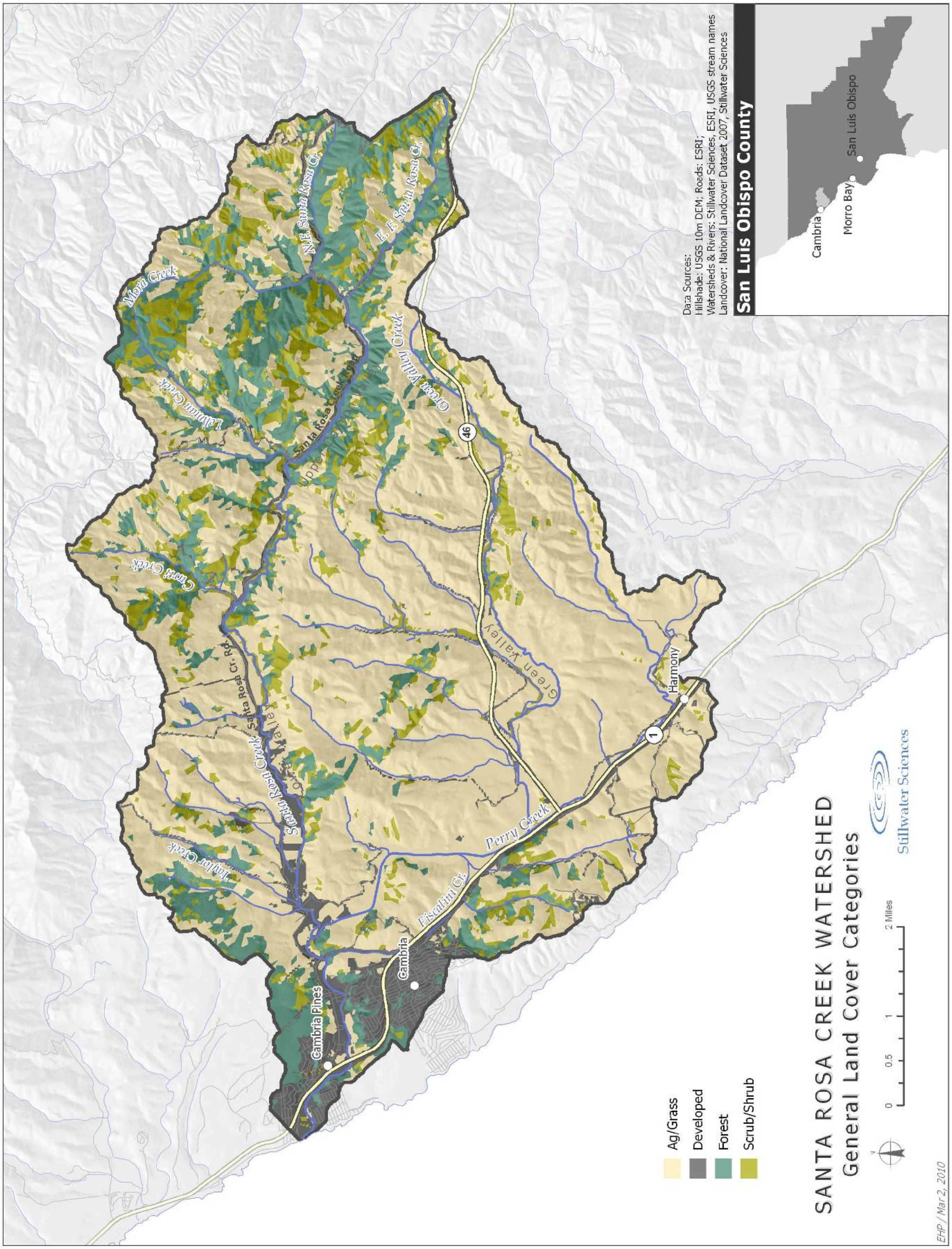


Figure 3-7. Generalized land cover categories used for the GLU analysis.

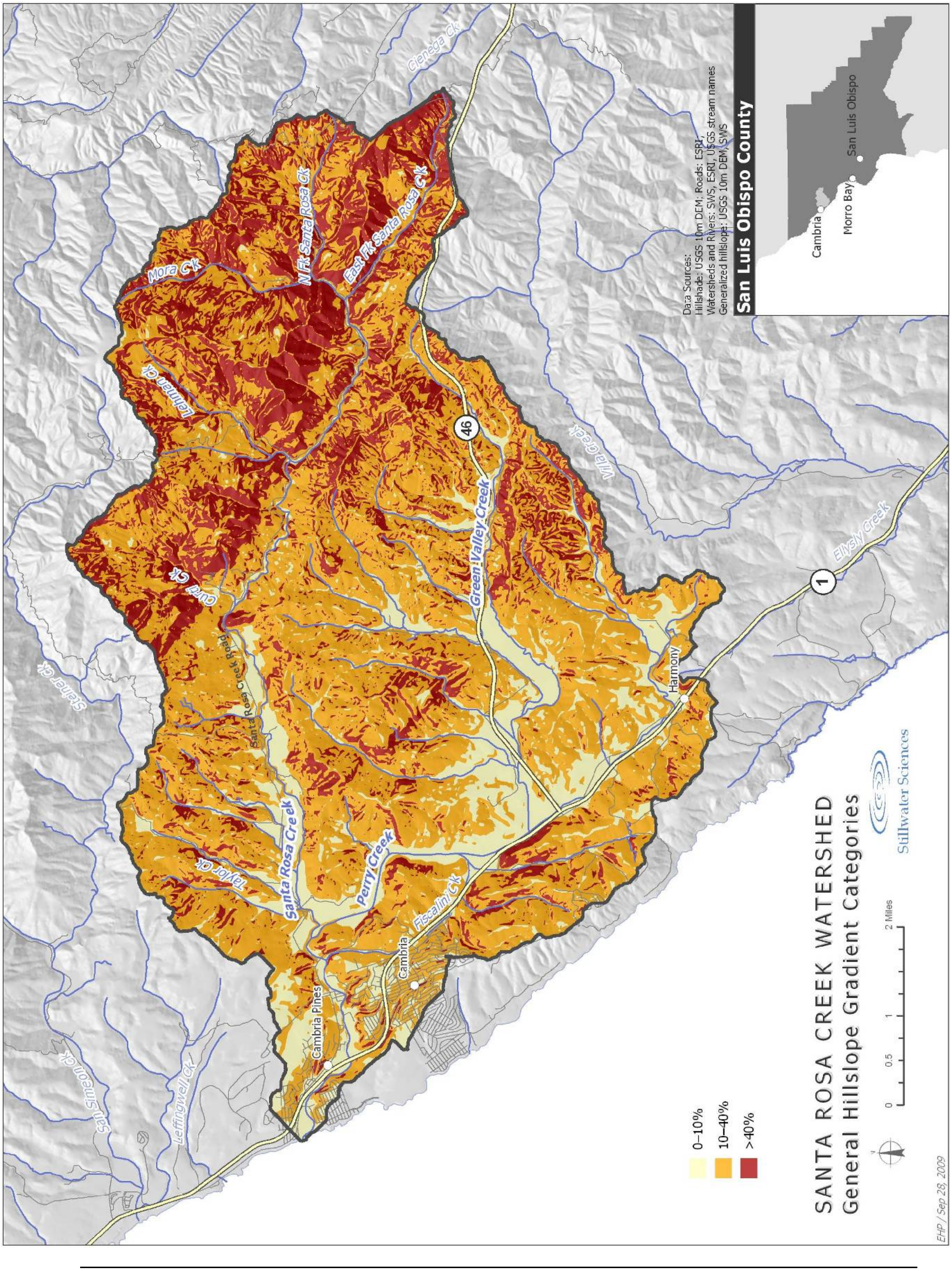


Figure 3-8. Generalized hillslope gradient categories used for the GLU analysis.

The discrete categories defined for these three factors (geology, land cover, and slope) could theoretically overlap into 36 possible geomorphic landscape units—that is, areas that each have a unique combination of these factors that are judged to be the major determinants of hillslope sediment production and, ultimately, sediment yield from the watershed as a whole. In fact, nearly every combination of these factors was represented in the watershed, but one category (geology = "coarse weak", land cover = "ag/grass", slope = 10–40%) represented one-third of the watershed area, which reflects moderately steep grazing lands underlain by Franciscan mélange bedrock. Only 16 of the possible combinations cover more than one percent of the total watershed area, and in total these 16 GLUs account for 94% of the watershed area (Table 3-8).

Table 3-8. Geomorphic landscape units (GLUs) as a percent of total watershed area (representation = 94.1% of the watershed).

Geomorphic landscape units	% of watershed area
Coarse weak; Ag/Grass; 10–40%	35.8%
Coarse weak; Ag/Grass; 0–10%	8.9%
Coarse weak; Ag/Grass; >40%	7.6%
Coarse weak; Forest; 10–40%	5.0%
Coarse competent; Ag/Grass; 10–40%	4.7%
Coarse weak; Scrub/Shrub; >40%	3.9%
Coarse weak; Developed; 10–40%	3.9%
Coarse weak; Forest; >40%	3.8%
Coarse weak; Scrub/Shrub; 10–40%	3.5%
Fine weak; Ag/Grass; 10–40%	3.4%
Coarse weak; Developed; 0–10%	3.3%
Fine weak; Forest; >40%	3.0%
Fine weak; Ag/Grass; >40%	2.5%
Fine weak; Forest; 10–40%	2.1%
Fine weak; Scrub/Shrub; >40%	1.8%
Coarse competent; Ag/Grass; 0–10%	1.0%

For this study, representative areas in each of the major categories were visited in the field and categorized into three relative sediment-production rates, based on observed indications of erosion and mass-wasting processes. Relative differences between many of the different GLUs were dramatic, lending confidence to this three-fold division of relative rates. Figure 3-9 illustrates some of these differences in relative sediment production processes. The assignments of relative sediment production, and in turn of sediment yield, by type of GLU are listed in Table 3-9.

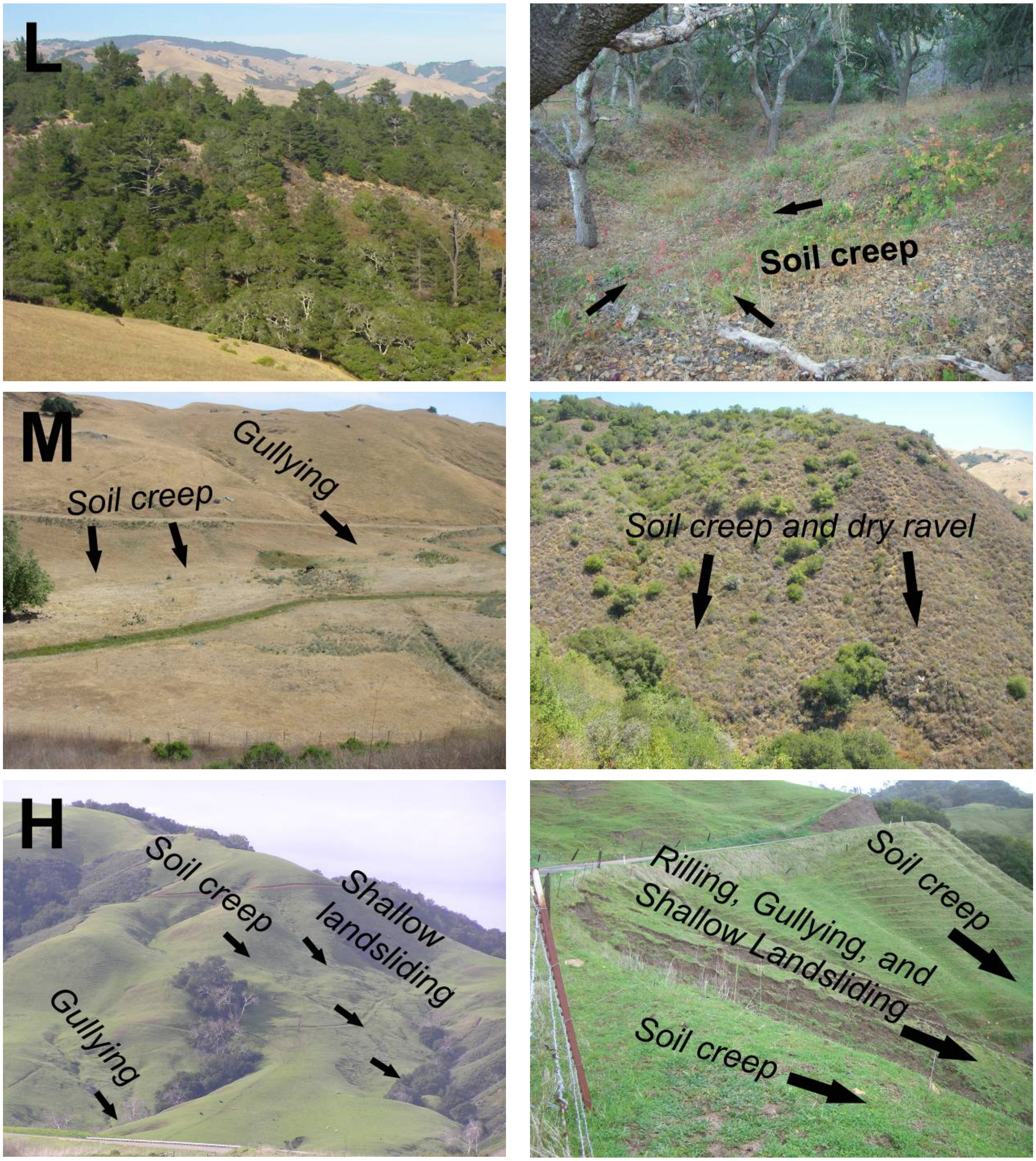


Figure 3-9. Examples of different geomorphic landscape units (GLUs) and their relative levels of sediment production. Top left, low production: coarse competent forest 10–40%; top right, low production: fine weak forest 10–40%; middle left, medium production: coarse weak ag/grass 10–40%; middle right, medium production: fine weak scrub >40%; bottom left, high production: coarse weak ag/grass >40%; bottom right, high production: fine weak ag/grass >40%. Arrows indicate approximate direction of sediment transport from identified erosion process.

Table 3-9. Relative sediment production by Geomorphic Landscape Unit (GLU) (n = 36).

Geomorphic landscape unit	Relative sediment production
Fine weak, Ag/Grass, >40%	High
Fine weak, Ag/Grass, 10–40%	High
Coarse weak, Ag/Grass, >40%	High
Fine weak, Ag/Grass, 0–10%	Med
Fine weak, Developed, >40%	Med
Fine weak, Developed, 10–40%	Med
Fine weak, Developed, 0–10%	Med
Fine weak, Scrub/Shrub, >40%	Med
Fine weak, Scrub/Shrub, 10–40%	Med
Fine weak, Scrub/Shrub, 0–10%	Med
Fine weak, Forest, >40%	Med
Fine weak, Forest, 10–40%	Med
Coarse weak, Ag/Grass, 10–40%	Med
Coarse weak, Ag/Grass, 0–10%	Med
Coarse weak, Developed, >40%	Med
Coarse weak, Developed, 10–40%	Med
Coarse weak, Developed, 0–10%	Med
Coarse weak, Scrub/Shrub, >40%	Med
Coarse weak, Scrub/Shrub, 10–40%	Med
Coarse weak, Scrub/Shrub, 0–10%	Med
Coarse weak, Forest, >40%	Med
Coarse weak, Forest, 10–40%	Med
Coarse competent, Ag/Grass, >40%	Med
Coarse competent, Ag/Grass, 10–40%	Med
Coarse competent, Ag/Grass, 0–10%	Med
Coarse competent, Developed, >40%	Med
Coarse competent, Developed, 10–40%	Med
Coarse competent, Developed, 0–10%	Med
Fine weak, Forest, 0–10%	Low
Coarse weak, Forest, 0–10%	Low
Coarse competent, Scrub/Shrub, >40%	Low
Coarse competent, Scrub/Shrub, 10–40%	Low
Coarse competent, Scrub/Shrub, 0–10%	Low
Coarse competent, Forest, >40%	Low
Coarse competent, Forest, 10–40%	Low
Coarse competent, Forest, 0–10%	Low

A map showing the distribution of the 36 GLU categories across the entire watershed is displayed in Figure 3-10; their distribution by relative sediment production category from Table 3-9 is shown in Figure 3-11.

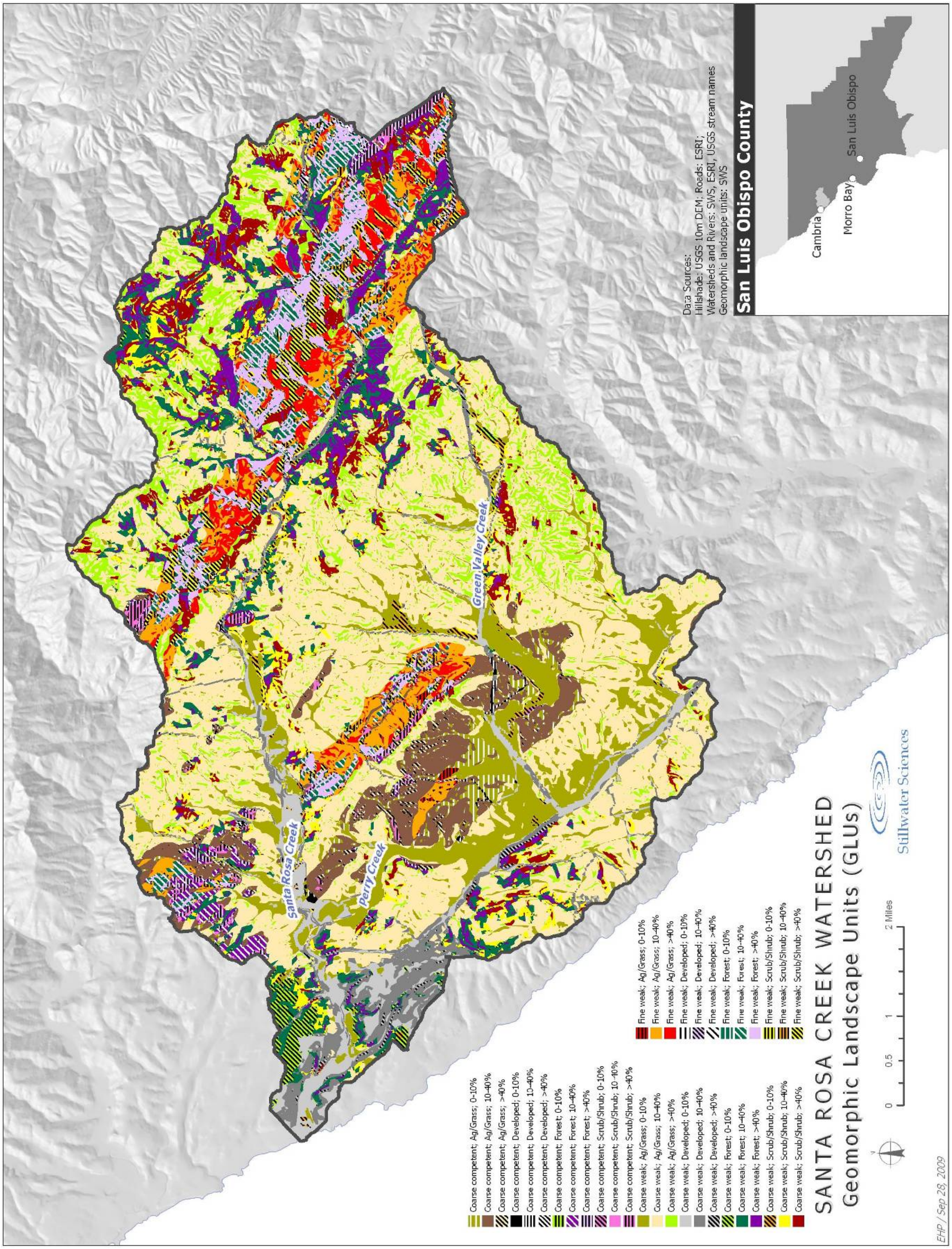


Figure 3-10. Geomorphic Landscape Units (GLUs) in the Santa Rosa Creek watershed.

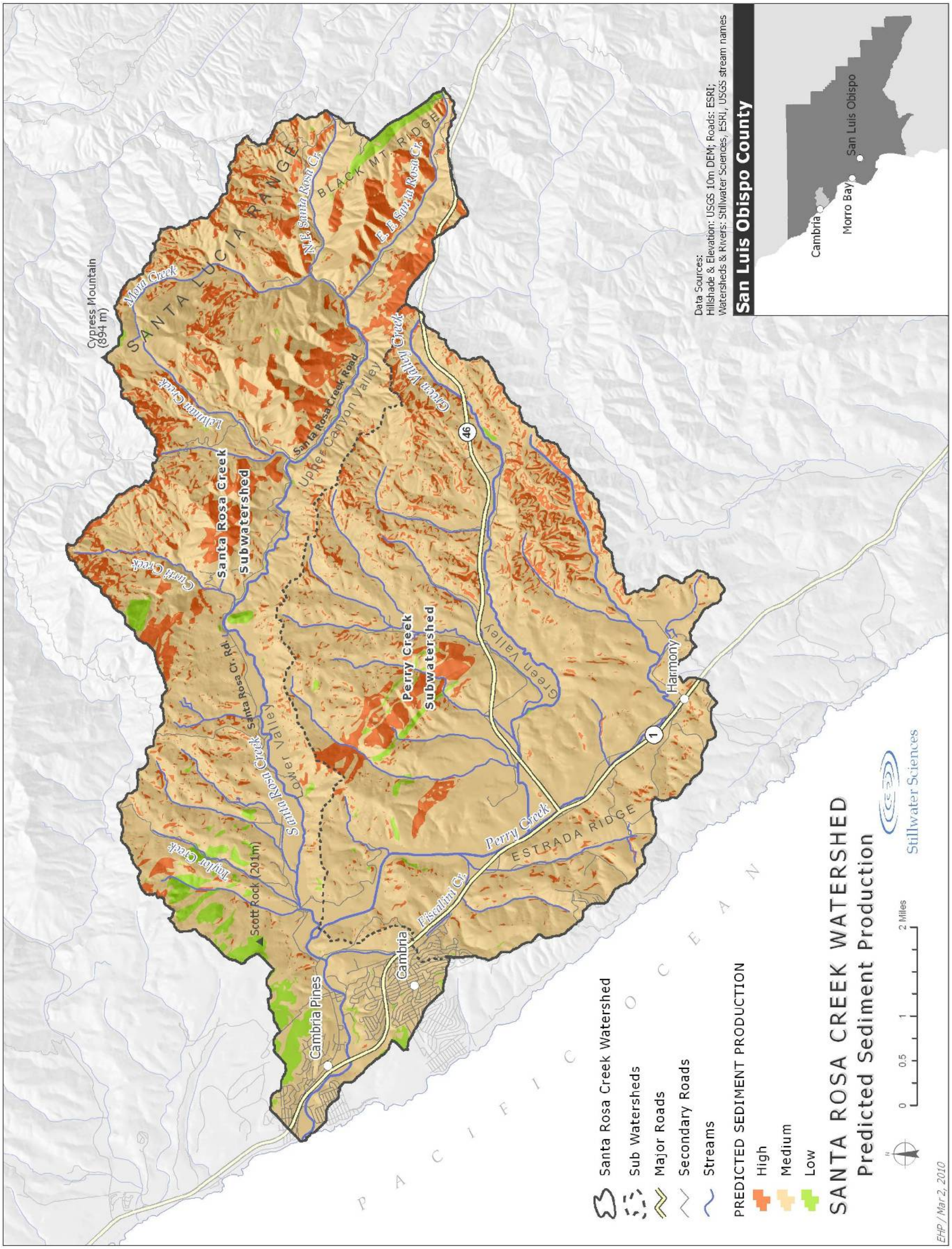


Figure 3-11. Predicted relative rates of sediment production in the Santa Rosa Creek watershed.

The map shown in Figure 3-11 effectively represents a prediction of the relative production of sediment from every part of the watershed. The most striking attribute of this map is the spatial uniformity of sediment generation across the watershed. This reflects the underlying combination of geology, land cover, and slope that place over three-quarters of the watershed areas into our assigned sediment production category of "Medium" (Table 3-10). Less than 15% registers "High", with these areas predominantly on steep bare or grass-covered hillsides concentrated mostly in the headwaters of Santa Rosa Creek and some others clusters concentrated in the headwaters of Perry Creek and long tributaries of Green Valley Creek. Less than 3% registers as "Low", signifying that there are few places in the watershed other than north of Cambria and Scott Rock that are composed of coarse competent rock with forested low- to moderate-gradient slopes.

Table 3-10. Relative total sediment production category as a percent of total watershed area.

Relative Total Sediment Production	% of Watershed Area
Low	2%
Medium	84%
High	14%

This spatial prediction is lacking in one significant respect: the GLU analysis does not account for any routing or storage of sediment within the channel network. This makes it difficult to equate estimated sediment production with actual delivery to the stream channels. However, it can be reasonably assumed in the upland areas of the watershed that sediment production roughly equals sediment delivery to the tributary channels as a function of the steep slopes and minimal storage potential occurring here, with the exception of the stream bed itself. Also, subwatersheds hosting a high proportion of "High" sediment producing GLUs are considered to have relatively high sediment delivery ratios based on the high occurrence of steep, poorly vegetated slopes (see Section 3.5 for discussion of relative sediment yields from the subwatersheds). In the valley reaches of the watershed where storage capacities are greater because of lower gradients and the presence of floodplain areas (i.e., downstream of Mammoth Rock), most sediment produced on adjacent hillslopes with minimal tributary density would simply deposit at the base of the hillside and/or the floodplain, especially in those areas where tributary channels have been filled in for agricultural purposes.

Although the GLU analysis does not explicitly account for discrete erosion processes, a comparison of our High, Medium, and Low sediment producing areas in the watershed against the erosion features shown in Figure 3-1 can be made to identify any apparent connections. Overlying the erosion features with the GLU categories (geology, land cover, and hillslope gradient) reveals that, overall, gullies—the most numerous and voluminous "macro-scale" erosion feature—are predominantly concentrated in the coarse competent and coarse weak (i.e., Franciscan mélange), ag/grass, and moderate slope (10–40%) landscape units (Table 3-11). The corresponding relative sediment-production rate for this GLU was estimated to be in the Medium range (see Table 3-9), which appears somewhat contradictory given that the occurrence of gullies could be indicative of a High yielding terrain. However, as is discussed further in Section 3.4.3 below, the estimated sediment-production rates from gullies is sufficiently lower than from micro-scale erosion features which are assumed here to occur with greater effect in the High GLU areas.

Table 3-11. Proportion of erosion features within GLU categories of the Santa Rosa Creek watershed.

GLU categories	Erosion feature (% of feature area within landscape unit, normalized by the proportion of the unit in the total watershed area)			
	Gully ($1.3\ km^2$)	**Landslide ($0.06\ km^2$)**	**Road erosion ($0.4\ km^2$)**	**Other erosion ($0.05\ km^2$)**
Generalized Geology				
Coarse competent	47	0	29	44
Coarse weak	43	31	39	49
Fine weak	10	69	32	6
Generalized Land cover				
Forest	3	42	<1	13
Scrub/shrub	25	51	13	85
Ag/grass	63	7	5	1
Developed	9	<1	82	<1
Generalized Hillslope gradient				
0–10%	25	<1	28	1
10–40%	47	31	45	36
>40%	28	69	27	63

3.4 Regional Estimates of Sediment Production

The above sections describe active erosion processes and relative sediment-production rates in the watershed using available data. This section takes the next step of presenting quantitative estimates on sediment yields from similar landscapes in the southern Coast Range and then scaling those estimates to the Santa Rosa Creek watershed for the purposes of providing an approximate total sediment yield. This is accomplished by utilizing information published in studies on tectonic uplift rates in the Santa Lucia Mountains and on sediment yield rates in nearby watersheds. Application of these regional estimates to the Santa Rosa Creek watershed is subsequently presented, in addition to GLU-derived sediment yield estimates.

3.4.1 Inference from geological evidence

Watershed topography reflects the interplay between uplift (if any) due to tectonic processes, and the sculpting and wearing away of slopes by erosion. In general, high steep mountains occur in areas that have been subjected to sustained rapid uplift, whereas gently sloping terrain is found where uplift is slow or has been followed by long periods of denudation. The linkages between uplift, slope steepness, and erosion imply that slopes should tend to contribute sediment in proportion to their uplift rates over the long term (Burbank et al. 1996)—that is, rapid uplift rates usually result in high rates of sediment production. Uplift rates, in turn, are directly related to the tectonic setting and deformation history of the landscape.

Late Cenozoic uplift (less than 3 million years ago) in the southern Coast Range is evident based on the following landscape features, which are also present in the Santa Rosa Creek watershed: uplifted and deformed marine strata (e.g., Monterey Formation), elevated marine terraces, and Quaternary faults and folds (Montgomery 1993). Christensen (1965, as cited in Montgomery

1993) estimated surface uplift along the Coast Range to vary between approximately 300 to 600 meters during this recent geologic period, with lower values near the coast and higher values in the Santa Lucia Mountains. The geomorphic response to this Coast Range orogeny is surface erosion, or denudation, of the sub-aerial landscape over time. Based on a comprehensive review of rock uplift and plate convergence rates in the region, Montgomery (1993) estimated erosion rates in the central Coast Range watersheds to range between 0.02 and 0.20 mm/yr (Table 3-12). The section below examines specific estimates of fluvially driven sediment yields from nearby watersheds which more closely match the denudation rates estimated by Montgomery (1993).

In contrast, Ducea et al. (2003) estimated a higher denudation rate of 0.9 mm/yr for the Santa Lucia Mountains over the past 2 million years. Ducea et al. (2003) acknowledged that their denudation estimates are likely one order of magnitude greater than fluvial erosion rates in the region, which they attribute to landslide activity that serve to denude landscapes yet store their sediments for significant time periods (~100 to 1,000 years). This offers a plausible, yet untested explanation for the difference between uplift, denudation, and fluvial erosion rates in the region.

Table 3-12. Long-term sediment yield from the Santa Rosa Creek watershed based on regional estimates of denudation rates.

Study	Denudation rate (mm a^{-1})	Time period [A]	Applied to the Santa Rosa Creek watershed	
			Long-term average annual sediment yield (t a^{-1}) [B]	Long-term average annual sediment yield per unit area (t km^{-2} a^{-1})
Montgomery (1993) – low estimate	0.02	<3 Ma	3,900	32
Montgomery (1993) – high estimate	0.2		39,000	320
Ducea et al. (2003) – low estimate “fluvial”	0.09	<2 Ma	17,700	144
Ducea et al. (2003) – high estimate “landslides and fluvial” [C]	(0.9)		(177,000)	(1,440)

[A] Ma = million years.
[B] Sediment yield calculated using an assumed sediment bulk density of 1.6 tonnes per cubic meter (t m^{-3}).
[C] Expected to overestimate sediment delivery into channels (see text).

3.4.2 Inference from sediment studies in nearby watersheds

Although there has been no direct measurement of sediment discharge or accumulation in the Santa Rosa Creek watershed, sediment yields can be estimated from yields in neighboring watersheds with similar landscape characteristics. Table 3-13 summarizes sediment-yield estimates from other watersheds in the southern Coast Range derived from studies, focusing on either measured sediment discharge at a point of a stream channel or measured sedimentation within a reservoir. The average annual sediment yields from these other watersheds vary between 229 and 1,171 metric tonnes per square kilometer (t km^{-2} a^{-1}), with a median value of nearly 400 t km^{-2} a^{-1}. In developing this tabular summary, we have generally assumed that the fine sediment fraction represents the suspended load fraction—those sand-size or smaller particles (<2 mm) transporting in suspension during high flow events—which likely accounts for approximately 90% of the total load as reported by several other studies in the region (e.g., Walling and Webb 1981, Hadley et al. 1985, both as cited in Farnsworth and Warrick 2007). These data include one study conducted in the nearby Pismo Creek watershed (Hecht 2006). The median denudation rate of 0.3 mm/yr, based on these results, closely matches the long-term (<3 Ma) rate estimated by Montgomery (1993). We therefore judge this rate to be the best available estimate to apply to the Santa Rosa Creek watershed for its long-term sediment yield.

Table 3-13. Estimated sediment yields from watersheds in the southern Coast Range region.

Study	Watershed	Years evaluated	Watershed area (km^2)	Total sediment yield per unit area ($t\ km^{-2}\ a^{-1}$)	Coarse (>2 mm) load fraction of the total load [A]	Equivalent denudation rates based on the total sediment yield ($mm\ a^{-1}$) [B]
Sediment Discharge Study						
Knott (1976) [C]	Santa Rita Creek	1943–1972	53	393	20%	0.2
	Arroyo Grande Creek		175	274	8%	0.2
Farnsworth and Warrick (2007) [D, E]	Pescadero Creek	1952–2005	120	398	10%	0.2
	San Lorenzo River	1937–2005	270	1,171		0.7
	Salinas River	1930–2005	10,760	229		0.1
	Carmel River	1963–2005	640	684		0.4
	San Jose Creek [F]	1972–1997	20	800		0.5
Reservoir Sedimentation Study						
Brown (1973)	Loch Lomond (Newell Ck.)	1961–1971	132	385	10%	0.2
Minear and Kondolf (2009) [G]	Los Padres (Carmel R.)	1949–1984	116	364		0.4
	Atascadero (Atascadero Ck.)	1918–1975	2.3	235		0.2
	Santa Margarita (Salinas R.)	1942–1975	287	349		0.4

[A] Coarse load fraction assumed to be 10% of the total load, unless otherwise stated by the study author.
[B] Sediment bulk density assumed to be 1.6 tonnes per cubic meter ($t\ m^{-3}$), unless otherwise stated (e.g., see note number G).
[C] Study included direct measurements of the size fraction of transported sediment.
[D] Study estimated total suspended sediment yield, which we have assumed represents sand size particles and finer (<2 mm).
[E] All watersheds except for San Jose Creek are located in the southern Coast Range region, which includes San Mateo, Santa Cruz, and San Luis Obispo counties.
[F] Located in the Transverse Mountains of Santa Barbara County and used here to exemplify a nearby drainage in southern California, yet with a relatively greater sediment yield potential due to weaker lithologies and higher tectonic uplift rates.
[G] This study assumed a bulk density of reservoir sediments = 0.96 $t\ m^{-3}$.

Plotting the average annual sediment yield (t a^{-1}) data against drainage area from these other southern Coast Range watersheds shows a strong correlation—the coefficient of determination (R^2) of 94% indicates that this model explains the variation well (Figure 3-12). This correlation is not surprising, since, generally, more sediment is produced from a larger watershed. Using the linear regression of the plotted data in Figure 3-12 with the drainage area of the Santa Rosa Creek watershed (123 km^2), we can derive an estimated total sediment yield that amounts to approximately 52,000 t a^{-1}, or a yield per unit area of 420 t km^{-2} a^{-1}. This estimate corresponds to a uniform, watershed-wide denudation rate (i.e., landscape lowering rate) of 0.3 mm/yr.

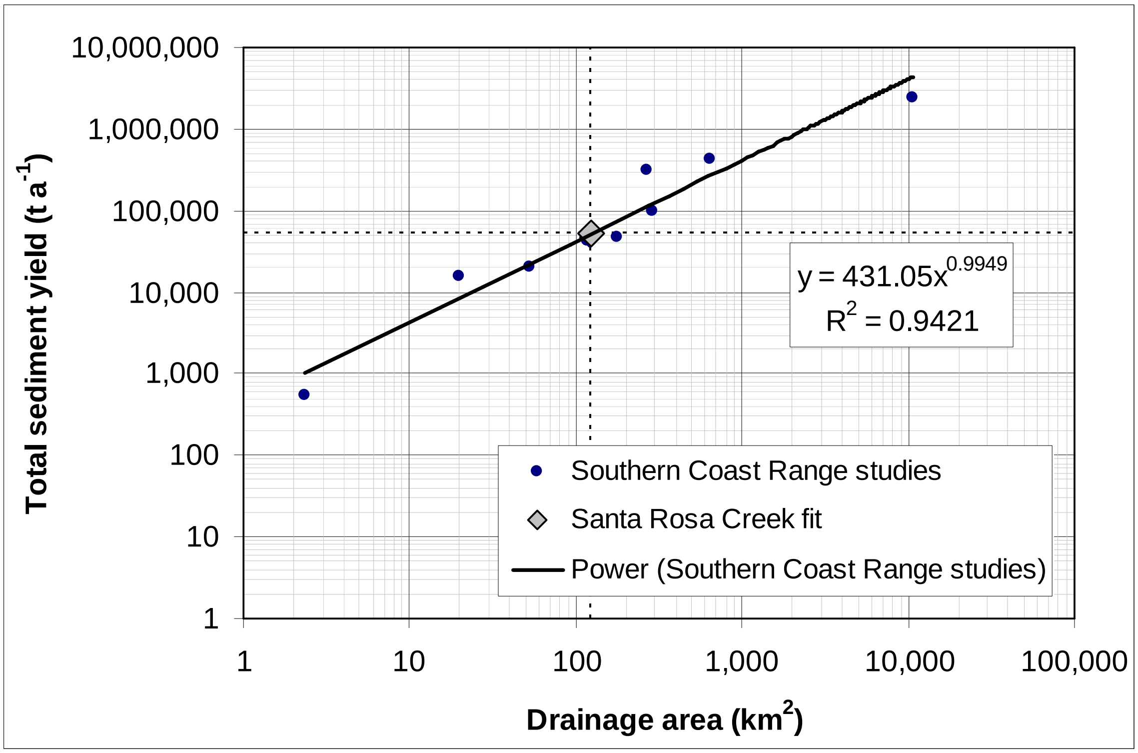


Figure 3-12. Correlation of estimated sediment yields from other watersheds in the southern Coast Range region with their drainage areas. Santa Rosa Creek watershed (123 km^2) is shown by the gray diamond.

3.4.3 Comparison of sediment yield estimates from hillslope erosion features and regional studies

The estimates of sediment yields from other studies throughout the southern Coast Range were used to derive an average annual estimate for the entire Santa Rosa Creek watershed: 52,000 t a^{-1}, or a sediment yield per unit area estimate of 420 t km^{-2} a^{-1}. This value exceeds the sediment-production rate of 17,000 t a^{-1} (140 t km^{-2} a^{-1}) estimated for the "macro-scale" hillslope erosion features located in the watershed, of which the majority (82%) is accounted for by gullies (Section 3.2). This result is expected because the macro-scale erosion rate does not include sediment production from other sources in the watershed, namely "micro-scale" hillslope erosion sources (e.g., soil creep, dry ravel, and rilling) and channel erosion sources (e.g., bank and bed erosion). The remaining two-thirds of the total sediment delivery to the channel network are likely accounted for by these other sources. This supports our previously stated assertion that other hillslope processes such as soil creep, dry ravel, and rilling, which were observed to be prevalent and highly effective in delivering sediment to the channel network in those High units, cooperatively lead to a relatively higher sediment-production rate as compared to the production rate specifically from gullies.

3.5 Sediment Yield Analysis Using Geomorphic Landscape Units

Use of our GLU methodology with the watershed sediment yield estimated from regional studies enables the allocation of the total yield to each identified GLU throughout the watershed based on its relative "High", "Medium", or "Low" sediment production potential. Following our previously stated assumption that sediment-production rates vary approximately by up to an order of magnitude (but perhaps less) between GLU categories, we have determined the relative sediment yield potential for each subwatershed for the purpose of ranking them in order from highest to lowest (Table 3-14). Absolute values are not reported here because an unknown degree of error likely exists in our predictions due to the lack of actual sediment yield measurements in the watershed. Varying the sediment yield differences between the High, Medium, and Low categories between a factor of 2 and 10 (i.e., up to an order of magnitude) results in the same ranking order. The tributaries draining to Santa Rosa Creek estimated to have the highest sediment yields are East Fork Santa Rosa and Curti creeks. Two of the other highest sediment producing subwatersheds host unnamed tributaries that drain to Green Valley Creek. All four of these subwatersheds are characterized by their high relief (i.e., large proportion of steep areas), low vegetation cover density, and weak lithologies which drive the relatively high sediment-production rates and, in turn, the high delivery rates to the channel network. Figure 3-13 shows the subwatersheds considered in this analysis; the figure also highlights those subwatersheds predicted to have the highest and lowest sediment yields.

Table 3-14. Relative sediment yield potential in subwatersheds in the Santa Rosa Creek watershed. [A]

Subwatershed			% of subwatershed area			Rank of sediment production rate [C]
ID	Stream Name [B]	Area (km^2)	High	Medium	Low	
1	Curti Creek	5.5	23	73	4	4
2	Mora Creek	6.8	15	84	1	10
3	Taylor Creek	2.2	4	84	12	20
4	*Santa Rosa Creek tributary*	2.7	8	64	28	17
5	Lehman Creek	6.5	20	79	1	6
6	North Fork Santa Rosa Creek	5.6	20	78	2	5
7	*lower Santa Rosa Creek*	5.3	1	85	14	25
8	*Green Valley Creek tributary*	4.4	17	80	3	8
9	*Santa Rosa Creek tributary*	1.4	<1	92	7	24
10	*Green Valley Creek tributary*	8.1	9	90	<1	15
11	*Green Valley Creek tributary*	2.7	15	84	<1	9
12	East Fork Santa Rosa Creek	4.8	33	60	7	1
13	Green Valley Creek	12.3	12	88	<1	12
14	*Green Valley Creek tributary*	2.3	24	73	3	2
15	*Green Valley Creek tributary*	1.7	24	70	6	3

Subwatershed			% of subwatershed area			Rank of sediment production rate [C]
ID	Stream Name [B]	Area (km^2)	High	Medium	Low	
16	Fiscalini Creek	3.7	1	98	<1	22
17	*lower Perry Creek*	6.3	4	95	1	19
18	*upper Perry Creek*	11.9	11	88	<1	13
19	*Perry Creek tributary*	1.6	15	85	0	11
20	*Perry Creek tributary*	1.3	3	97	0	21
21	*Santa Rosa Creek tributary*	3.6	6	91	3	16
22	*Fiscalini Creek tributary*	3.0	5	95	<1	18
23	*Santa Rosa Creek tributary*	1.0	<1	99	<1	23
24	Santa Rosa Creek	17.1	18	81	1	7
25	*Santa Rosa Creek tributary*	1.1	10	90	<1	14

[A] Location of subwatersheds are shown in Figure 3-13.
[B] Names in italics are descriptive only for those tributaries without official names (see Table 1-1).
[C] Listed in order of highest to lowest sediment producing subwatersheds.

Numerous water storage basins located throughout the watershed (Section 3.2) have the potential to trap sediment, particularly coarse-grained materials, which further alters sediment-routing processes in the watershed (see Figure 3-2). Determination of a sediment yield for the contributing areas above each basin feature (or point) was determined in GIS using our GLU methodology and was then used to estimate the total sediment yield contributing to these basins. The results suggest that the amount of sediment “trapped” in the basins is relatively low, accounting for a watershed-wide reduction of approximately 5 to 10% of the previously estimated total sediment yield of 52,000 t km-2 a-1 (see Section 3.4.3). Not surprisingly, the greater number of basins present in the Perry Creek subwatershed (including Green Valley and Fiscalini creeks) contributes to a greater reduction in the total sediment yield from that subwatershed. Considering the low trap efficiencies of these basins and that coarse sediment probably accounts for approximately 10% of the total load, the basins likely trap only 40–50 tonnes of coarse sediment annually in the entire watershed. Although this trapping may be locally significant to downstream habitat formation, the watershed-wide amount is only about one percent of the approximately 5,000 t a^{-1} of coarse sediment yield estimated for the watershed as a whole (Table 3-9).

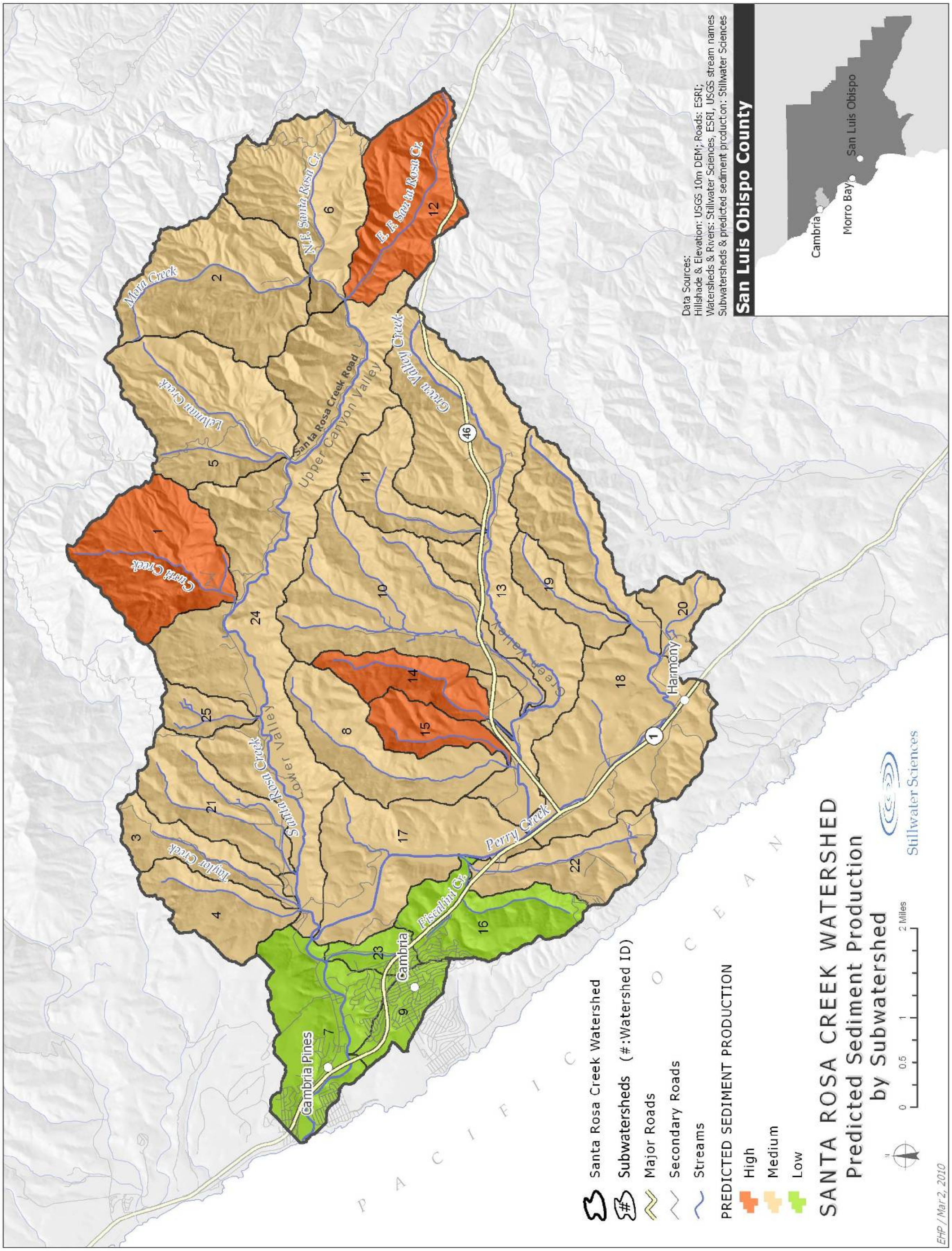


Figure 3-13. Predicted sediment production potential by subwatershed in the Santa Rosa Creek watershed.

4 FLUVIAL GEOMORPHIC PROCESSES OF SEDIMENT TRANSPORT AND MORPHOLOGICAL CHANGE

4.1 Overview

This section assesses fluvial geomorphic processes and morphology of the channel network of Santa Rosa Creek watershed as the basis for understanding the potential implications for, and impacts of, management decisions related to steelhead trout or other aspects of watershed management. We begin by assessing data related to the frequency and magnitude of high flows which are the fundamental control on fluvial geomorphic processes (Section 4.2). We then characterize the morphology and sediments of the channel network to the extent permitted by time, access, and available data: this information is one of the building blocks for determining aquatic habitat quality and the probably extent of impacts to the channel network (Section 4.3). Third, we examine the morphological dynamics of the creek network using historical data, measures of the potential for sediment transport, and our understanding of the history of direct and indirect human impacts on the creek to determine how the creek has changed in the recent past (Section 4.4). Finally, we provide a brief narrative related to available information on the morphology and dynamics of the barrier lagoon at the mouth of Santa Rosa Creek: the lagoon potentially plays an important role in aquatic life cycle for steelhead trout (Section 4.5).

4.2 Frequency and Magnitude of Flows

The magnitude of flow in Santa Rosa Creek ultimately determines the magnitude of sediment transport and the nature and rate of geomorphic change. As a consequence of its Mediterranean climate and historical changes to land uses in the watershed, discharge within Santa Rosa Creek is characterized by long durations of low flow, punctuated by high-flow events that travel relatively quickly through the watershed. Over the past 50 years, a variety of notable floods have occurred in the watershed (e.g., in Water Year [WY] 1969, 1973, 1986, 1995, and 2005; see below). These high-flow events are instrumental in transferring sediment from the hillslopes to the channel, downstream river mouth lagoon, and near-shore waters, and they are integral in controlling changes in the geomorphic character of the creek channel and floodplain over time. The specific short- and long-term impacts of these high-flow events on channel morphology and geomorphic processes are a function of a variety of factors, including both natural and anthropogenic influences.

Discharge has been measured over the past 50 years in both the upper (i.e., above Mammoth Rock) and lower watershed (i.e., below the Perry Creek confluence) by three gauges operating at different time periods (Table 4-1; see Figure 1-5). Flows recorded in the upper Santa Rosa Creek are indicative of the flows entering the alluvial section of the Santa Rosa Creek valley whereas flows recorded by the lower gauges represent the magnitude of flow passing through the town of Cambria and through the lagoon to the Pacific Ocean. From WY 1958 through 1972, the USGS recorded both daily mean and annual instantaneous maximum flow in upper Santa Rosa Creek at a gauge located approximately 0.7 km upstream of the Curti Creek confluence (USGS 11142200). The gauge was designed to assess flow for a potential dam to be build in the upper watershed but never constructed. Following the decommissioning of the USGS gauge, SLO County recorded daily mean and annual instantaneous maximum flow in lower Santa Rosa Creek at a gauge located just upstream of the Highway 1 bridge (SLO County Station 16) from WY 1976 through 1992. The Highway 1 bridge gauge was replaced by another gauge installed in lower Santa Rosa Creek approximately 2.2 km upstream at the Main Street bridge (SLO County Station 21) which has been recording daily mean and annual instantaneous maximum discharge since WY 1989. Summary details are provided in Table 4-1.

Table 4-1. Stream gauges of Santa Rosa Creek. [A]

Stream gauge ID	Stream gauge operator [B]	Stream gauge location	Period of record (water years)	Drainage area above stream gauge (km^2)
USGS 11142200	USGS	Upper gauge: 0.7 km upstream from Curti Creek	1958 – 1972	32.4
SLO County Station 16	SLOCWR	Lower gauge: Highway 1 bridge	1976 – 1992	121.5
SLO County Station 21	SLOCWR	Lower gauge: Main Street bridge	1989 – present	116.6

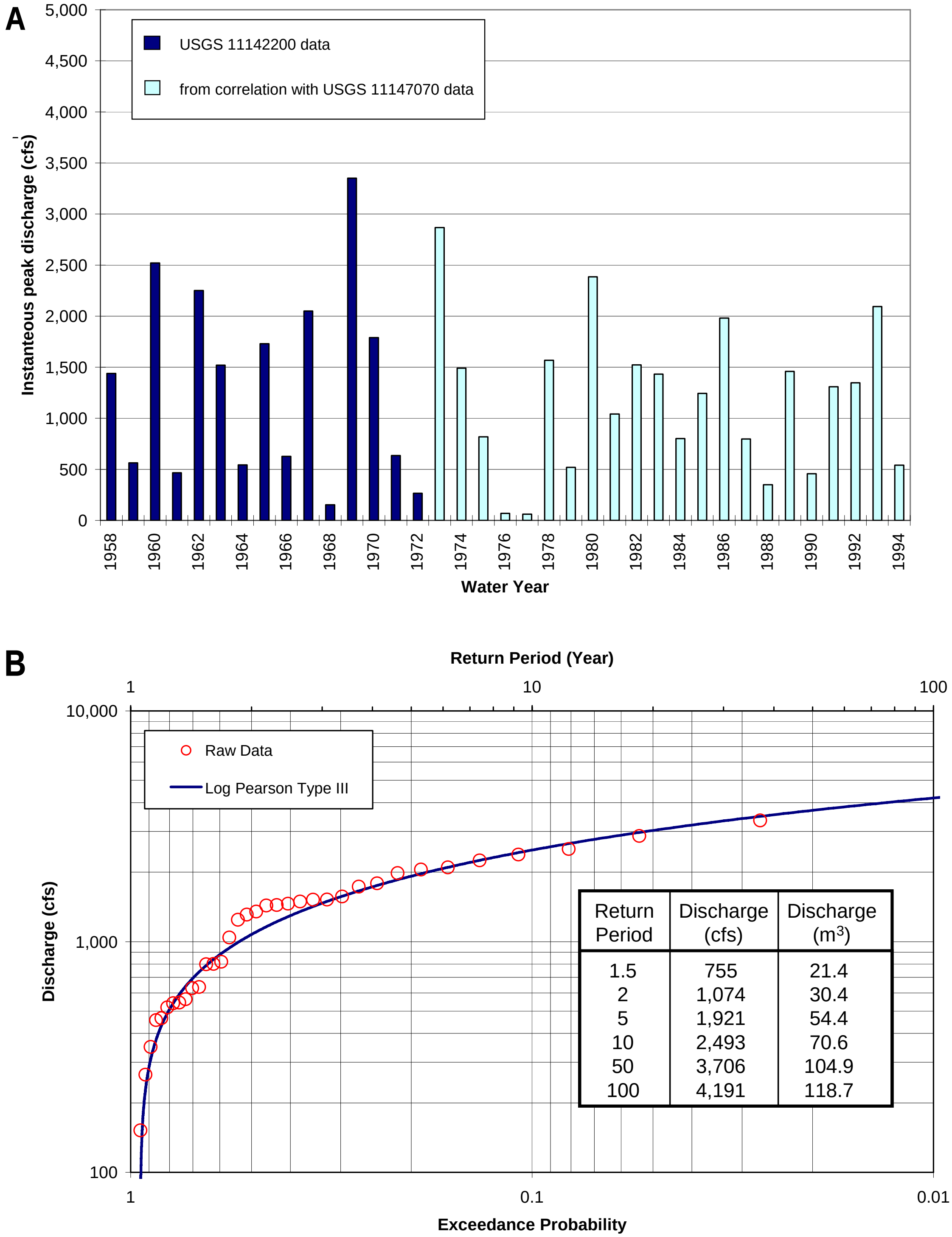
[A] See Figure 1-5 for locations of stream gauge locations on Santa Rosa Creek.
[B] USGS=United States Geological Survey; SLOCWR = San Luis Obispo County Water Resources, Division of Public Works.

In addition to the different operating periods for each gauge, the quality of flow information varies. Flow data from the lower gauges has not been subject to USGS operating protocols and so are not well calibrated restricting confidence in the data; calibration is the process of taking actual measurements of flow taken at a range of low to high flows to develop a reliable relationship between flow depth and flow discharge that allows the operators to infer discharge from depth in unmeasured events. There are large variations in reported annual maximum discharge at SLO County Stations 16 and 21 during the period where both gauges were operating (WY 1989–1992) despite their close physical proximity. At Station 21, calibration of the rating curve has occurred only during very moderate flows (below 9 $m^3 s^{-1}$, 320 cfs) and yet has been used to predict annual instantaneous maximum discharges over 35 times higher. Conversely, flows at Station 16 were deemed sufficiently accurate to use as part of a recent USGS groundwater recharge study conducted in the watershed (Yates and Van Konyenburg 1998). As such, we concentrate our analysis of stream flow dynamics on the USGS gauge 11142200 and SLO County Station 16, and include data from SLO County Station 21 sparingly and with caveats regarding flow magnitude. Also to provide consistency with the study of Yates and Van Konyenburg (1998), gaps in the records of annual maximum flow were filled using correlation with the annual maximum flow record from the neighboring Santa Rita Creek tributary gauge at Templeton, CA (USGS gauge 11147070; flow record from WY 1958-1992). However, without additional calibration of the Station 21 gauge, there are no particularly reliable measurements of high flows in the watershed since WY 1992, including the high flow events in WY 1995 and 2005.

Within these limitations, the compiled data were used to illustrate inter- and intra-annual flow variability within the Santa Rosa Creek watershed since WY 1958. Annual maximum flow has ranged by a factor of ~50 (1.7 to 95 $m^3 s^{-1}$; 60 to 3,350 cfs) in the upper watershed, and even more widely (<0.03 to 340 $m^3 s^{-1}$; <1 to <12,000 cfs) in the lower watershed between WY 1962–1994, with the largest flow recorded at both locations occurring in WY 1969 (Figure 4-1 and Figure 4-2). From the extended annual maximum flow data, the annual maximum discharge expected to be equaled or exceeded approximately once every 1.5 to 2 years (the statistical "bankfull" flow event) during this time period is approximately 21–30 $m^3 s^{-1}$ (760–1,100 cfs) in the upper watershed and 50–78 $m^3 s^{-1}$ (1,800–2,700 cfs) in the lower watershed. For low flows, discharge data from the upper watershed indicates that, on average, the daily mean flow was less than 0.03 m^3s^{-1} (1 cfs) for the period the gauge was in operation (WY 1958–1972) and approximately 99% of the daily mean flow values were at or below 4.5 $m^3 s^{-1}$ (160 cfs) (Figure 4-3). In the lower watershed, mean daily discharge also averaged less than 0.03 $m^3 s^{-1}$ (1 cfs) over the period of record (WY 1976–1992), with most of the daily mean flow values at or below 13.6 $m^3 s^{-1}$ (480 cfs) (Figure 4-4).

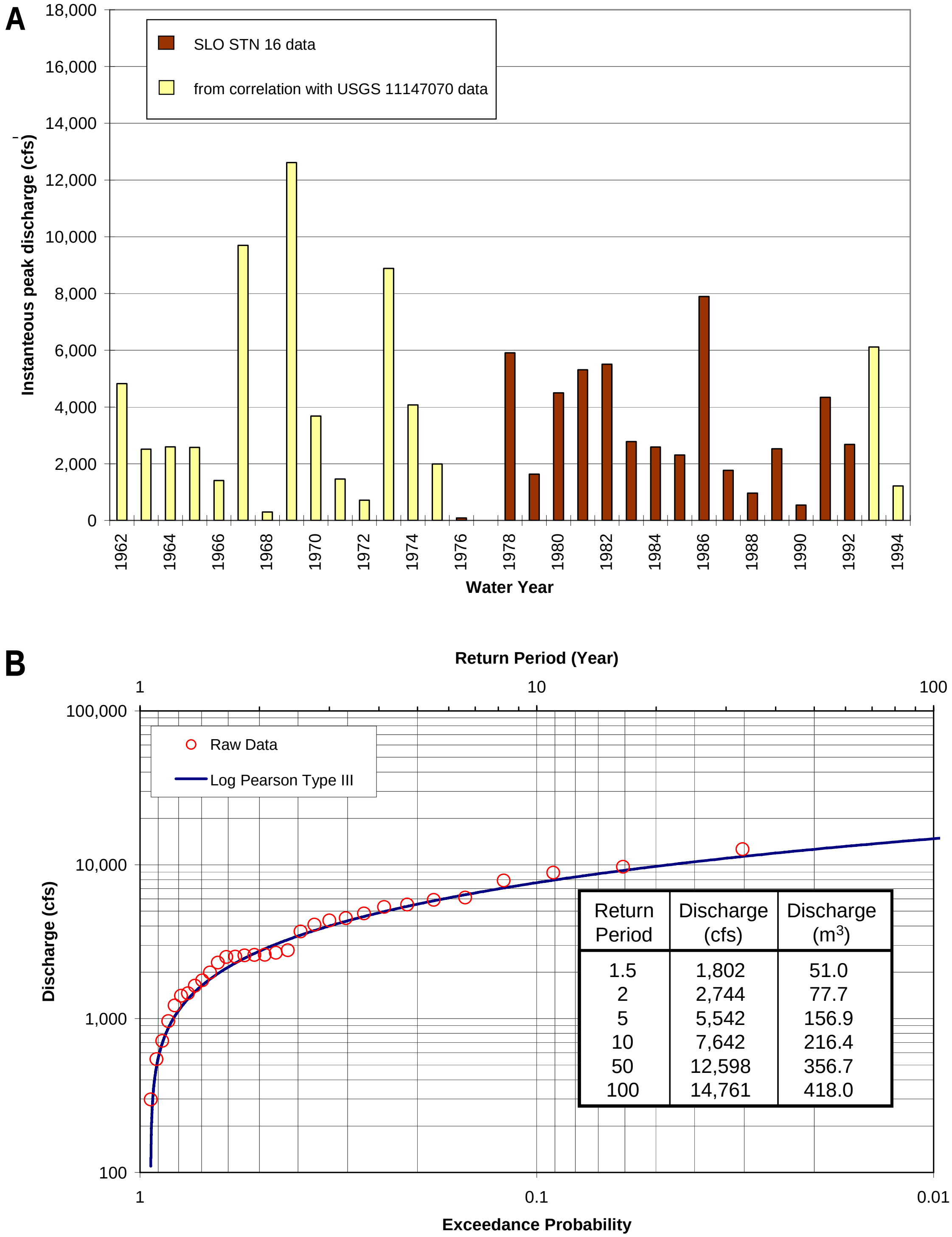
Flood flows within the Santa Rosa Creek watershed are "flashy", meaning that there is a rapid increase in discharge over a short time period with a quickly developed peak discharge in relation to normal baseflow (Ward 1978). Flashiness represents the combined expression of both natural features (e.g., local storm intensity, topographic relief, geology, and soil development) and factors related to human activities (e.g., watershed land use, vegetation cover, extent of impervious surfaces). A measurement of "flashiness" is the ratio of the annual maximum instantaneous discharge to the associated daily mean discharge for that day. For those periods with adequate flow data, this ratio averaged 4.8 (range = 2.6 to 11.1) within the upper watershed (WY 1958–1972), and averaged 7.2 (range = 2.1 to 32.0) within the lower watershed (WY 1976–1992). For comparison, the unregulated and relatively undeveloped Big Sur River watershed (Monterey County, CA) to the north has an average "flashiness" ratio of 2.4 near the mouth (USGS gauge 11143000).

The three largest *recorded* floods in the watershed (i.e., using the SLO County Station data) occurred in WY 1978 (167 $m^3 s^{-1}$ [5,910 cfs]), WY 1982 (156 m^3s^{-1} [5,510 cfs]), and WY 1986 (224 $m^3 s^{-1}$ [7,890 cfs]). With the inclusion of extrapolated data to cover the full flow record from WY 1962 to WY 1994 (Figure 4-1A, Figure 4-2A), the four largest floods during this period may have actually occurred in WY 1969 (by correlation, and also recorded as the highest event in the upper USGS gauge), WY 1967 (by correlation), 1973 (correlation, and also the second highest flow at the upper gauge), and 1986 (recorded), respectively. The floods in WY 1969, 1973, and 1978 are correlated with the El Niño–Southern Oscillation (ENSO) climatic phenomenon (see section 1.2.3). ENSO years in Southern California are generally characterized by relatively high rainfall intensities, with rivers and streams exhibiting higher annual peak flow magnitudes than they do in non-ENSO years (Cayan et al. 1999, Andrews et al. 2004). Andrews et al. (2004) describe the statistically positive occurrence of high floods with ENSO years using data from 20 rivers south of 35ºN. Santa Rosa Creek occurs just to the north of the sample set of rivers used to prove this relationship (the latitude of Cambria is 35ºN) so the ENSO influence exists but is statistically less certain than for rivers to its south. As evidence, in the upper watershed, the annual maximum flow record from WY 1958 to 1994 indicates that there is a 4% chance that flow will exceed the 10-year recurrence interval flow event (Q_{10}: ~70 $m^3 s^{-1}$; 2,500 cfs) during non-ENSO years but a four times greater likelihood (16%) during ENSO years (Figure 4-5a). In the lower watershed, the annual maximum flow record from WY 1962 to 1994 indicates that there is a 10% chance that flow will exceed the Q_{10} (~216 $m^3 s^{-1}$; 7,600 cfs) during non-ENSO years but double that during ENSO years (Figure 4-5b). Overall, there is reason to believe that flood events are likely to be greater during the El Niño years in the watershed, so correlating fluvial process activity (and the potential implications for management) with the ENSO cycle.



Return Period	Discharge (cfs)	Discharge (m^3)
1.5	755	21.4
2	1,074	30.4
5	1,921	54.4
10	2,493	70.6
50	3,706	104.9
100	4,191	118.7

Figure 4-1. Annual maximum discharge and flood frequency for Santa Rosa Creek at Cambria (USGS gauge 11142200). Discharge values reported in the units in which they were measured.



Return Period	Discharge (cfs)	Discharge (m^3)
1.5	1,802	51.0
2	2,744	77.7
5	5,542	156.9
10	7,642	216.4
50	12,598	356.7
100	14,761	418.0

Figure 4-2. Annual maximum discharge and flood frequency curve for Santa Rosa Creek at Highway 1 bridge (SLO County Station 16). Discharge values reported in the units in which they were measured.

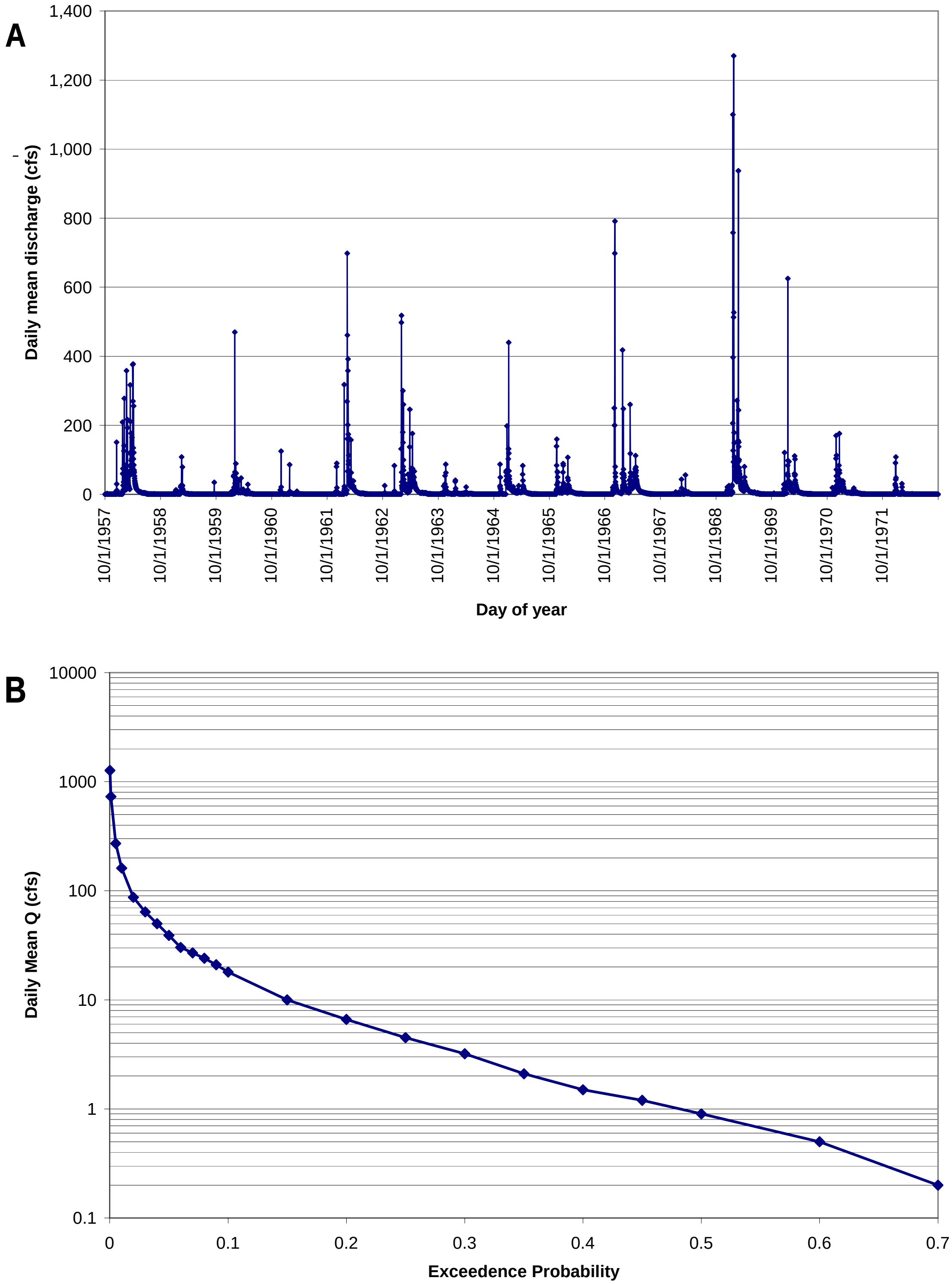


Figure 4-3. Daily mean discharge and flow duration curve for Santa Rosa Creek at Cambria, CA (USGS gauge 11142200).

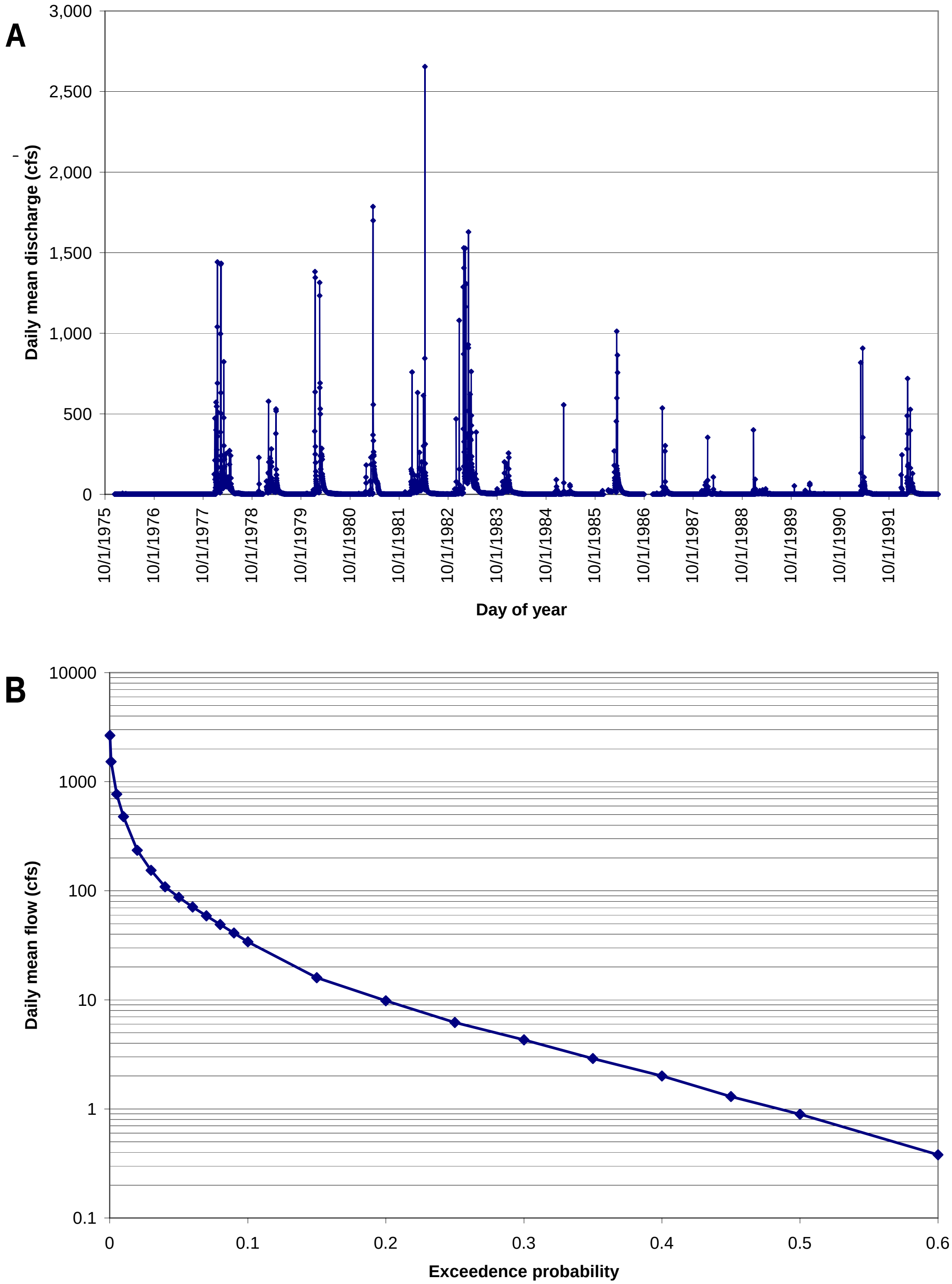


Figure 4-4. Daily mean discharge and flow duration curve for Santa Rosa Creek at Highway 1 bridge (SLO County Station 16).

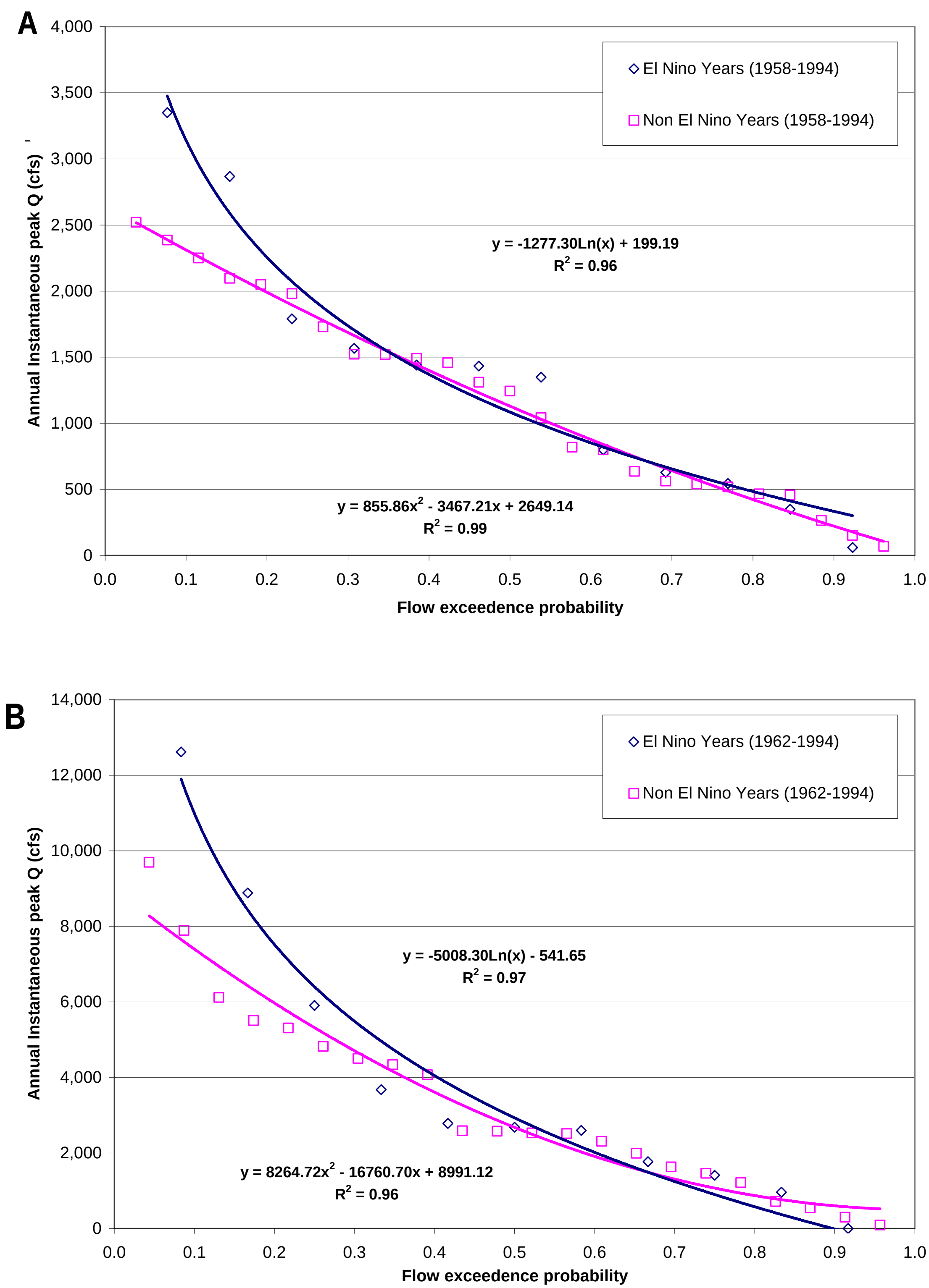


Figure 4-5. Flow exceedance in El Niño/non-El Niño years at (a) Santa Rosa Creek at Cambria (USGS gauge 11142200: WY 1958–1994) and (b) Santa Rosa Creek at Highway 1 bridge (SLO County Station 16: WY 1962–1994).

4.3 Creek Morphology and Sediment Character

Understanding the character of the creek morphology and its sediment is a fundamental component in understanding how fluvial processes will affect the creek, the likely extent and availability of aquatic habitat for native fish, the extent of human impacts on the creek, and should be used to condition appropriate management actions into the future (e.g., Downs and Gregory 2004). Below, we summarize conditions in mainstem Santa Rosa Creek, and in the Perry Creek subwatershed, based on available data and field reconnaissance of Santa Rosa Creek conducted during summer 2009. Time and access constraints prevented a comprehensive survey of Perry and Green Valley creeks and so our results focus on the Santa Rosa Creek mainstem, as the primary fish-bearing creek in the watershed. The field investigation entailed traversing the channel, interpreting channel conditions, assessing bed sediment facies (i.e., areas of similar sediment sizes), taking field measurements at representative channel locations within each reach, and using the field evidence to evaluate the relative input of fine and coarse sediment from tributaries. Measurements included median bed surface particle size counts (Wolman pebble-count method [1954]) at select locations and estimates of bankfull channel dimensions, channel gradient, bank and channel substrate, and channel erosion dynamics. Particle-size distribution data were used to corroborate sediment facies delineation. The channel erosion assessment included estimates of both bank and bed erosion, where the extent of recent bank erosion was determined by considering bank retreat relative to estimated tree age for exposed roots on the adjacent floodplain, and the amount of recent bed erosion, or channel incision, was estimated relative to the age of bank and in-channel vegetation. A full description of the geomorphic character of various reaches of Santa Rosa Creek is provided in Appendix C, with a summary provided below.

4.3.1 Santa Rosa Creek

Mainstem Santa Rosa Creek flows for approximately 25.4 km (15.8 mi) from its headwaters in the Santa Lucia Range, through the town of Cambria, to the creek mouth at the Pacific Ocean. The upper reaches are characteristic of a mountain river, with a steep gradient channel and strong bedrock control on channel form; while the middle and lower reaches display the features of a classic alluvial channel, with a lower gradient channel that meanders through deposited alluvium. The watershed is asymmetrical, with all of its major tributaries draining from the north into the creek and the valley floor set to the southern boundary of the watershed. Throughout the mainstem channel, morphology and geomorphic character are strongly impacted by the degree of channel confinement—that is, the ratio of channel width to the overall valley floor width (Montgomery and Buffington 1997). The mainstem channel transitions from a moderate to highly confined channel in the watershed upstream of Mammoth Rock to a low to moderately confined channel in the middle reaches (Mammoth Rock to the Perry Creek confluence) to a moderately confined channel in the lower watershed from the Perry Creek confluence to the river mouth (Figure 4-6). In long profile, the channel is gently concave on average, with local gradients ranging from approximately 0.0320 (3.2%) near the creek's headwaters to 0.0030 (0.3%) near the river mouth (Figure 4-6). The average gradient is approximately 0.0090 (0.9%). The creek transports a mixed sediment load ranging in size from silt/fine sand to boulders, with the dominant sediment bed particle size ranging from very coarse cobble in the upper reaches to fine gravel in the lower reaches. Bed texture and sediment transport dynamics within the mainstem Santa Rosa Creek are strongly influenced by the size and amount of sediment delivered from several tributaries, including Lehman, Curti, and Perry creeks. Processes in the creek vary according to a combination of local and regional factors. Locally, hydraulic controls exert influence on the dynamics of erosion and deposition according to features such as bedrock exposures, the presence of large woody debris (LWD) and in-channel infrastructure. Regionally, processes are influenced by factors such as the degree to which the valley is confined by bedrock control and the extent to which the channel is incised into its alluvial floodplain.

Based on the field data, the Santa Rosa Creek mainstem was delineated into nine reaches that are relatively homogenous with regard to their morphology and dominant geomorphic processes (Figure 4-6). Delineation provides an effect means of collapsing the complexity of real world differences in reach character into a manageable set of discrete occurrences. The reaches range from 1.8–3.3 km in centerline length and were divided where there was evidence for a distinct break in reach character. Delimiting criteria include tributary junctions where the tributary provides considerable flow and sediment input, abrupt changes in channel gradient, changes in the degree of valley confinement or channel incision, and influence of human influences such as roads that impinge on the active channel meander zone or part channel management activities. Key geomorphic attributes of the reaches determined from the field effort are summarized in Table 4-2.

Table 4-2. Mainstem Santa Rosa Creek reach attributes.

Zone	Reach	Channel length (km) [A]	Degree of confinement [B]	Channel gradient [C]	Bankfull width estimate (m)	Bankfull depth estimate (m)	Dominant sediment facies [D]
Upper	U1	2.5	High	2.29%	8–10	0.75–1.0	BGC
	U2	2.1	High	1.17%	12–14	0.75–1.0	CG
	U3	3.3	Moderate	1.16%	11–15	1.0–1.25	CG
	U4	1.8	Moderate	1.20%	11–12	1.0–1.25	CG
Middle	M1	2.0	Low	0.80%	Unknown [E]	Unknown [E]	CG [F]
	M2	2.4	Moderate	0.62%	12–14	0.75–1.0	CG
	M3	2.4	Moderate	0.75%	9–11	1–1.25	CG
Lower	L1	2.9	Moderate	0.33%	12–19	1.0–1.25	CG SG
	L2	2.1	Moderate	0.29%	20–22	1.25–1.5	SG

[A] Channel length measured from the centerline derived from the USGS 10-m DEM of the watershed.
[B] Confinement estimated from a combination of field observations and the USGS 10-m DEM of the watershed.
[C] Channel gradient derived from the USGS 10-m DEM-derived channel centerline.
[D] Facies designation from the approach developed by Buffington and Montgomery (1999). The dominant sediment size is listed last and the subdominant sediment sizes are listed first. BGC = boulder-cobble-gravel (gravel constitutes >50% of the sediment and boulder and cobble each constitute ≥5%), CG = cobble-gravel (gravel constitutes >50% of the sediment and cobble constitutes ≥10%).
[E] Measurements not taken due to restricted channel access.
[F] Estimated from Santa Rosa Creek Road.

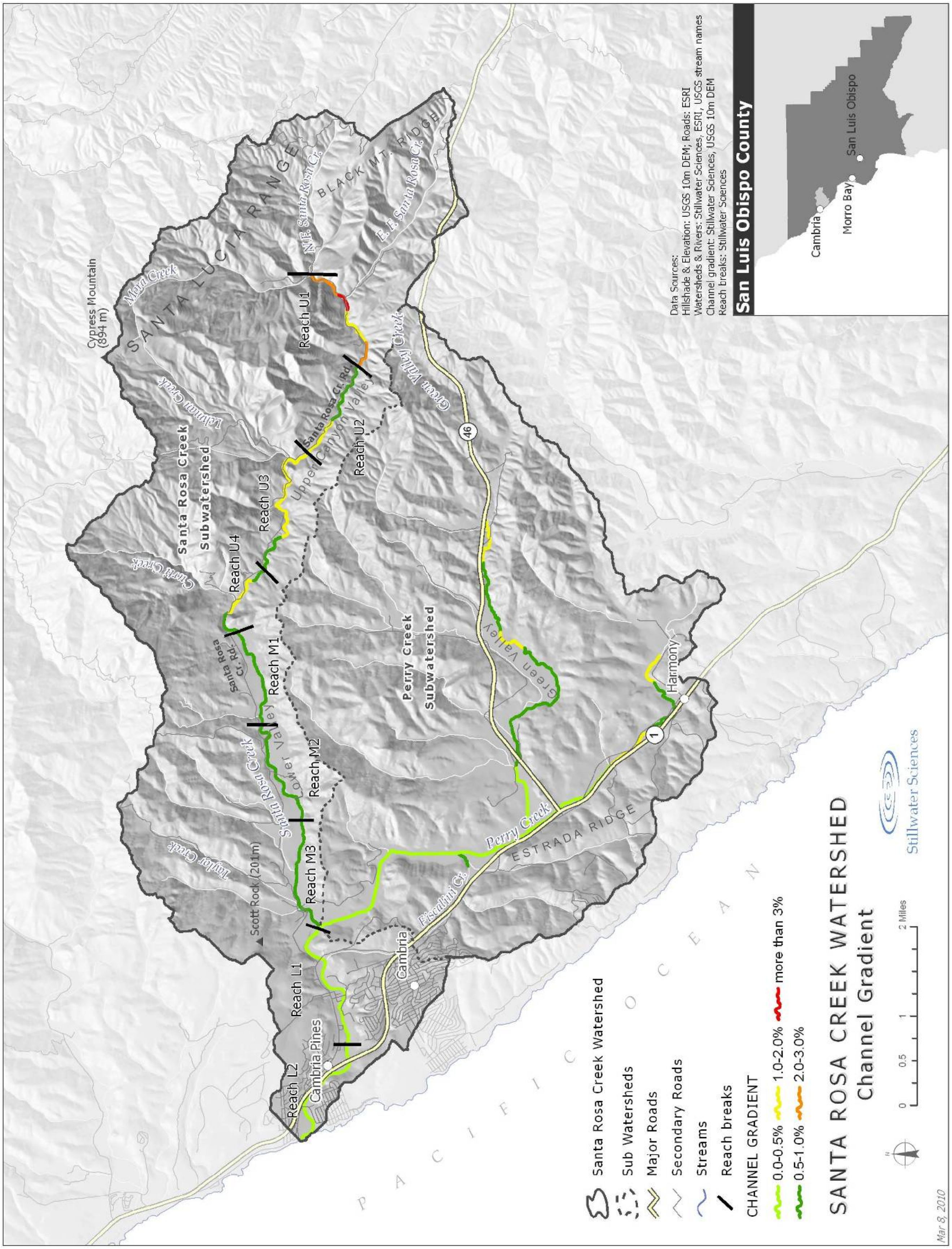


Figure 4-6. Channel gradients of Santa Rosa, Perry, and Green Valley creeks. Study reaches of Santa Rosa Creek are also shown.

Within the upper reaches, the channel transitions from a plane-bed morphology in the steeper, more confined reach U1 to a pool-riffle morphology in the lower gradient, less confined reaches U2—U4 (Figure 4-7a). Bedrock exerts a strong control on channel morphology throughout all reaches within this zone. The channel bed within these upper reaches is interpreted as being from quasi-stable to somewhat subject to deposition, due to a combination of bedrock control on depositional dynamics and relatively high tributary sediment inputs, particularly from Lehman Creek (entering U3) and Curti Creek (U4). The middle reaches transition from a highly incised reach with active bank erosion and high sediment input (M1) to a moderately incised and apparently less dynamic reach M3) as the degree of channel confinement increases and bedrock control once again becomes an influence near the confluence with Perry Creek (Figure 4-7b). The channel bed possesses a pool-riffle morphology and has several reaches showing evidence of sediment stored following recent flood events. In the lower reaches, both channel gradient and the degree of incision decrease and the channel becomes part of a more depositional zone with a channel gradient ultimately controlled by mean tidal elevation in the lower parts of reach L2. Sediment delivered to the lower subreaches from upstream Santa Rosa Creek, the Perry Creek subwatershed, and from local tributaries has resulted in a large amount of stored sediment in the reach which reduces the occurrence of channel bedforms (Figure 4-7c). Banks are relatively stable, not least where extensive riprap protection exists in reach L1. A recent channel erosion inventory conducted by the CDFG (Nelson et al. 2009) shows that bank erosion is most prevalent in the lower gradient (i.e., local channel slope ≤1%) upper and middle reaches (Figure 4-8).

Bed sediments along the mainstem Santa Rosa Creek ranges from boulder-cobble-gravel (BGC) with a median particle size (D_{50}) of 64–128 mm in the upper reaches to sand-gravel (SG: D_{50} of 4–8 mm) in the lower reaches. The bed is predominantly composed of cobble-gravel (CG: D_{50} of 16–32 mm) in the Middle reaches (Table 4-2; Figure 4-9). From our limited sampling, the measured median grain size, D_{50}, in mm, decreases downstream in almost direct proportionality with the drainage area, Ad, as $D_{50} = 1510\ Ad^{-1.0}$ ($r^2 = 0.69$). The size difference between channel bed and adjacent bar sediment as well as the degree of sediment sorting (or, range of sediment sizes) varies considerably along the length of the mainstem channel due in part to local hydraulic controls on sediment transport and deposition dynamics and the size of sediment derived from local and upstream sediment sources. Coarse sediment (gravel and larger) delivered to the mainstem Santa Rosa Creek appears to be delivered primarily from Lehman and Curti creeks in the upper reaches, and from the tributary that runs adjacent to Main Street (Unnamed Tributary SRC-6) in the lower reach (see Figure C-1 in Appendix C – Channel Reach Descriptions). Fine sediment (sand and silt) appears to be predominantly derived from both tributary sources such as Curti Creek that delivers sediment to the upper reach and Perry Creek that delivers sediment to the lower reach, and local in-channel sources such as bank erosion of the high bluffs at the upstream end of the middle reaches.

Figure 4-7a. Views of reaches U1, U2, U3, and U4 along upper Santa Rosa Creek.

Figure 4-7b. Views of reaches M1, M2, and M3 along middle Santa Rosa Creek.

Figure 4-7c. Views of reaches L1 and L2 along lower Santa Rosa Creek.

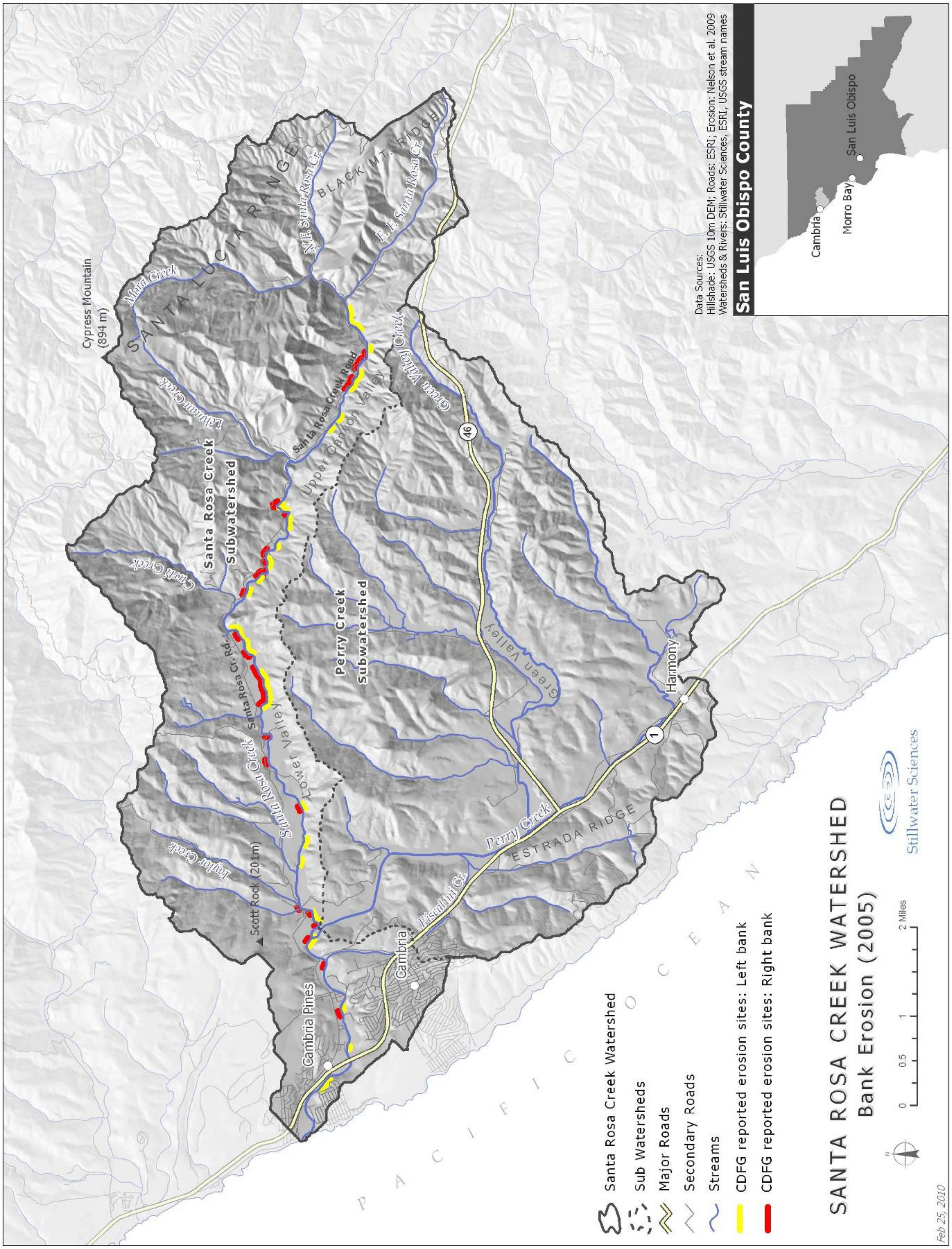


Figure 4-8. Bank erosion along Santa Rosa Creek observed by CDFG in 2005 (after Nelson et al. 2009).

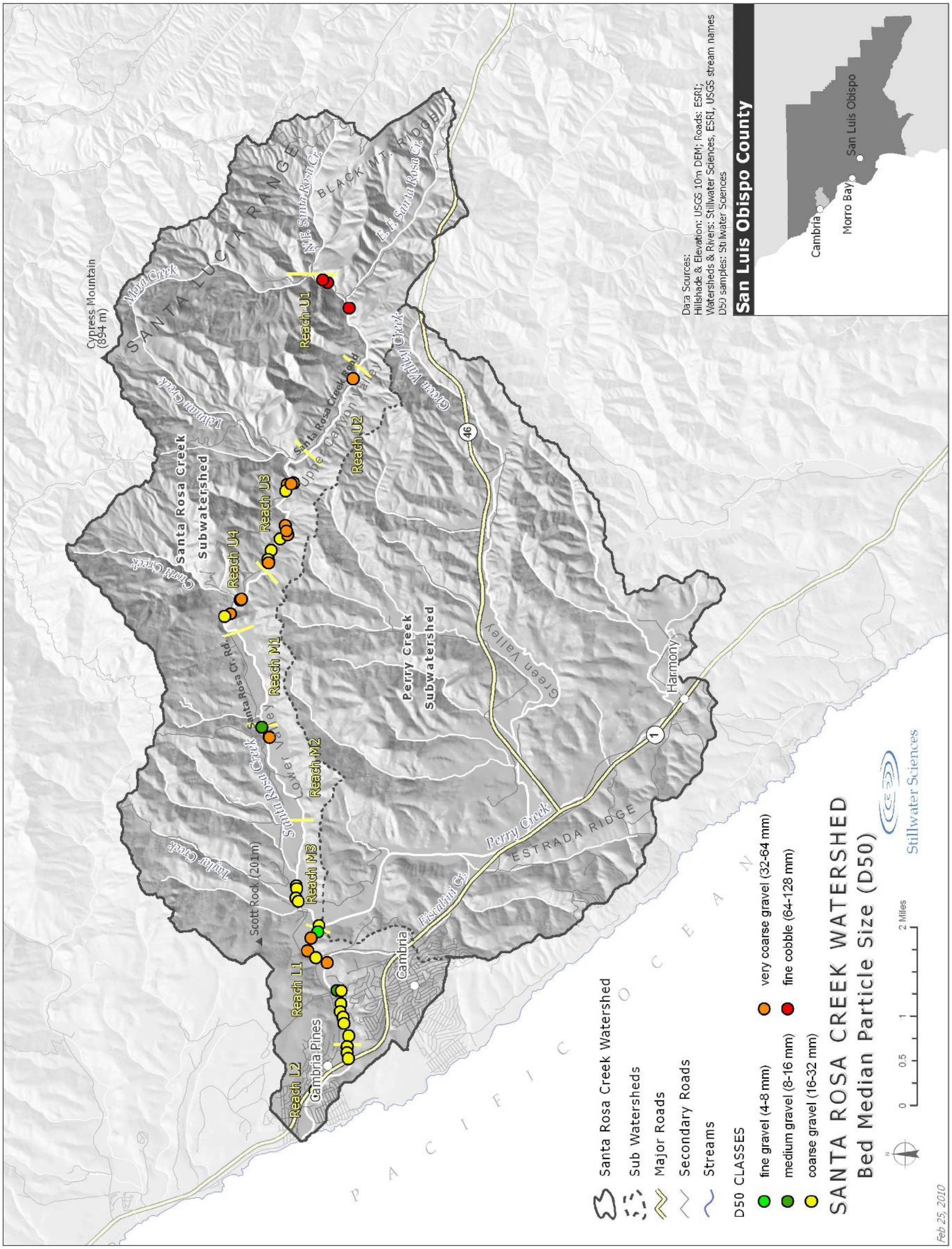


Figure 4-9. Median bed particle size (D_{50}) along the mainstem Santa Rosa Creek.

4.3.2 Perry Creek

Perry Creek enters mainstem Santa Rosa Creek approximately 3 km (1.8 mi) upstream of the Highway 1 bridge and is the largest tributary comprising almost 50% of the overall Santa Rosa Creek watershed (drainage area = 59.3 km^2; 22.9 sq. mi). Perry Creek is characterized by a moderately confined channel with finer bed sediment that flows approximately 16 km (10 mi) from the town of Harmony downstream to the confluence with Santa Rosa Creek. The channel transitions from an actively meandering planform in the upper reaches to a straight-cut planform that extends for the majority of the channel length downstream from Harmony. Channel straightening occurred in two phases, first, related to the draining of Estrada Lagoon in the 1870s to form Lower Perry Creek and then further modifications during the improvements of Highway 1. The degree of channel incision increases downstream, reaching a maximum of approximately 8–10 m (26–33 ft) at the Santa Rosa Creek confluence: incision reduces upstream from the confluence until it reaches an abrupt knickpoint (i.e., distinct break in the channel gradient) approximately 0.6 km (0.4 mi) upstream. Perry Creek has a consistently low gradient along the entire length (average gradient is less than 0.005 [0.5%] (Figure 4-6). The creek transports a mixed sediment load skewed toward finer sediment that includes silt/fine sand to fine cobbles, with the dominant sediment bed particle size ranging from coarse gravel in the upper reaches to fine gravel in the lower reaches.

The major tributary of the Perry Creek subwatershed is Green Valley Creek, which enters Perry Creek approximately 5 km upstream from Santa Rosa Creek confluence. Green Valley Creek originates in the steep, south-facing hillslopes along Highway 46, flows west through a confined alluvial valley, and enters Perry Creek in a broad alluvial zone near to Highway 1. Like the Santa Rosa Creek subwatershed, the Green Valley Creek subwatershed is also highly asymmetrical with long, steep tributaries draining from the northern edge of the watershed south into the west flowing Green Valley Creek. From limited field observation and available data, the upper reaches of mainstem Green Valley Creek appear somewhat similar to the upper reaches of Santa Rosa Creek in terms of valley confinement, but unlike Santa Rosa Creek, Green Valley develops a very wide alluvial valley through its middle and lower reaches. The sediment load includes silt/fine sand to boulders, with the dominant sediment bed particle size ranging from medium gravel in the upper and lower reaches to very coarse gravel in the middle reaches. The middle reaches are highly incised and actively eroding their banks with the amount of incision decreasing as the creek approaches the Perry Creek confluence. The middle and lower reaches are primarily low gradient, with an average channel gradient less than 0.01 [1%] (Figure 4-6).

4.4 Dynamics of Channel Morphology and Sediment Transport

This section extends the section above to describe the morphological dynamics of the creek network using historical data, measures of the potential for sediment transport, and our understanding of the history of direct and indirect human impacts on the creek to determine how and potentially why the creek has changed in the recent past. Understanding historic changes in channel morphology can be important in determining the expected future conditions as the channel morphology evolves. Determining which reaches have been relatively static and which are highly changeable is useful information, especially if the changes can be linked to watershed perturbations such as major storm events, changes in sediment and/or water inputs, or management modifications of the channel. Such information is a critical component in developing a watershed management plan that accounts for both natural geomorphic variability and the short- and long-term impacts of restoration actions.

4.4.1 Recorded changes in channel planform, 1937-2007

Various channel morphologic characteristics, including channel centerline location, channel sinuosity, and channel width were compared over the past 70 years (the limit of available historic sources). Data sources included orthorectified topographic maps from 1937, 1948, and 1959, and aerial photography from 2007. Examination of changes in channel-bed elevation along mainstem Santa Rosa Creek, however, was precluded by lack of available data. The following sections discuss the differences in channel morphology and associated drivers for geomorphic change, or lack of change, over the last several decades.

Comparing the 1937 to 2007 channel centerline reveals a relatively modest degree of channel planform change over the past 70 years within the upper (U1–U4) and lower reaches (L1–L2) of Santa Rosa Creek (Figure 4-10). Conversely, the middle reaches (M1–M3) experienced considerable planform change and channel adjustment, expressed by significant increases in channel sinuosity (Table 4-3). These recorded changes in the middle reaches took place largely during a reasonably static period in land use history (see Section 2), but during a period that encompasses large flood flows resulting from the relatively intense ENSO period since 1969 (see Section 4.1).

Table 4-3. Channel sinuosity change by reach (1937–2007).

Zone	Reach	% change in channel sinuosity (1937–2007)
Upper	U1	+1.2%
	U2	+2.1%
	U3	+2.2%
	U4	+0.5%
Middle	M1	+8.6%
	M2	+17.9%
	M3	+8.3%
Lower	L1	-0.3%
	L2	+4.2%

Within the Upper reaches, the relative lack of change in observed centerline location, sinuosity, and channel width from 1937 to 2007 is likely due to the relatively high degree of channel confinement caused by extensive bedrock controls that limit channel migration (Table 4-3; Figure 4-10a, b). A small amount of sinuosity increase did occur in the mid-upper reaches (U2 and U3) and is interpreted to reflect the somewhat lower degree of channel confinement in these reaches. Reach U4 had the lowest overall amount of change in channel planform, but significant channel change did occur in several locations including downstream near Mammoth Rock where a channel meander migrated downstream over 50 m (165 ft) over the 70 years.

In the middle reaches downstream of Mammoth Rock to the Perry Creek confluence, valley confinement gives way to a broad alluvial valley setting in which the channel has been very active over the past 70-years (Table 4-3; Figure 4-10b, c). The channel centerline position shifted up to 50 m towards the opposite bank in several locations and channel width increased by over 50 m at the meander just downstream of Mammoth Rock. The active meandering has resulted in a considerable increase in channel sinuosity throughout the Middle reaches (Table 4-3) but especially in reach M2 where the sinuosity increased by 18%. Increased sinuosity reflects a lengthening of the channel and a decrease in channel slope suggesting the channel is trying to "recover" from a severe disturbance (e.g., Schumm et al., 1984; Simon 1989; Hupp and Simon 1991). This interpretation is given extra credence because of the incision of the middle reaches from the original floodplain surface, which is now commonly over 6.1 m (20 ft) above the channel bed. The most likely explanation is that increases in flow resulting from land clearance in the Nineteenth century caused the significant incision and the channel is now attempting to gain a new energetic "equilibrium" with its surroundings by developing a new inset floodplain and a more gentle channel gradient. A conceptual model of this channel evolution process, as developed by Hupp and Simon (1991), is shown in Figure 4-11 to help illustrate the likely evolution and trajectory of Santa Rosa Creek.

In the lower reaches downstream of the Perry Creek confluence, the channel is subject to increased confinement again as a combination of valley topography and, more recently, utilization of floodplain for the urban growth of Cambria, enlargement of Highway 1, and related bank protection efforts. Therefore, a narrower meander zone exists with less opportunity for centerline movement than in the middle reaches, but there are local areas of channel widening, centerline migration, and increased sinuosity towards the downstream end (Table 4-3; Figure 4-10c). For instance, within a relatively unconfined area just downstream of the Highway 1 bridge (which was not present in 1937), the channel widened by approximately 20 m and the centerline location shifted approximately 50 m towards the opposite bank. This channel widening may be associated with a depositional zone caused by flow expansion downstream of the bridge during large flood events.

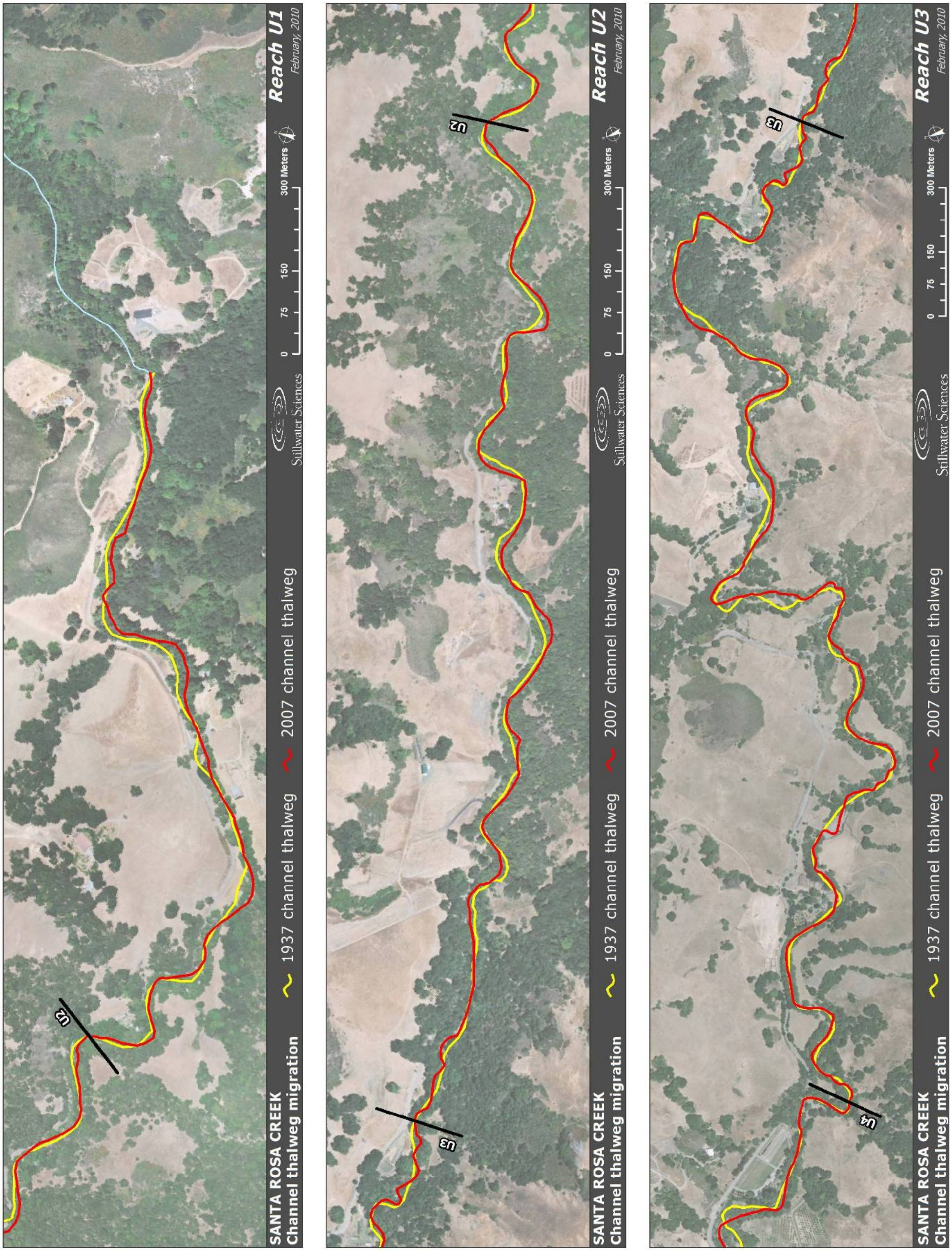


Figure 4-10a. Santa Rosa Creek centerline migration 1937–2007—Reaches U1, U2, and U3.

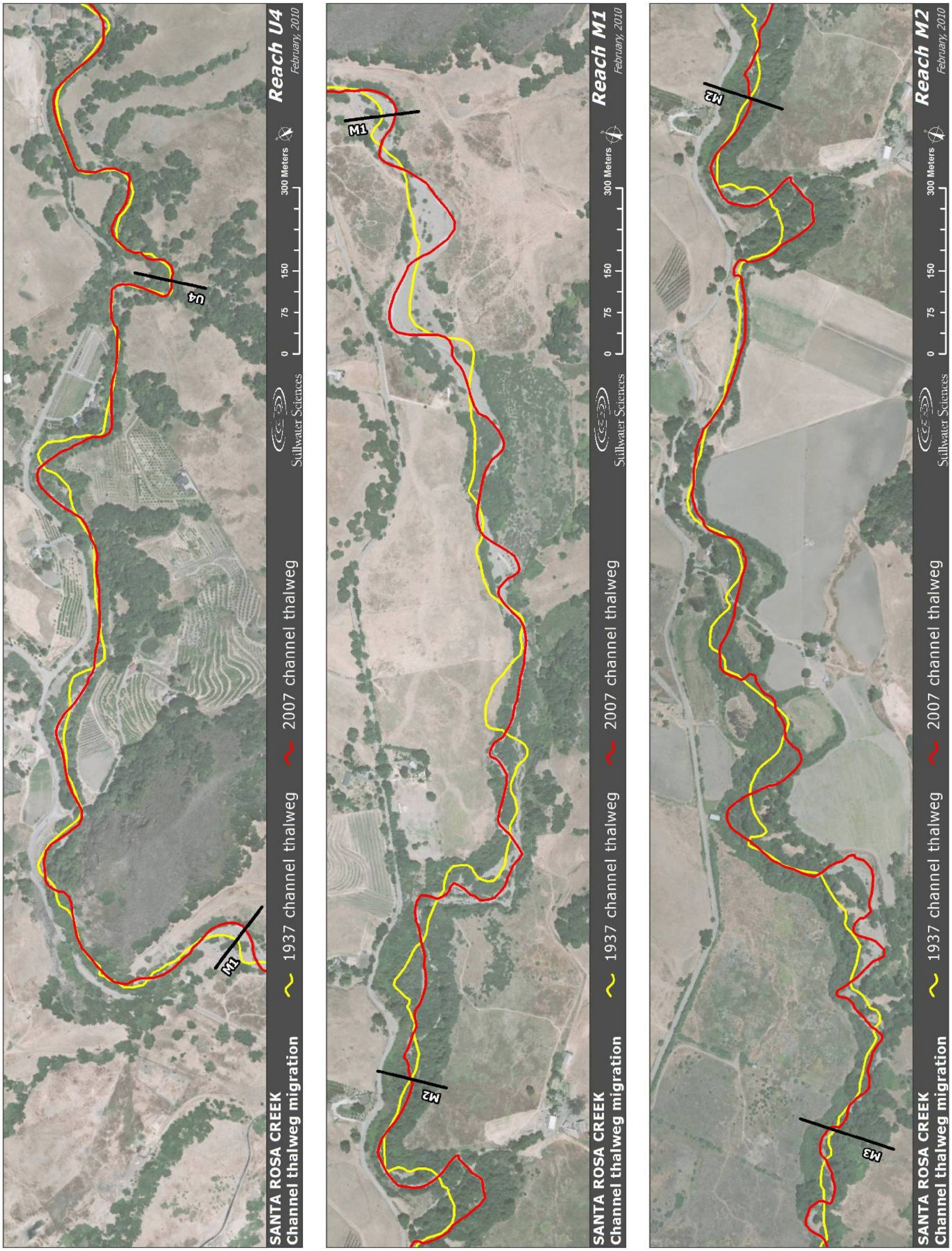


Figure 4-10b. Santa Rosa Creek centerline migration 1937–2007—Reaches U4, M1, and M2.

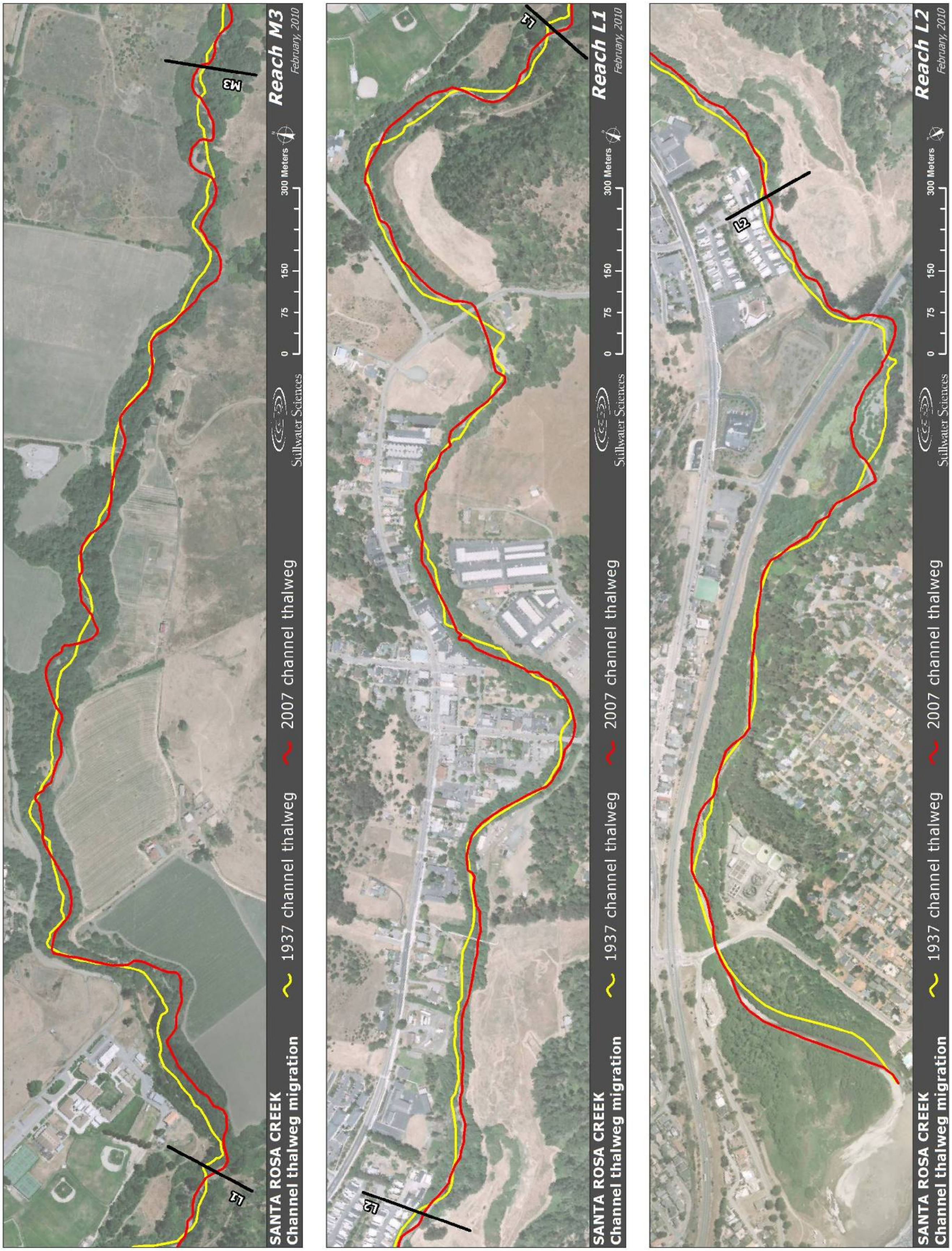


Figure 4-10c. Santa Rosa Creek centerline migration 1937–2007—Reaches M3, L1, and L2.

Stage 1:
Undisturbed

Stage 2:
Channel disturbance
(channelization, riprap, changes to runoff patterns in drainage network)

Stage 3:
Degradation
(channel bed incision)

Stage 4:
Degradation and widening

Stage 5:
Aggradation and widening

Stage 6:
Quasi-equilibrium
(channel re-adjustment)

Stage 7:
Late stage/evolution

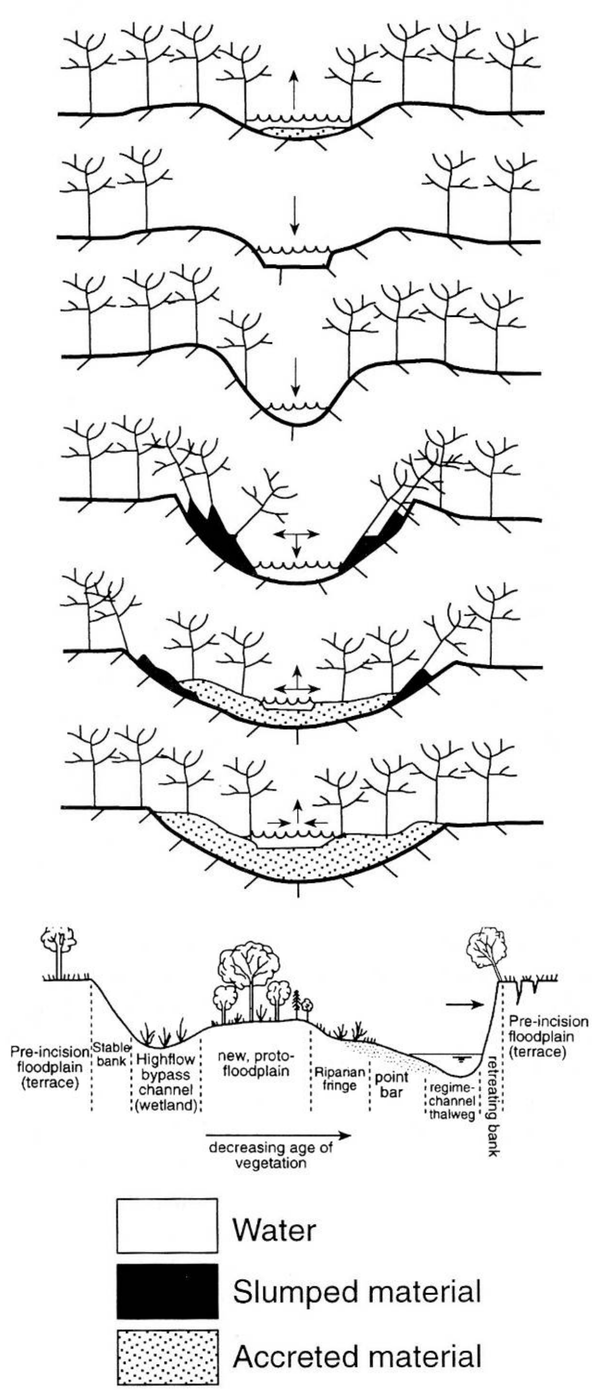


Figure 4-11. Conceptual model of channel evolution following watershed disturbances, such as channelization or incision. Arrows indicate the direction of degradation or aggradation (reprinted from Simon and Hupp [1986] and Hupp and Simon [1991], Copyright ©1991, Elsevier Science).

4.4.2 Potential for future change and sediment transport

Analysis of changes in channel morphology, as permitted by available data, indicated a combination of local changes in individual bends of the river in combination with more extensive alternations in the middle reaches of the river over the past 70 years. However, it is also apparent from reconnaissance surveys that large sections of the creek are significantly incised in character, indicative of a response to a strong perturbation in watershed conditions. Like many other creeks, there is insufficient channel bed survey data available to understand quite how bed elevations have changed over time, preventing a simple extrapolation of how the channel may change in the future. As a surrogate, several indices reflecting the channel's *potential* for change were estimated from collected field data, and compared against expected or threshold values as the basis for inferring the potential for change.

One index for reach-level potential for morphological change is unit stream power. Unit stream power is the energy available per unit area of river bed to overcome friction and transport sediment. It can be used as a surrogate for potential sediment transport (e.g., Bagnold 1966), but is more generally used to indicate the potential energy available to "do work" generally in the channel (Bull 1979), with higher stream power indicative of channels more likely to change their form (Richards 1982, Graf 1983). Stream power is usually reported per unit area of the channel bed ("specific stream power", Wm^{-2}, commonly given the symbol ω) and is proportional to the channel gradient and the discharge per unit of channel width (e.g., cubic meters per second per meter of channel width). Because normalization of discharge by channel width reduces the significance of downstream increases in discharge, the unit stream power in steep watersheds varies largely with channel gradient and this is witnessed in Santa Rosa Creek where our estimated relationship with drainage area (*Ad*) is:

$$\omega = 3128.7 \, Ad^{-0.7026} \qquad (r^2 = 0.70)$$

Consequently, results range from approximately 500 Wm^{-2} upstream to 135 Wm^{-2} downstream (Figure 4-12). The highest stream power occurs in the upper reaches (200–500 Wm^{-2}) with similar ranges in the middle and lower reaches (135–300 Wm^{-2}). The results are indicative both of a significant reduction in the downstream ability to do work, which is consistent with the notion of creeks eroding material in their upper reaches and then depositing some of it in their lower reaches, but also of a highly dynamic channel overall. In comparison with a study made for various channel settings in Australia (Nanson and Croke 1992), the results represent a high (>300 Wm^{-2}) or medium-high (50–300 Wm^{-2}) energy floodplain setting. In lowland settings, a value of 35 Wm^{-2} has been used to indicate "active" channel environments (Brookes 1990) whereas low energy channels general subject to deposition are general represented by values of unit stream power below about 10–15 Wm^{-2} (Brookes 1990; Nanson and Croke 1992). Clearly, in comparison, Santa Rosa Creek is a highly dynamic stream channel.

Related more directly to the ability to transport sediment, we also calculated the shear stress of flows at bankfull discharge relative to the shear stress required to move the median-sized bed particles at this flow. By definition, "bankfull discharge" refers to the discharge required to fill a stream channel in equilibrium with the surrounding landscape to the point at which flow starts to overtop the banks; statistically, this flow event has a return period of 1.5-2 years (Williams 1978). In incised channels, such as the lower parts of Santa Rosa Creek, it takes a much larger discharge (i.e., far in excess of 1.5-2 year return period) to overtop the banks but the 1.5-2 year return period discharge is still called the bankfull discharge to allow comparibility between streams. Shear stress (Nm^{-2}) is a measure of the force acting parallel to the bed of the creek; that is, the force generated by moving water that is available to overcome forces of friction and gravity that keep bed material particles in place on the bed of the creek. The critical shear stress is the exact measure of shear stress needed to cause the median particle size to become mobile. If the ratio of shear stress at bankfull flow to critical shear stress exceeds unity, then bed particles are likely to be in transport at bankfull and higher flows.

Based on our available data, the shear stress ratio at nine sites varied between 3 and 16, indicating that the bed of Santa Rosa Creek is highly mobile even in flood events that occur with a recurrence interval of two or less years (Figure 4-12). While the sample set is relatively small, it is notable that the range in shear stress ratios increased downstream (upper reaches: 3.2 – 4.8; middle reaches: 3.5 – 7.5; upper reaches: 3.8 – 16.3) perhaps indicating the progressive input of excess fine sediment into the fluvial system. Certainly the highest ratio (16.3) occurs in finer-grained material just downstream of the Perry Creek confluence which is suspected of supplying high volumes of fine sediment. Overall, we can conclude, therefore, that during large flood events, such as those that frequently occur during ENSO years, Santa Rosa Creek is probably capable of transporting large volumes of sediment along its bed (coarse sands, gravel, and cobbles) and in suspension in the water column (silts, clays, and fine sand). The shear stress values are sufficient also to erode the bed and banks in those reaches of the creek not controlled by bedrock or bank revetments.

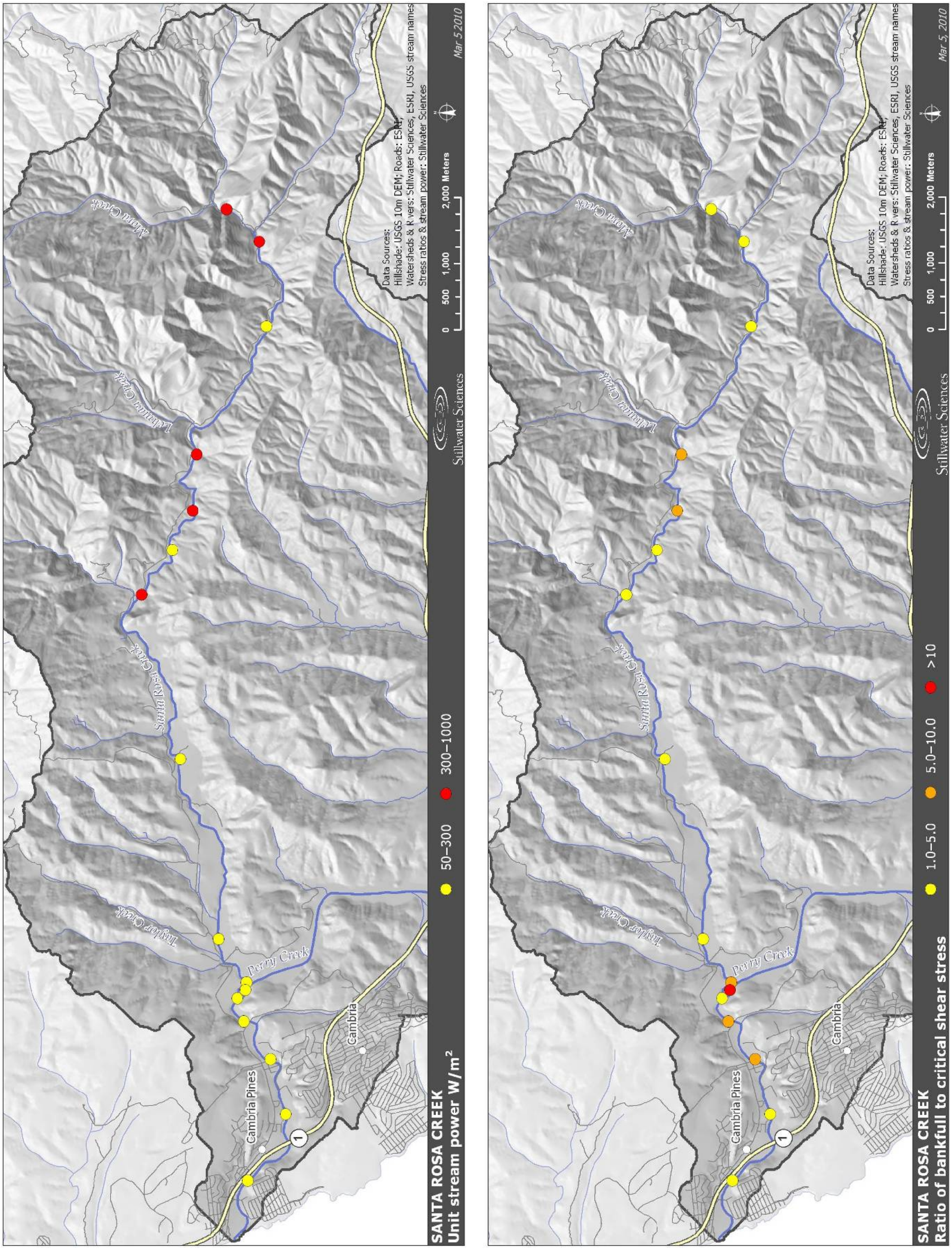


Figure 4-12. Calculated unit stream power and the ratio of bankfull to critical shear stress in Santa Rosa Creek.

4.4.3 Inference of human impacts

Like all watersheds, stream channel morphology and process in Santa Rosa Creek and its tributaries is influenced by a combination of natural and human factors. The human factors, especially land cover changes and near- and in-channel infrastructure, frequently create the challenges facing contemporary river channel management. Further, because geomorphological systems change over multi-decadal timeframes, creek morphology and process can still be influenced by factors that occurred many decades or centuries before, meaning that historical changes in land cover can still present issues for modern-day management.

4.4.3.1 Land cover change

From the chronology of watershed changes described in Section 2.1, and summarized in Figure 2-1, there are two time periods in recent history that likely had the greatest effect on watershed geomorphic processes.

The first was during the Nineteenth century, when Euro-American settlers moved to the watershed and progressively replaced native trees, shrubs, and grasses with non-native species less suited for preventing erosion. This period probably reached its peak during the period 1860 – 1880 as the watershed became more densely settled and developed with more intensive agricultural practices, accelerated logging rates, mercury mining, and associated expansion of road and urban infrastructure. It is apparent from historical sketches that as early as the 1870s the majority of this "first-wave" of land cover changes was complete (Angel 1883; see Figures A-3, A-4, and A-5). The impact of changes in the rainfall-runoff relationships caused by such land cover changes were probably magnified by the large California flood of 1862 (Engstrom 1996) followed by the devastating droughts of 1863 and 1864 and the increased storm activity of the 1880s. The overall result of land cover changes in addition to general soil erosion in the watershed was the development of an extensive series of gullies across the watershed that are still active today (see Figure 3-1).

The relative economic quiescence of the watershed from the 1880s until the 1950s means that land cover changes in this period were generally minimal (see comparative photographs from 1930 and 2009 in Figure A-6) and so influences on geomorphic processes during this period would have been largely restricted to legacy impacts resulting from earlier land cover changes, and changes to the character of farming, both again focused in wetter periods and large storm events (e.g., 1884–94, 1901–17, 1935–45).

Thus, the second period of land cover change that may have impacted Santa Rosa Creek watershed involves population expansion in the watershed from about 1950 into the mid-1990s. This period saw a 278% increase in the urban area of the watershed around Cambria (1959–1996: Table 2-2) which has had impacts on water abstraction rates in the watershed resulting in lower base flows and some subsidence during dry periods. However, because Cambria is near the mouth of the watershed, the geomorphic impacts of changes in runoff caused by urban development will have been focused in those lower reaches of the creek (e.g., reach L1 and especially reach L2) downstream of drainage outfalls. The other major land cover change during this period involved several changes to the road network within the watershed, particularly the improvement of Highway 1 and the construction of Highway 46, completed in 1974. The attendant need for an extensive series of fill embankments and cuttings for Highway 46 greatly increased rates of fine sediment input to Green Valley Creek during and shortly after construction, and has led to on-going problems of embankment and culvert-related erosion since (see Figure 3-1), as well as accelerating runoff into Green Valley Creek.

Overall, the two periods of intensive development will have both led to increased flashiness of flows, more rainfall entering the creek as runoff than from baseflow, and increases to the volume of sediment entering stream channels, especially fine sediment. In comparison, it is likely that land clearance for lumber and agriculture probably created more extensive geomorphic impacts, including the majority of the 1,048 gullies still in evidence across the watershed, whereas the impact of road and urban developments more recently will have preferentially impacted Green Valley Creek and the lower reaches of Perry Creek and Santa Rosa Creek.

4.4.3.2 Water-related infrastructure and anthropogenic channel modifications

While the impact of land cover changes on channel morphology and process is usually indirect, being transmitted through changes in rainfall-runoff relationships and sediment supply and texture, near- or in-channel infrastructure has the potential to directly modify geomorphic processes and channel morphology. Infrastructure involves physical features such as dams, roads, and bridges, and facilities related to water diversion and return. Channel modifications include straightening channels, construction of levees for flood control purposes, and bed and/or bank revetments as protection against bank erosion. Generally, these modifications are related to the development of floodplains including routing of roads near stream channels.

Much infrastructure in the watershed is related to creek crossings, and most of these are highlighted as potential fish passage barriers in Figure 1-5. Bridges and other crossings frequently cause hydraulic constrictions during high flow, which promote local geomorphic changes including sediment deposition upstream of the structure and erosion of the bed and banks of the creek downstream of the structure as flow accelerates. Likewise, when crossing structures are not built to grade seamlessly with the channel bed, similar impacts are likely. Both causes may result in a significant “step” in the channel bed thereby disrupting geomorphic processes locally (and can be an impediment to upstream fish passage). Along Santa Rosa Creek, no significant steps are known to occur; however, constrictions that limit sediment transport occur under most bridge crossings; the only remaining significant channel crossing is the Ferrasci Road bridge and fish ladder, which is currently being planned for removal in the near future.

In Santa Rosa Creek watershed, there is a concentration of road drainage and crossing-related impacts along Green Valley Creek as part of the Highway 46 construction in 1970s. Perhaps the greatest geomorphic impact has come from drainage modification approximately 5 km from the junction of Highways 1 and 46. At this location, road drainage is directed towards Green Valley Creek (outboard side of Highway 46) and towards a south-facing tributary (inboard side of Highway 46) (Figure 4-13). The south-facing tributary flow (including the inboard road drainage) is now diverted through a 7-ft culvert under Highway 46 near the historic tributary confluence (Figure 4-14). The increase in flow to Green Valley Creek at this location appears to have, at least in part, caused substantial downstream channel enlargement (i.e., bed incision and channel widening) in Green Valley Creek and erosion of the tributary channel downstream of the culvert. The impact appears to extend approximately 2 km downstream to where the channel gradient decreases, the channel width increases, and sediment deposition is observed to occur. Upstream of the road drainage and culvert, exposed bedrock and coarse bed material seem to be controlling the channel grade, thereby inhibiting channel enlargement due to the flow increase.

Figure 4-13. Historical (1937) and current (2009) aerial photographs showing the reach of Green Valley Creek with the large culvert drainage adjacent to Highway 46.

Figure 4-14. View looking upstream at a large, 7-ft diameter culvert that passes beneath Highway 46 and drains into Green Valley Creek.

There are also numerous instances of bank revetment in the watershed, lining one or both banks of the creek (Figure 4-15). The majority of riprap, which is composed primarily of boulder-size quarry rock, was reportedly installed immediately following the damaging floods of 1969 to repair banks that had eroded during the floods (D. Dunlap, pers. comm., 2009). In most instances, bank revetment is frequently installed as a piecemeal solution to an on-going bank erosion concern that either threatens infrastructure or results in land loss. Unfortunately, bank revetment is also a symptomatic solution that does not account for the reason that high energy flow exists and is causing erosion. Therefore, bank revetments frequently cause flow to be deflected back across the channel resulting in further erosion downstream (e.g., Brookes 1988). The subsequent threat to downstream land and infrastructure promotes the continuing construction of further revetments and maintenance of existing revetments until such time that the channel is almost entirely revetted. Extensive revetment tends to cause channel incision, more rapid flows, channel bed armoring (i.e., coarse bed surface layer), and reduced topographic complexity of the channel bed resulting in significant reductions in habitat suitability for native aquatic organisms including salmonids.

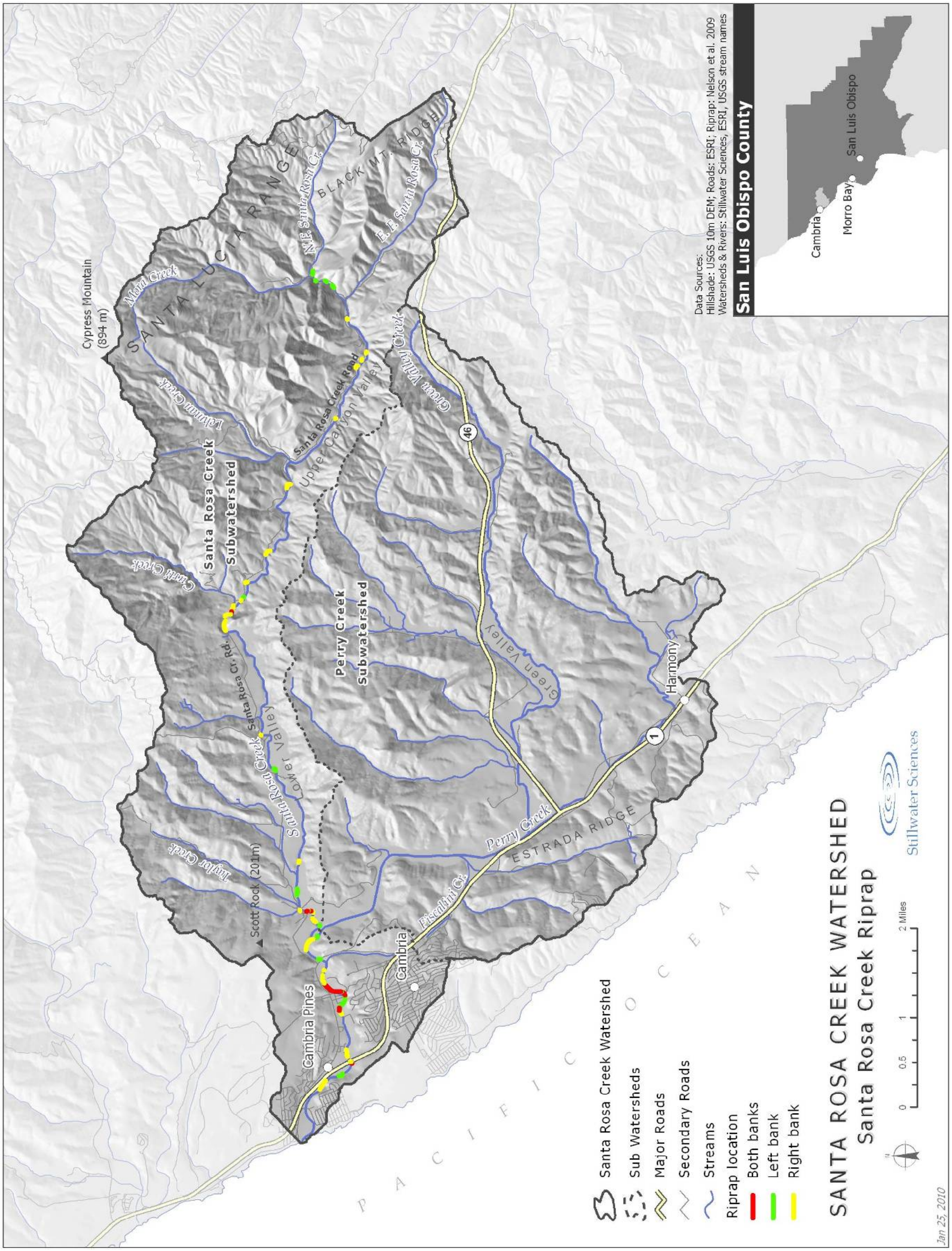


Figure 4-15. Bank riprap locations along Santa Rosa Creek (after Nelson et al. 2009).

In addition to in-channel structures, development along channel banks and the adjacent floodplain can have a significant impact on channel morphology. There are two primary drivers for channel change caused by floodplain development: (1) increased runoff associated with impervious area that has the potential to cause channel incision and/or widening (see Section 4.4.3.1); and (2) increased channel confinement associated with bank hardening and structures built along channel banks. Increased confinement also has the potential to cause channel incision due to increased flow velocities during high flow events. Since 1937, there has been concentrated development on the north bank (i.e., right bank) floodplain along Santa Rosa Creek in the Lower reaches from Highway 1 downstream (Figure 4-16). The floodplain development includes building of Highway 1, a housing development, and many of the businesses and residences along Main Street. During the improvement of Highway 1 (bypass construction), many of the lower reaches of the channel were modified. In an effort to improve building conditions, an abandoned channel meander approximately 0.5 km downstream of the Highway 1 bridge was filled-in sometime after 1937. These development features have undoubtedly played some role in controlling the current channel geomorphic character.

Figure 4-16. Historical (1937) and current (2009) aerial photographs showing the Lower reach of Santa Rosa Creek near the town of Cambria.

4.5 Lagoon Morphology and Dynamics

Understanding the sedimentation dynamics in the lower reaches and lagoon of Santa Rosa Creek are vital in understanding the stability of the lagoon and suitability of aquatic habitats (e.g., residing tidewater goby and migrating southern steelhead). Santa Rosa Creek discharges into a seasonal lagoon located behind Moonstone Beach before reaching the Pacific Ocean. By definition, a coastal lagoon is a body of water fed mostly by freshwater streamflow and is generally separated from the sea by a sandbar, except when that sandbar is breached during high-flow events (Carter 1988). The amount of freshwater and sediment throughput past the lagoon to the ocean is variable depending on streamflow and tidal elevation. Lagoon morphological change over short and long time periods can provide an indication of changes to historical land-sea interactions (i.e., sea-level change) and contributing watershed streamflow and sediment delivery dynamics. To date, there have been very few studies conducted to characterize the morphologic evolution or depositional history of the Santa Rosa Creek lagoon. This section, therefore, provides a baseline summary of the lagoon's historical and current morphology based on available information, including fisheries monitoring reports, regional studies, field observations, and historic aerial photographs.

The Santa Rosa Creek lagoon is a barrier lagoon separated from the Pacific Ocean by a sandbar for much of the year (Figure 4-17). Quaternary-age marine terraces (unit Qm in Figure 1-3) effectively constrain the maximum width of lower Santa Rosa Creek valley and also the lagoon. The south bank (or left bank) at the upstream end of the lagoon near Shamel Park is presently protected from wave attack by riprap materials on both the lagoon-side and creek-side banks. The adjacent floodplain to the east of the lagoon is a well vegetated expanse of scrub-shrub that remains dry except during extreme flood events. The small rock island situated approximately 150 m (~500 ft) offshore from Moonstone Beach functions as a natural breakwater that reduces approaching wave energy. The combination of marine terrace confinement and approaching wave direction causes the Santa Rosa Creek lagoon to be situated north (or upcoast) of the mainstem river channel. The upstream end of the lagoon is defined by the upstream extent of tidal influence. Although tidal records are available for use to help calculate this location, identification of the upstream end is not possible due to the lack of high resolution channel elevation data; however, the upstream end of tidal influence is likely well below the Highway 1 bridge crossing based on the fact that a stream gauge once occupied that location.

Similar to other lagoons along the California coast, the Santa Rosa Creek lagoon exhibits a "wet" and "dry" state during any given year, whereby winter and spring flows fill up the lagoon and the lack of flows during late summer and early fall often result in a dry lagoon. During the relatively wet year of 2005, D. W. Alley & Associates (2006) reported that the lagoon remained full throughout the monitoring they conducted during the dry months. They also reported that lagoon water depth was predominantly controlled by streamflow and that tidal overwashes and throughflow (i.e., subsurface flow through the sandbar) had a minimal effect. Sandbar breaching typically occur in the winter when high streamflows rapidly fill the lagoon and cause the natural barrier to fail. Often, high wave energy can also contribute to sandbar breaching. Reformation of the sandbar and closure of the lagoon occurs when lower stream discharges and lower-intensity wave action facilitate onshore sediment transport and deposition at the mouth. Lagoon closure can take weeks to months, depending on the stream discharge and wave conditions.

Figure 4-17. Oblique view of the Santa Rosa Creek lagoon looking east toward Cambria and the watershed with the Santa Lucia Mountain Range in the background (Photo taken October 28, 2005, Copyright © 2002–2009 Kenneth & Gabrielle Adelman, California Coastal Records Project, www.californiacoastline.org).

The general planform of lower Santa Rosa Creek and the lagoon have remained relatively static in recent time, as seen in one historical topographic map from 1919 and a series of eight historical and present-day aerial photographs taken since 1937 (Figure 4-18). Two main features are made apparent when examining these historical views of the lagoon: (1) the mouth is nearly always positioned on the north end of the beach adjacent to the marine terrace, with few exceptions (e.g., 1986), and (2) the amount of vegetation cover adjacent to the lower creek channel and lagoon appear to have increased considerably between 1937 and 1976. The "upcoast" lagoon orientation is common among lagoons of similar size along the central and southern California Coast. Although no known aerial photographs of the lagoon were taken prior to the 1930s, we can infer from Julien Estrada's sketch diagram of his holdings of Rancho Santa Rosa in 1841 that the lagoon may have exhibited a similar planform whereby the creek and lagoon sharply curved from the south to the north just before discharging to the ocean (see Figure A-2 in Appendix A). However, given that this diagram was not drawn to scale and there are insufficient landmarks shown, it is possible that the northerly "swing" of the lower creek may represent the portion of Santa Rosa Creek below present-day Highway 1 rather than the lagoon. The vegetation cover as viewed in the 1937 aerial photograph is limited to the a riparian corridor that lines the lower creek channel as it enters the lagoon, but minimal woody vegetation is present upon the adjacent floodplain areas. By 1976, the floodplain areas supported a denser vegetation cover comprised of woody scrub/shrub, riparian forest, and wetland plants (see Figures 1-6 and 4-16). The reason for this lack of vegetation cover in 1937 is unknown, but may be due to general land clearing that occurred throughout the watershed during the late 1800s and early 1900s. The subsequent re-vegetation of the lagoon area has implications maintaining the lagoon's position (i.e., vegetation providing bank strength) and promoting overbank deposition (i.e., decreased competence due to presence of roughness elements).

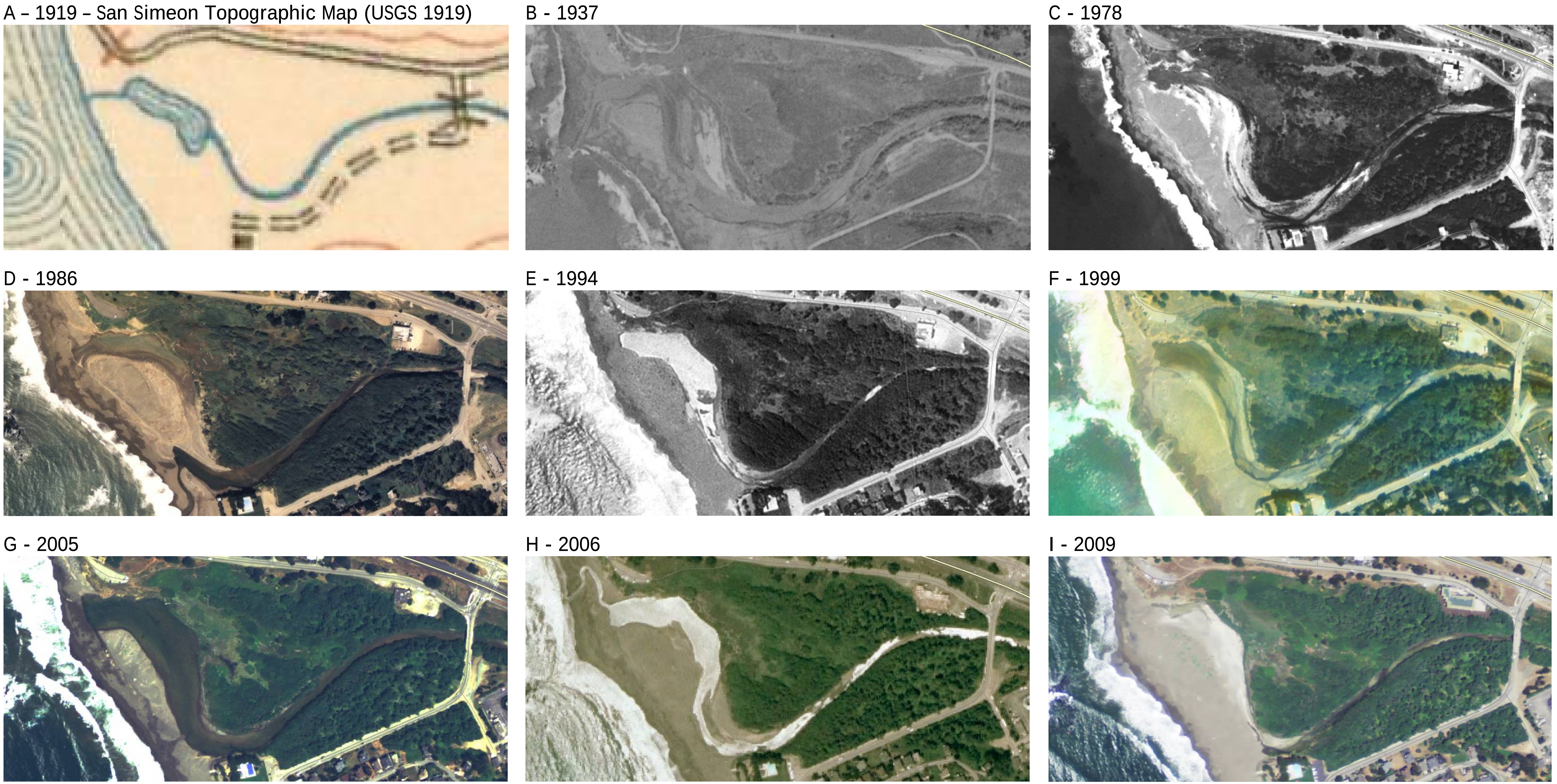


Figure 4-18. Historical topographic map and aerial views of the Santa Rosa Creek lagoon. The lagoon has generally maintained a similar planform shape since the early 1900s, with few exceptions (e.g., 1986). Also shown are examples of a breached sandbar during higher stream flow conditions (e.g., 2005) and a closed sandbar during lower flow conditions (e.g., 2009).

In general, sands that make up Moonstone Beach and the majority of California beaches are supplied from a combination of stream discharge and seacliff erosion (Patsch and Griggs 2006). These sands only temporarily reside at any one beach, including Moonstone Beach, as they are transported along the coast by a nearshore, or littoral, current. Along the entire California coast, waves breaking onshore are generated in the winter by extra-tropical storms, mid-latitude low-pressure systems, and cold fronts that originate in the North Pacific (Hapke et al. 2006). During the remainder of the year a weaker, southern swell dominates that is generated by winter storms in the Southern Hemisphere (Hapke et al. 2006). As a result, the predominant direction of littoral sediment transport along the California coast is from north to south; however, local reversals in this general direction can occur seasonally and/or where variations in the coast orientation relative to the approaching currents exist (Patsch and Griggs 2006). Southward transport can also be reduced or reversed during El Niño winters when waves generally approach from the west or southwest (Patsch and Griggs 2006). Santa Rosa Creek likely discharges into a littoral cell with a reverse transport direction based on an airphoto review of the morphology exhibited by its lagoon and by several other lagoons in the region. Littoral cells are discrete coastal regions that can be considered closed systems within which sediment is transported. All of the significant streams in this region between San Simeon Point to the north and Point Buchon to the south of Santa Rosa Creek (e.g., Pico, San Simeon, Villa, and Morro creeks) have lagoons that discharge to the ocean on the north- or northwest-end of their beaches, which is likely driven by wave action that approaches these beaches from the west-southwest direction (Figure 4-18).

As stated above, sedimentation dynamics within the Santa Rosa Creek lagoon are driven by both fluvial and littoral sediment transport processes; however, little is known about whether net sediment aggradation or erosion has been occurring over time. D. W. Alley & Associates (2006) recorded discrete, yet not significant bed elevation changes in the lagoon between Shamel Park and the downstream (northern) end of the lagoon during the years of 2003 through 2005 as part of their fish monitoring study. These observations represent short-term bed elevation changes rather than long-term changes in the lagoon's evolution.

Overall, it can be inferred from the historical aerial photographs shown in Figure 4-18 that neither net aggradation nor erosion has occurred during the past 70-plus years based on the following: (1) the lower stream channel and lagoon have maintained a relatively static position (i.e., no meandering or avulsions); and (2) the lower stream channel exhibits a similar, albeit transitory, bar and pool morphology. This has positive implications for the continued functionality of an ecologically-important lagoon.

5 DISCUSSION

5.1 Summary: Understanding of Watershed Geomorphology

The Santa Rosa Creek watershed drains 123 km^2 (48 mi^2) of the southern Coast Range, rising on the western flanks of the Santa Lucia Mountain Range and emptying into the Pacific Ocean by the town of Cambria. The three main creeks, Santa Rosa, Perry, and Green Valley, and their tributaries are set primarily on Franciscan mélange and other meta-sedimentary rock units. Crustal convergence along the San Andreas Fault Zone has resulted in the occurrence of relatively weak rock units at higher elevations (e.g., Monterey Formation shales) which gives the watershed relatively high natural rates of erosion. Natural erosion is driven by the winter storms typical to a Mediterranean climate and is high flashy, accentuated by the high relief of the watershed—the highest point of the watershed at Cypress Mountain (894 m; 2,922 ft) receives nearly twice the rainfall at the coast (940 mm [37 in] versus 533 mm [21 in]). The highest rainfall events, and thus storm flows typically (but not always) occur during ENSO cycles. Land cover in the watershed is primarily grassland related to cattle grazing and other agriculture practices; the urban footprint is limited to the town of Cambria near the mouth of the creek, and two highways.

Like much of the American West, the greatest single physical change in the watershed occurred with the onset of Euro-American settlement in the mid-1800s: high population growth resulted in land clearance for agriculture and lumber, with native tree, shrub, and grass species replaced by shallow-rooted non-native grasses. These vegetation changes created a more flashy rainfall-runoff regime while at the same time providing less reinforcement of soils against erosion. The large California flood of 1862 followed by the devastating droughts of the 1860s and the increased storminess of the 1880s likely exacerbated the impacts of this land conversion, with significant erosion of both hillslopes and river channels (see below). The most significant channel modification during this period was probably the draining of Estrada lagoon and its replacement by the trapezoidal ditch that now forms the lower part of Perry Creek. However, unlike many other watersheds in California, the relative isolation of Santa Rosa Creek meant that this period of disturbance (focused around 1860–1880) was followed by quiescence until about 1950.

Since 1950 until about 1995, population in Cambria again began to increase partly because of the post World War II increase in population in California generally, but also because improvements to Highway 1 (early 1960s) and the building of Highway 46 along Green Valley (completed 1974) allowed the development of a thriving tourism industry. This period probably represents the second greatest impact on the geomorphology of the watershed, albeit with impacts focused on erosion in Green Valley Creek, and around the town of Cambria. Significantly, limited extent of the aquifer in the lower watershed meant that population growth has slowed since 1995 partly because of limits to water resources, safeguarding the largely rural nature of the watershed.

Hillslope erosion processes are similar to those active elsewhere throughout much of the southern Coast Range region: gullies are the most evident “macro-scale” erosion accounting for 72% of observed features including landslides, road-related erosion, and other macro-scale features. The gullies have evidently been in existence for a long time, being illustrated in sketches of the watershed from the 1880s and evident in aerial photographs from the 1930s. A coarse estimate of gully-based erosion annualized for the 150 years since 1860 would indicate gullies to have contributed 17,000 tonnes of sediment annually, although in reality much of the sediment delivery would have been focused in the early years of gully existence. Other sediment sources in the watershed include "micro-scale" erosion features such as dry ravel, soil creep, and rilling, and erosion of channel bed and banks. By inference with nearby watersheds and regional tectonic uplift rates, the total erosion rate may be around 420 t km^{-2} a^{-1} (52,000 tonnes, annually). This value is somewhat higher than typically estimated in coastal watersheds around the Bay Area of California farther north where rainfall extremes are less pronounced, but less than estimated for watersheds draining the highly erodible Transverse Ranges to the south; thus, in the absence of watershed-specific data, it appears to be credible. By our coarse estimate, macro-scale erosion such as that from gullies may account for approximately one-third or less of this erosion total, suggesting that soil creep, dry ravel, rilling, and channel erosion are also significant sediment sources. A small proportion (<8%) of this eroded sediment may be intercepted by small water-storage basins.

Overall, hillslope erosion is focused particularly in grassland landscapes that are underlain by rock composed of the highly sheared and fractured Franciscan mélange and characterized by moderately steep slopes (10–40%). This combination of geology, land cover, and hillslope gradient is also the most prevalent in the watershed, accounting for approximately one-third of the watershed area. This combination of features was assigned an erodibility rating of "Medium", which applies to 84% of the study area and emphasizes the largely uniform terrain conditions in the watershed. Erosion by unit area, most discretely in the form of gullies, is concentrated in rock units of the fine–weak Monterey Formation and the coarse–weak Franciscan mélange, on grassland/ herbaceous land cover, and moderately steep (10–40%) hillslopes. Landslides were observed to concentrate primarily in mixed forest and scrub/shrub-covered terrains but are somewhat insignificant in terms of total eroded area. By subwatershed, hillslope erosion rates are estimated to be largely related to watershed size. Thus erosion in the Santa Rosa Creek sub-watershed closely matches that from the Perry Creek (erosion ratio = 56:44; area ratio = 52:48). To the extent that our method and available data allows, sediment supply per unit area is highest in the subwatersheds of East Fork Santa Rosa and Curti creeks and two unnamed tributaries draining to Green Valley; and it is lowest from the hillslopes draining directly to the Lower reach of Santa Rosa Creek. Given the relative uniformity of rock type and land use in the watershed, these results are entirely consistent with the fact that the high yielding subwatersheds have the highest relief and the lowest yielding have the lowest relief.

Significant rates of geomorphic process activity in stream channels of the watershed occur in response to rainfall-driven storm events (e.g., during El Nino years of the ENSO cycle). Streamflow gauges have been deployed in the upper watershed (WY 1958–1972) and in two locations of the lower watershed (WY 1976–1992; WY 1989–present). Unfortunately, the rating curve of the current gauge is inadequately calibrated, reducing confidence in flow records since 1994. Following a previous report (Yates and Von Konyenburg 1998), flow records are supplemented with records from Santa Rita Creek (WY 1958–1992). To the extent allowed by available data, bankfull flow in the lower watershed is approximately 50–78 m^3 s^{-1} (1,802–2,744 cfs) while the 10-year recurrence interval event has an approximate magnitude of (~216 m^3s^{-1}; 7,600 cfs). Since 1958, large flood events have occurred in 1967, 1969, 1973, 1978, 1986, 1993, 1995, and 2005, corresponding with the increase in ENSO circulation intensity in the latter year of the Twentieth century (Inman and Jenkins 1999). Of these, the two largest were probably 1969 and 1995.

Channel morphology of Santa Rosa Creek can be usefully subdivided into an upper, middle and lower zone and a total of 9 reaches therein. Channel gradients by reach vary from 0.032 in the creek headwaters to 0.003 near the river mouth, with an average gradient of 0.009 (i.e., 0.9%). The Upper zone is characterized by a steep, boulder-cobble-gravel bedded reach above Mammoth

Rock and the Middle reaches extending down to Perry Creek are incised into alluvium with a sinuous cobble-gravel bed characterized by pool-riffle bedforms. Bedrock control returns at the junction with the Lower reaches which have a sand-gravel bed and are moderately confined by terrain and development and show signs of aggradation before becoming tidally influenced near the river mouth. From deposits at tributary confluences, it appears that Lehman and Curti creeks provide significant coarse sediment delivery to Santa Rosa Creek while Perry Creek delivers abundant fine sediment. The pattern of creek morphology transformations in Green Valley Creek is similar to those of Santa Rosa Creek but occurs over a shorter distance. The upper reaches of Perry Creek are meandering and finer-grained than either of Santa Rosa and Green Valley creeks. Lower Perry Creek was channelized from the former Estrada Lagoon and begins as a trapezoidal cut roughly paralleling Highway 1 while the lowest reach is incised into the organic-rich sediments of the former lagoon.

Human influences on Santa Rosa Creek include the impacts of land cover changes and water-related infrastructure. Regarding land cover change, it appears that in Santa Rosa Creek the biggest single influence was the conversion from native woodland and shrub/scrub to non-native grasslands subsequent to the arrival of Euro-American settlers in the mid-Nineteenth century. This likely resulted in the observed incision of the Middle, and to some extent, Lower reaches which still influences creek dynamics today. In Green Valley Creek, it seems probable that a second major impact relates to the construction of Highway 46 in the early 1970s. Regarding infrastructure, there are numerous creek crossings along Highways 1 and 46 and Santa Rosa Creek Road that may locally influence the dynamics of deposition and erosion, most recently including the series of culverts related to the drainage of Highway 46 in Green Valley Creek. Along Santa Rosa Creek and likely along some sections of Perry and Green Valley creeks, there are also numerous instances of localized bank revetment but no extensive bank protection or levee building.

Evidence for channel dynamics can be derived from aerial photographic overlays and from hydraulic geometry relationships. Comparing photographs from 1937 to 2007, there have been local changes in planform in both the Upper and Lower zones of Santa Rosa Creek, with a significant increase in the sinuosity of the Middle zone, especially reach M2 which has increased in sinuosity by 18%. The increase in sinuosity of this incised reach is taken as indicative of evidence that the channel is still recovering from the impact of land cover change in the mid-Nineteenth century. Evidence for the potential for channel change was determined using field measurements collected as a by-product of the reconnaissance survey. While a dedicated campaign of data collection is ideally required, this available data indicates both a logical relationship between channel width, depth, and drainage area. Derivative measurements indicate that the channel should be highly dynamic in its alluvial reaches according to stream power, while estimates of shear stress on the bed of the channel suggest that the bed sediments are highly mobile even in frequently occurring high flows such as bankfull (recurrence interval of 1.5–2 years).

The morphology of the coastal barrier lagoon at the mouth of Santa Rosa Creek is influenced by prevailing onshore currents and the effects of a rock island close offshore, by flows from Santa Rosa Creek, and by topographic constraints that are both geologic and a function of a landfill and riprap. Overall, the lagoon responds largely to incoming streamflow including its pattern of seasonal breaching which is usually in response to high discharges from Santa Rosa Creek that overwhelm the capacity of the lagoon. The morphology has remained remarkably static since available records began which likely indicates that the morphology of the lagoon, unlike its seasonal breaching, is controlled primarily by the prevailing direction of coastal sediment transport. While the majority of coastal sediment movement in California is from north to south, the lagoon morphology at Santa Rosa Creek and of neighboring creeks suggests a south to north movement, presumably in response to dominant wave action from the west-southwest direction.

5.2 Sediment Production, Transfer, and Storage

As a geomorphic unit, a watershed serves to transport sediment from its place of origin to an eventual place of lasting storage. In so doing, a distinctive relief is developed in the watershed that reflects the balance between long-term processes of tectonic uplift and rates of erosion driven by physical, chemical and biological factors. This balance is generally achieved through the medium of moving water. Sediment sources are those sites predominantly characterized by erosion and often most commonly have steep slopes. Sediment storage, particularly in a small coastal watershed such as Santa Rosa Creek, occurs mostly offshore as sediment-laden water exits the watershed, but it also occurs where sediments are deposited on floodplains (where the material is termed *alluvium*) and at breaks to gentler hillslope gradients (termed *colluvium*). Connecting sediment sources with their sites of long-term storage is a flux of sediment transport through the watershed, typically occurring on a time scale from years to centuries. The flux of sediment is intermittent and driven mostly by large rainfall or streamflow events, and so most such "short-term" sediment transfer occurs along the river channel. The exact locations of the short-term sources and storage sites of sediment, however, are influenced as strongly by human activities as by natural factors. A typical short-term sediment source is the erosion of alluvial river banks, representing the re-mobilization of previously stored sediment; while short-term sediment storage often occurs on the channel bed in the form of a wave of "excess" sediment deposited after a flood event. Therefore, the typical transfer of sediment through a watershed involves a flux in which changes to the creek morphology is an integral part.

As aquatic habitats are intimately linked to creek morphology and process, it follows that habitats also respond to the flux created by sediment sources and storage sites within a watershed. They are particularly affected by changes away from "normal" conditions. For this reason, aquatic habitats are closely linked to geomorphic processes and the influence of human activity. The benefits and hazards of living near to a river are also linked strongly to changing channel morphology and process. Using the same examples as above, significant erosion of channel banks is often perceived as land loss by the owner, while sediment deposition raises channel bed elevations and makes the adjacent floodplain more prone to flooding. As such, understanding of geomorphic processes and their alteration is also central to river and watershed management in general.

As a gauge of relevant activities, we have characterized a series of sediment sources and stores through this report, and estimated the dynamics of sediment transfer. This characterization is summarized in Table 5-1 and the various source locations brought together in Figure 5-1.

Table 5-1. Sediment sources, storage, and transfer dynamics in the Santa Rosa Creek watershed.

Location	Process/Description
Sediment Sources	
Landslides	Only 17 landslides (combination of shallow and deep-seated) are recorded in the areas of watershed without canopy cover, but they are individually high-yielding accounting for approximately 3,500 m^3 of material per slide. Landslides are concentrated in high relief, steep-sided subwatershed areas, primarily in the headwaters of Santa Rosa Creek. Landslides erode previously stored colluvium on hillslope swales and, potentially, weathered bedrock closer to the failure plane. Mixed-load sediments released as part of large deep-seated landslides, as mapped in geologic maps of the watershed, may reside for years to centuries before eventually being completely delivered to the stream network.
Gullies and rills	Gullies (macro-scale features) and rills (micro-scale features) are numerous throughout the watershed. Over 1,000 gullies have been recorded and many have evidently been present since the late Nineteenth century and so may be past their sediment production peak. These features primarily result in the production of fine-grained sediments as they erode soil-mantled, moderately steep hillslopes and, because they are often connected directly to the stream network, a near 100% delivery ratio of sediment can be inferred. The inception of gullying in the watershed is likely to have resulted in far higher volumes of fine sediment delivered to the channel network
High yielding Geomorphic Landscape Units	By our estimates, areas of the watershed with the highest sediment yield potential are primarily situated on steep, grassland and barren hillslopes composed of weak rock. These areas result in the production of both coarse and fine sediments, but fine sediments are probably derived preferentially from the widespread Franciscan mélange terrain. Sediment delivery from these GLUs is likely high given the steep hillslopes and confined and steep channels.
Creek incision	Channel incision in the major streams is assumed to have occurred quickly after initial land clearing activities began in the mid-Nineteenth century. Incision is widespread but focused in the Middle reaches of Santa Rosa Creek and the middle and upper reaches of Perry and Green Valley creeks. Incision initially releases channel bed sediments which may be relatively coarse.
Bank erosion of high bluffs following incision	Over time, channel incision eventually causes the mass instability of channel banks of the former floodplain which then makes them a highly effective source of finer sediment as the channel widens. More recently, meander activity as the incised reaches try to recover their equilibrium has allowed erosion of high alluvial banks of the former floodplain, causing a net sediment supply biased towards fine sediment.
Road-related erosion	Over 250 instances of recorded road-related erosion exist in the watershed. Erosion is focused along cut and fill sections of Highway 46 and Santa Rosa Creek Road (and to a lesser extent Highway 1). Because road drainage frequently serves channel road runoff from the road surface efficiently to the channel network, sediment (particularly fine sediment) is also delivered very effectively to the channel network.
Sediment Storage	
Lower Perry Creek in the vicinity of the former Estrada lagoon	Historically, Estrada Lagoon at the downstream of end Perry Creek probably trapped all coarse and most fine sediments delivered by the contributing streams, meaning that few sediments from the Perry Creek subwatershed ever reached Santa Rosa Creek. Subsequent draining of the lagoon to create a

Location	Process/Description
	trapezoidal channel permitted the transport of sediment, especially fine sediment, from the Perry Creek subwatershed into Santa Rosa Creek. Subsequent incision of the lowest reach of Perry Creek must have resulted in the remobilization of former lagoon sediment (i.e., fine, organic-rich sediment). The broad-bedded, low gradient ditch farther upstream still favors the deposition of coarse sediments before Santa Rosa Creek, and a noticeable fining of bed material occurs on Santa Rosa Creek downstream of the Perry Creek confluence.
Water storage ponds	There are 41 recorded small water storage ponds throughout the watershed, with a greater proportion in the Perry Creek subwatershed. They regulate 8% of the watershed area but are likely to have low sediment-trapping efficiencies, trapping primarily a small amount of coarser-grained sediments.
Channel bed in upper reaches	Field evidence indicates temporary storage of coarse sediments delivered from the steep, high relief tributary subwatersheds (e.g., East Fork Santa Rosa and Curti creeks) into mainstem Santa Rosa Creek. Along the mainstem, there is also field evidence for the temporary storage of coarse material in channel and floodplain locations. Remobilization of the coarse sediment occurs during high flow events with material either wholly entrained or abraded into finer, more easily-transportable particles.
Channel bed in lower reaches	While lower gradient reaches are frequently characterized by finer sediment beds and sediment deposition, field evidence of short-term storage of fine material on the channel bed may reflect high rates of fine sediment supply to the lower reaches, especially from the Perry Creek subwatershed.
Transfer Dynamics	
Upper reaches	The shear stress ratio (3.2–4.8) indicates that the upper reaches are competent to transport the median grain sizes (~50–90 mm) and larger supplied to the reaches during even moderate flood events. Very high stream power (~200–500 Wm^{-2}) also indicates a highly active channel. Fine sediment is presumably transferred quickly from the reaches, whereas field evidence indicates the temporary storage and probable breakdown of very coarse material.
Middle reaches	The shear stress ratio (3.5–7.5) indicates that the middle reaches are competent to transport the median grain sizes (~20–50 mm) and larger supplied to the reaches during even moderate flood events. High stream power (~135–275 Wm^{-2}) also indicates a highly active channel, borne out by increased sinuosity in these reaches since the early Twentieth century in which coarse sediment is deposited in the form of channel bars and larger volumes of fine sediment are derived from the high banks of the former floodplain surface.
Lower reaches	The shear stress ratio (3.8–16.3) indicates that the lower reaches are highly competent to transport the median grain sizes (~5–45 mm) and larger supplied to the reaches during even moderate flood events. Stream power (~150–300 Wm^{-2}) is unusually high for such low gradient reaches and may reflect bank protection which prevents the exchange of sediment from channel banks and prevents channel widening in response to flood events.

In summary, present day Santa Rosa Creek watershed is characterized, as most other watersheds, by a wide variety of sediment sources that potentially affect management decisions. Of particular note is the potential for high sediment yields from the very steep hillslopes in the headwaters of Santa Rosa Creek (and some tributaries in Green Valley Creek), and the extent of highly effective sediment delivery from active gullying, high bluff bank erosion, and road-related erosion in the middle watershed areas. In the lower watershed areas, the primary impacts probably relate to the "reconnection" (in terms of sediment) of Perry Creek to lower Santa Rosa Creek achieved by draining Estrada lagoon. Direct impacts on channel morphology with repercussions for future management decisions include piecemeal bank protection in various locations through the watershed, and the somewhat undetermined effect of extensive bank protection and other channel modifications of lower Santa Rosa Creek. Other than the potential for high sediment yields from steep gradient locations, the other highlighted sources result primarily from previous land and channel management actions. It seems likely that, in geomorphic terms, the historically-noted fish populations in the watershed result in part from the habitats created by the delivery of very coarse sediment from the upper reaches of Santa Rosa Creek. Human actions, in addition to increasing the flashiness of runoff in the watershed, have apparently served primarily to increase the fine sediment component of the river bed which has probably been deleterious to steelhead habitat. Study is required of the cumulative effect of various physical, chemical, and biological factors currently limiting steelhead trout populations to determine whether fine sediment impacts are among the primary causes of fish population decline.

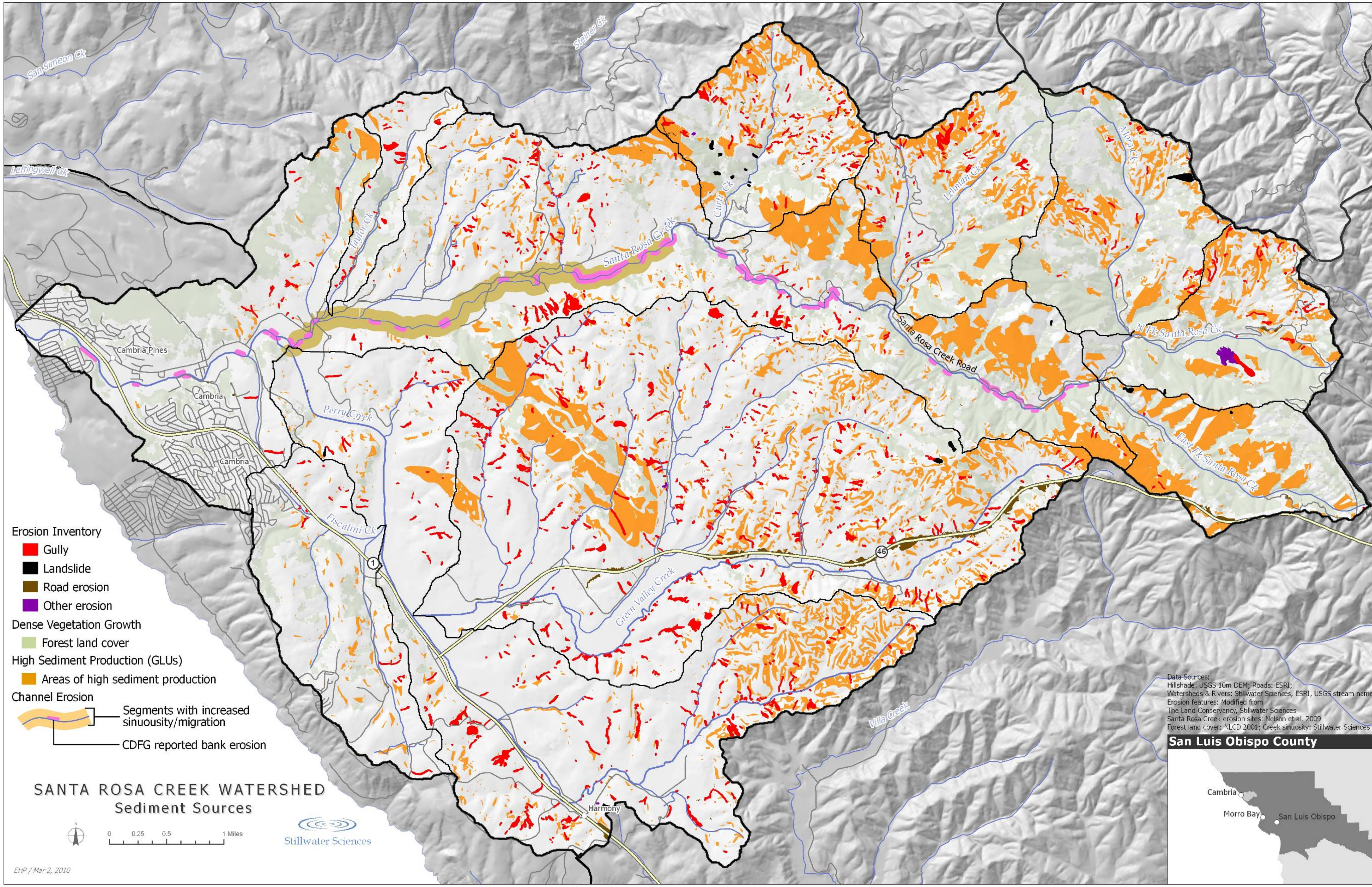


Figure 5-1. Sediment source and transfer areas in the Santa Rosa Creek watershed.

5.3 Data Gaps in the Current Understanding

Through the process of compiling the data to undertake the analysis required for this report, we have become aware of several significant gaps in the availability of data that might be used to better characterize geomorphic processes, and so as to better support watershed management planning. The data gaps are listed below in the hope that resources might eventually be made available to fund their collection.

- ***Reliable calibration of the lower watershed gauging station (SLO #21)***: reliable flow information is central to nearly every facet of watershed management, and is especially critical where water resources are limited. The current gauging station at the Main Street bridge urgently needs real-time flow measurements taken during high discharge events as the basis for constructing a reliable stage-discharge relationship that maximizes the utility of the gauge. Taking high flow measurements is potentially dangerous and must be made by qualified hydrology technicians.
- ***Aerial LiDAR scanning as the basis for more accurate characterization of the watershed topography***: aerial laser swath mapping, commonly known as LiDAR (Light Detecting And Ranging) is revolutionizing watershed characterization, allowing a far greater resolution of the watershed surface than achieved by photogrammetrically derived USGS Digital Elevations Models. The accuracy of LiDAR mapping is frequently to decimeter-scale (inches) in the horizontal and vertical. Other than the inherent advantages of a more accurate base map of the watershed, computer algorithms developed for LiDAR data can be used to create a "bare earth" surface (i.e., an image cleared of surface vegetation and buildings) allowing the identification of erosion sources that cannot otherwise be seen, such as old landslides under canopy cover that might still be providing a significant source of sediment. County-wide programs of LiDAR mapping are rapidly being added to surveys of aerial photography (e.g., Ventura County).
- ***Comprehensive (headwater-to-mouth) survey of stream channel conditions***: the channel surveys in this report represent a strategic sampling of conditions to establish a baseline understanding of general conditions. A more thorough survey would enable better understanding of the extent of incision-related erosion problems in the watershed and the dynamics of habitat conditions. LiDAR data could be used in place of ground surveys to some degree (see above).
- ***Additional research on the extent of direct channel change brought about by channel management activities and the construction of Highway 46***: in many watersheds including Santa Rosa Creek, it is difficult to build an exact picture of the extent to which past management activities have directly impacted river channels. We are aware, from anecdotal evidence that the improvement of Highway 1 involved some creek modifications and that extensive riprap placement in the lower creek followed the flood of 1969, but were not able to discover engineering plans for these activities within the timeframe and resources allocated to this project. Further, we are aware that the construction of Highway 46 involved large volumes of fill material some of which subsequently entered the channel system during the wet winter of 1972/3, but are unaware of any systematic recording of this event. Acquisition of official information in any of these matters would create a better understanding of creek change that might benefit assessment of habitat conditions, particularly in the lower watershed.

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Ochs, A. 2009. Volunteer researcher, San Luis Obispo County Historical Society. Email to G. Leverich, Stillwater Sciences, providing historical population information.

APPENDICES

Appendix A

Historical Watershed Impacts

Table A-1. Chronology of major activities and geomorphic disturbances in the Santa Rosa Creek watershed.

Historical period		Watershed activity/Disturbance
European Arrival: Resource Development (1760s–1859)		• 1769 – Portola Expedition encounters ~300 Native Americans residing in Santa Rosa Creek area. Portola records observations of a "canyon… and arroyo surrounded with hills of pine" in the area now known as Cambria. [1] • Late 1700s – Early coast trail established; followed Perry Creek along eastside of the "Estrada Laguna", crossed Santa Rosa Creek, and headed west toward coast [1, 2] • 1840 – Establishment of Rancho Santa Rosa; primary land use is ranching of cattle, sheep, and horse [1, 2, 3, 4] • 1850 – Coast wagon road constructed between San Luis Obispo and Santa Rosa Creek following coast trail [3] • 1859 – First Americans settle Santa Rosa Creek and Green Valley lowlands [1, 2] • 1859 – Early Santa Rosa Creek Road/Trail established [1]
Ranching, Logging, and Mining (1860–1949)	Rapid Development Period (1860–1880)	• 1862 – Little Bonanza mercury deposit discovered immediately east of watershed [1, 4, 5] • 1863/64 – Severe drought kills off livestock; shift to crop cultivation and dairy cattle and processing [1, 2, 3, 4] • 1865 – Watershed-wide logging of pines and oaks begins [1, 3] • 1866 – Establishment of Cambria [1, 2, 3, 4]; filling of gullies within town limits [1] • 1868 – "Cienaga Trail" established along Green Valley [1, 6] • 1870s – Walker Ditch constructed to drain "Estrada Laguna" along lower Perry Creek [1, 2] • 1874 – Oceanic Quicksilver Mine begins production in Curti Creek subwatershed; quicksilver mining boom continues elsewhere throughout region [1, 3, 4, 5] • 1875 – Cambria population: ~300 [7;] Cambria and vicinity population: ~1,000-2,000 [1] • 1876 – Coast Road re-routed away from lower Perry Creek to along present day Main Street [1]
	Quiescent Period (1880–1949)	• 1889 – Cambria Fire destroys downtown [1, 4]; largest recorded fire in watershed [8] • 1890 – Cambria population: 700 [7]; Santa Rosa Creek Valley is "quite thickly settled" [3] • 1900 – San Simeon Township (Cambria, San Simeon, and surrounding areas) population: 1,036 [7] • 1914 – January floods occurred during wet water year; Cambria flooded [1] • 1914-1918 – Second peak in production at Oceanic Quicksilver Mine [1, 4, 5] • 1916 – Logging production declines with removal of old growth [1] • 1927 – Cambria Development Company begins housing development of Cambria Pines [1, 4] • 1939 – Highway 1 and Santa Rosa Creek Road improved (oiled) [1]

Historical period		Watershed activity/Disturbance
Urbanization (1950–2010)	Population Growth Period (1950–1994)	• 1950 – Cambria population: 788 [7] • 1956 – Second large flood event, again inundated Cambria [1, 2] • 1958 – Tourism industry begins with opening of Hearst Castle [1, 4] • 1960 – Cambria population: 1,260 [7] • 1960s – Third peak in production at Oceanic Quicksilver Mine [1, 4, 5] • 1960s – Unauthorized logging of California bay trees in upper watershed [2] • 1960s – Shift from dairy cattle back to beef cattle [1, 2] • 1964 – Highway 1 bypass constructed around downtown Cambria [1, 4] • 1965 – Cambria population: 2,010 [7] • 1969 – Third large flood event [1, 2]; greatest annual precipitation amount on record, estimated at 12-21 inches over 8 days [9, 10]; widespread bank erosion and bed scouring [2] • 1971 – Closure of last sawmill in watershed (near Scott Rock) [11] • 1974 – Highway 46 constructed through Green Valley [1, 4] • 1976 – Municipal groundwater extraction from the Santa Rosa basin peaks at 520 acre-feet [12, 13] • 1980 – Cambria population: 3,061 [14] • 1980s – Steelhead population decline [15] • 1990 – Cambria population: 5,382 [14]
	Population Growth Slow Down Period (1995–2010)	• 1995 – Fourth large flood event with water depths in Cambria reaching 6 feet [2, 10]; several landslides occurred in upper watershed [2] • 2000 – Cambria population: 6,232 [14] • 2003 – San Simeon magnitude 6.5 earthquake buckles roads throughout County and alters stream flow patterns in adjacent watersheds [16] • 2009 – Cambria population: 6,624 [17]

Sources:

1. Hamilton 1974
2. D. Dunlap, pers. comm., 2009.
3. Angel 1883
4. Baker 2003
5. Cambria Historical Society, pers. comm., 2009.
6. Harris 1874
7. A. Ochs, pers. comm., 2009.
8. CAL FIRE 2009
9. SLO County Water Resources Division of Public Works rain gauges: Cal Poly #1, Cambria #180, Soto Ranch #169
10. SLO County 2005
11. Coffman 1995
12. Yates and Van Konyenburg 1998
13. CCSD 2009
14. US Census Bureau 2003
15. McEwan and Jackson 1996
16. USGS 2004
17. Cambria Chamber of Commerce, pers. comm., 2009.

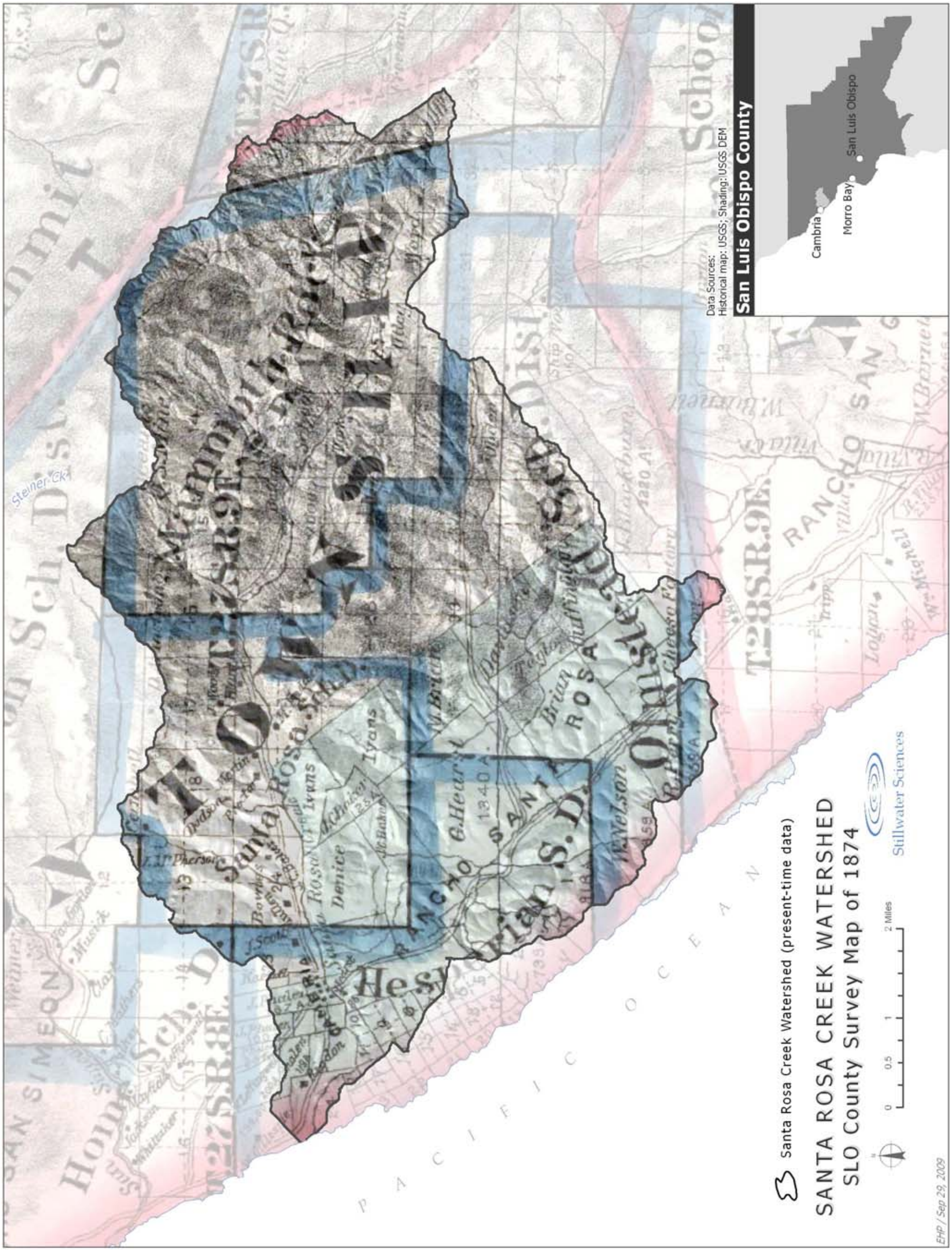

Figure A-1. Santa Rosa Creek watershed and vicinity as depicted in the first survey map of San Luis Obispo County (Harris 1874).

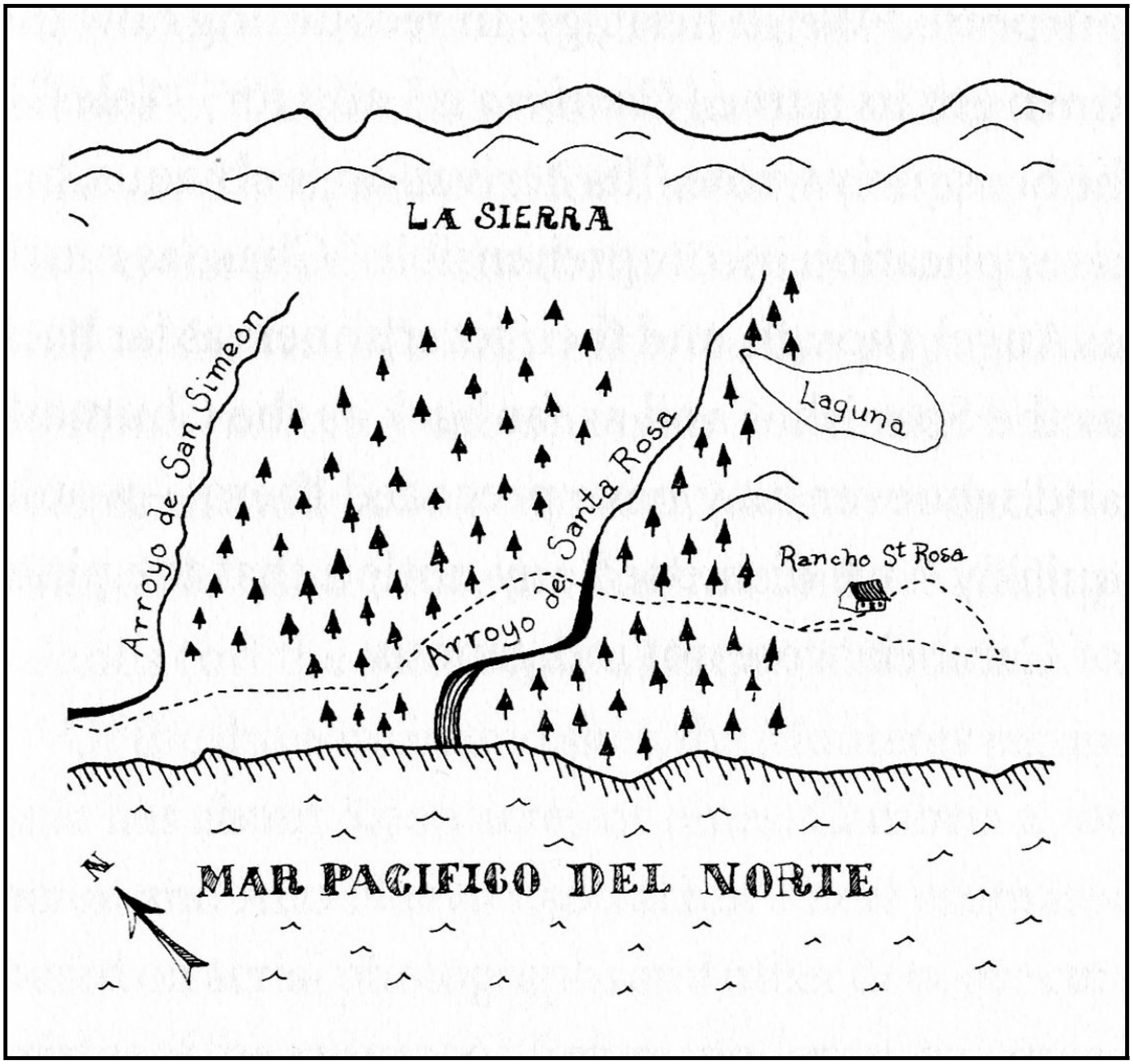

Figure A-2. Illustration of Rancho Santa Rosa drafted by its owner, Don Julian Estrada, as part of his application for the land grant in 1841. Visible in this image are Santa Rosa Creek, the pine tree forest along hillslopes surrounding present-day Cambria, a coastal trail/road running parallel to the coast, and "Estrada Laguna" located along where lower Perry Creek flows into Santa Rosa Creek. Illustration source from Coffman 1995.

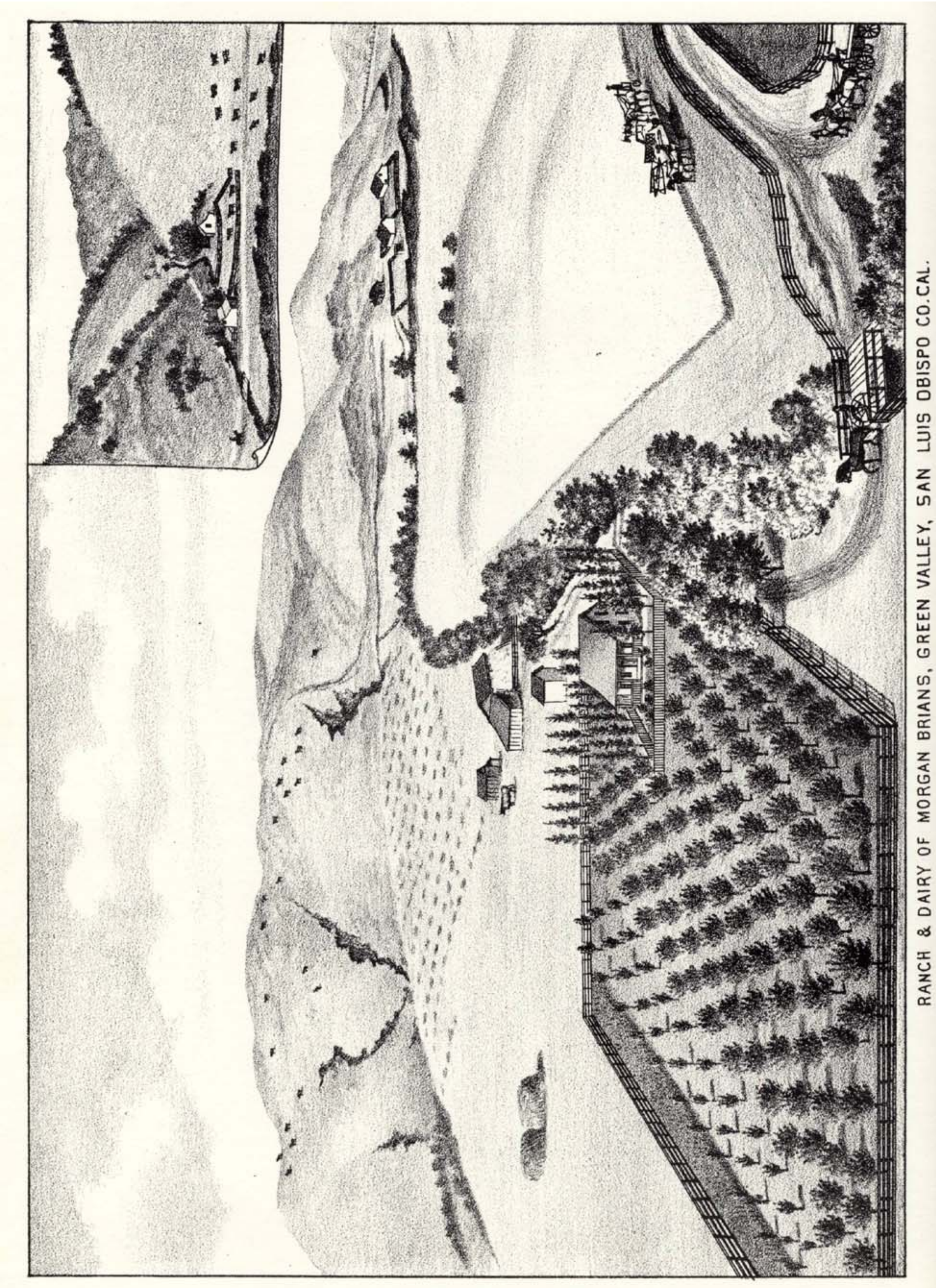

Figure A-3. Historical illustration of the Morgan Brians property in Green Valley (Angel 1883). Illustration depicts hillslopes free of trees or shrubs, with gullies developed in swales.

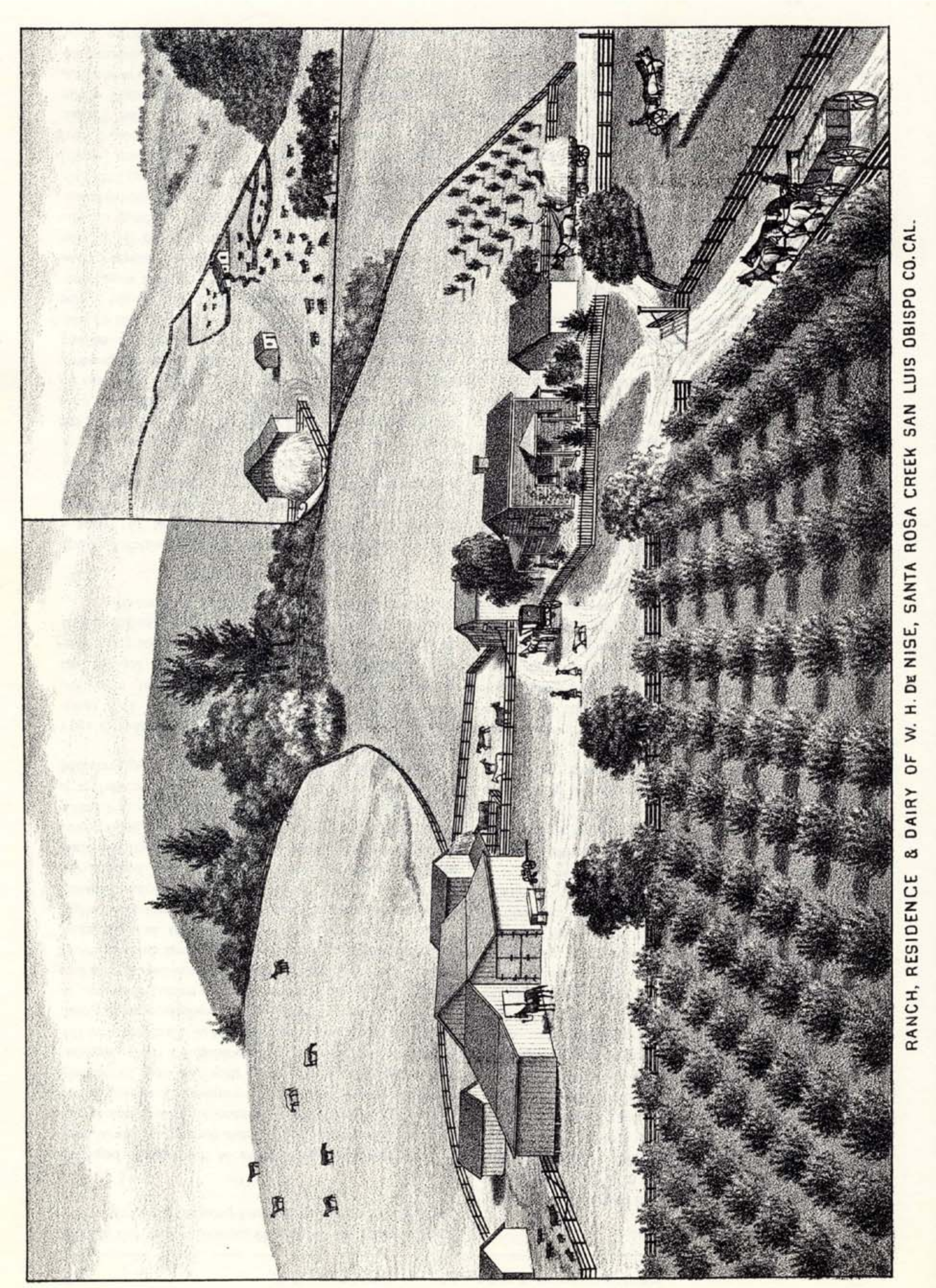

Figure A-4. Historical illustration of the W. H. De Nise property in near in Santa Rosa Creek valley (Angel 1883). Illustration depicts mostly hillslopes free of trees or shrubs, but with patch of forest remaining between ridges.

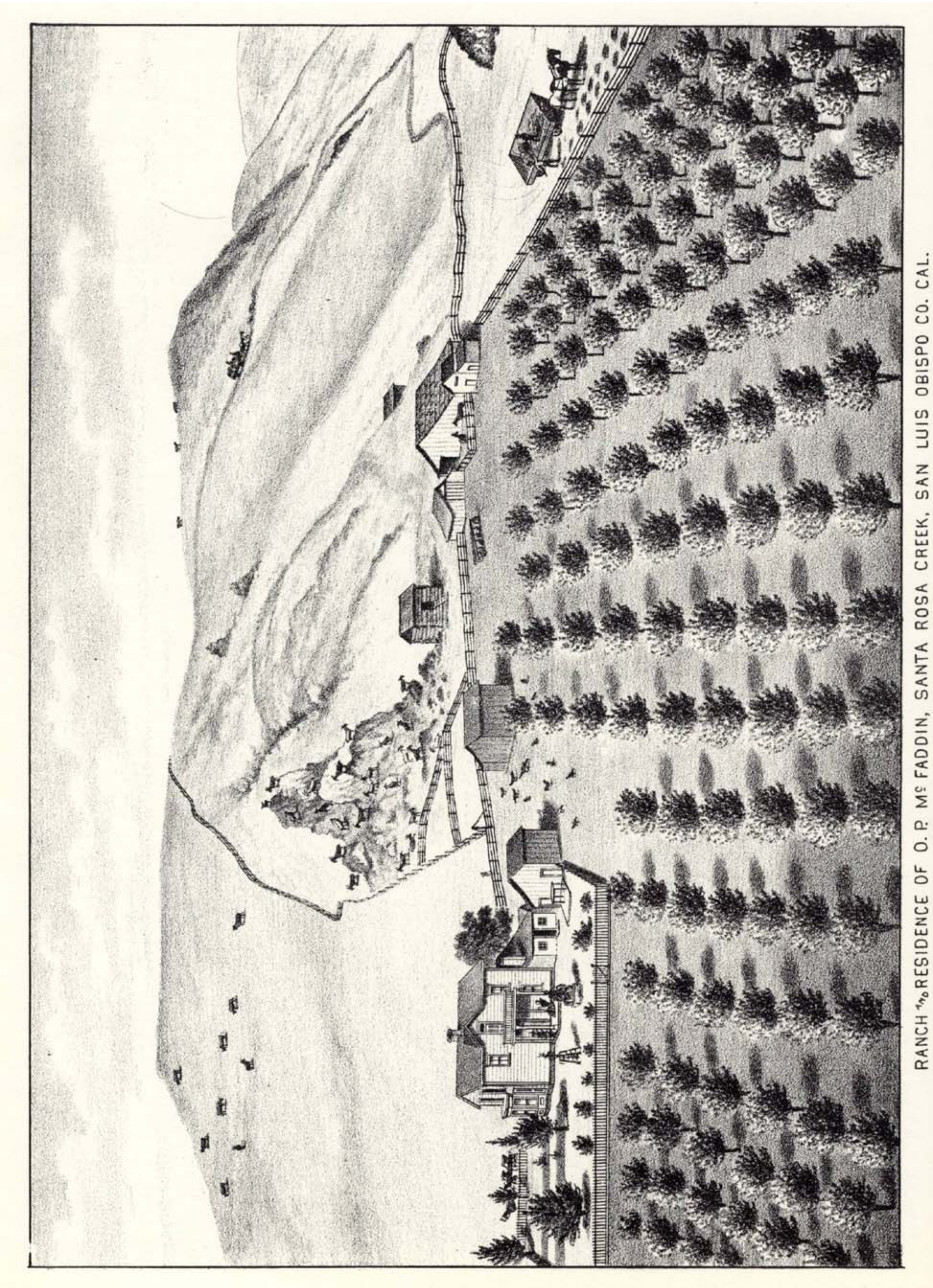

Figure A-5. Historical illustration of the O. P. McFaddin property in the Santa Rosa Creek valley (Angel 1883). Illustration depicts hillslopes free of trees or shrubs, with large bedrock outcrop of Franciscan mélange and gully development in swale behind farm.

Figure A-6. Comparison of similar areas of south-facing, pine tree-covered hillslopes in the Santa Rosa Creek valley near Cambria. Upper photo taken as part of the Wieslander Vegetation Type Mapping project, 11 December 1930. Lower photo taken by G. Leverich, Stillwater Sciences, 27 July 2009.

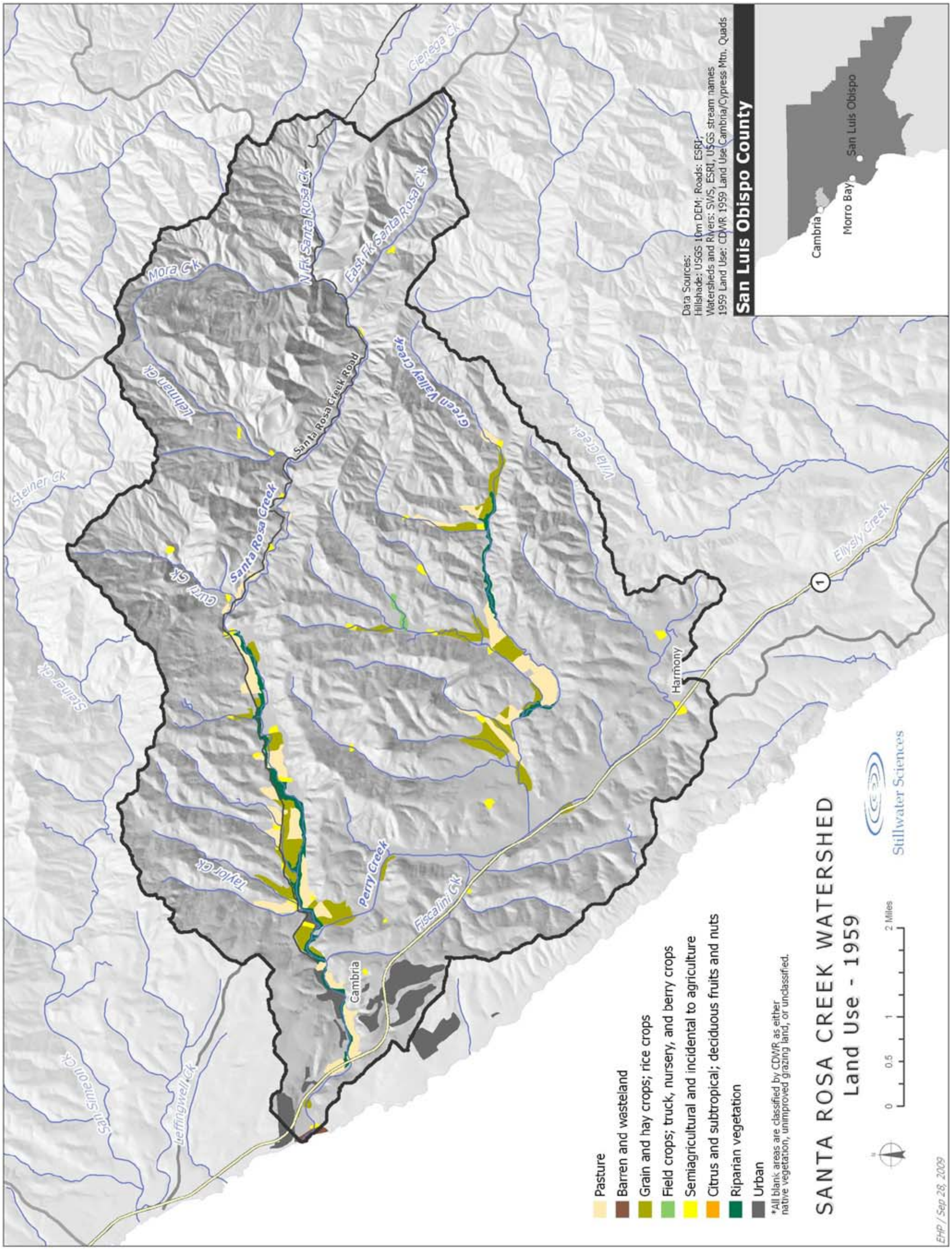

Figure A-7. Land use types present in 1959 within the Santa Rosa Creek watershed (after CDWR 1959).

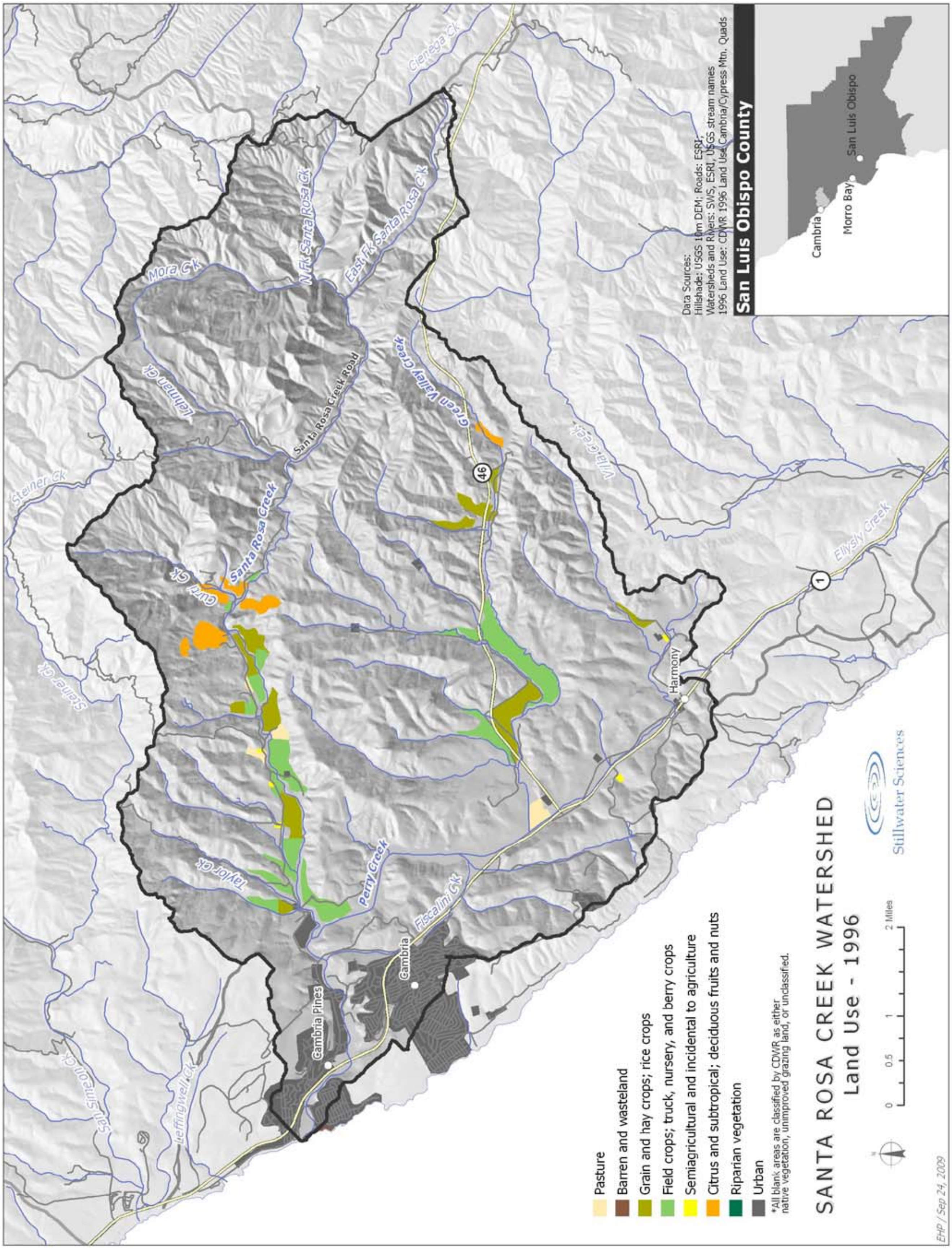

Figure A-8. Land use types present in 1996 within the Santa Rosa Creek watershed (after CDWR 1996).

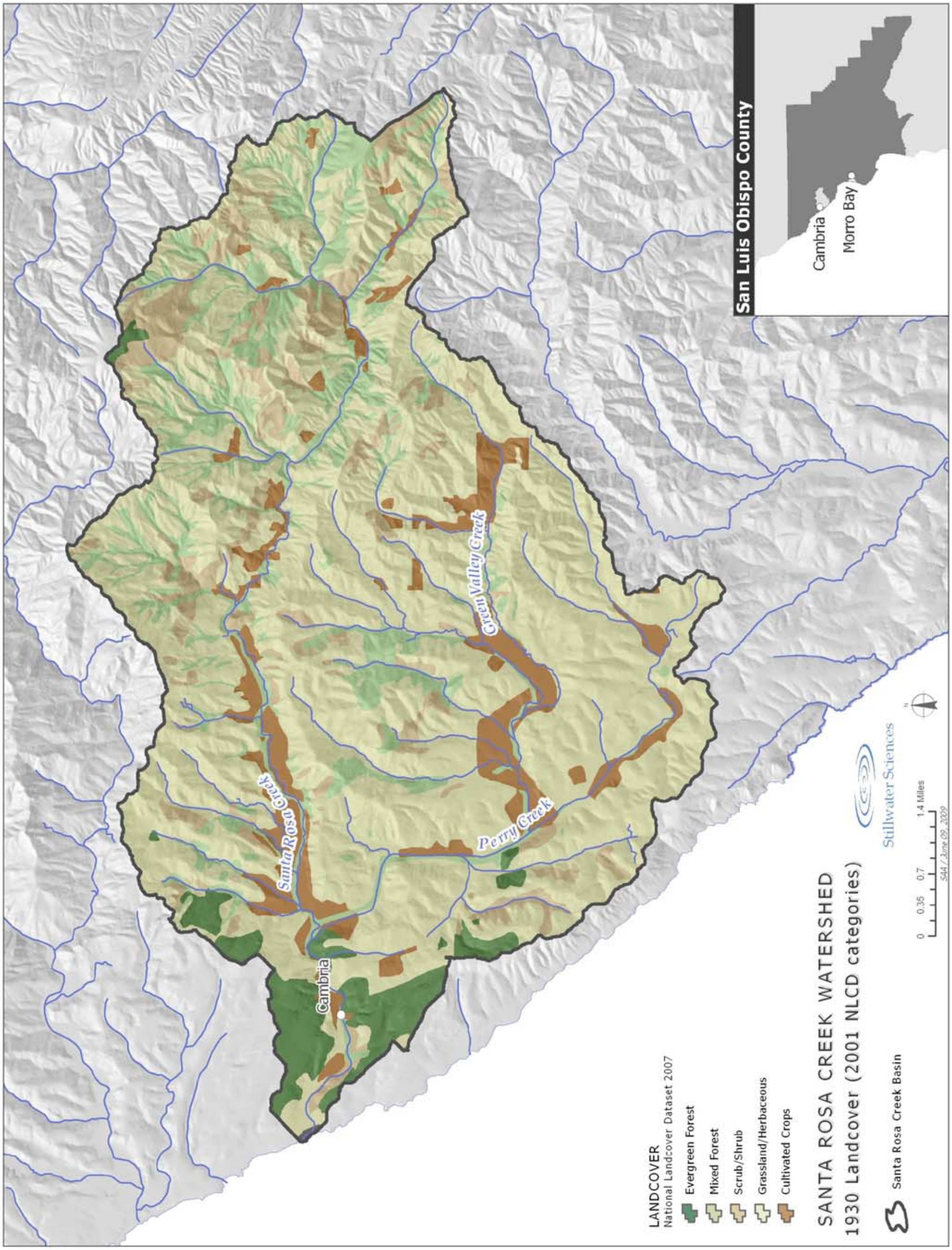

Figure A-9. Land cover present in 1930 within the Santa Rosa Creek watershed (after Weislander 1930).

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Appendix B

Supporting Data for the Geomorphic Landscape Units (GLUs) Analysis

SUPPORTING DATA FOR THE GEOMORPHIC LANDSCAPE UNITS (GLUs) ANALYSIS

This appendix provides supplementary data that were used in the geomorphic landscape unit (GLU) analysis performed for this study to estimate relative sediment production rates across the Santa Rosa Creek watershed. Specifically, data presented here were used in the development of the GLU analysis for this study. The results of the analysis, along with several tables and figures, are presented in the Chapter 3 of the main report. References cited here are listed in the main report.

Geologic Units

Underlying geology information used in the GLU analysis was based on information contained within geology maps published by Dibblee (2007a, 2007b) (see Figure 1-3 in the main report). A list of rock units occurring within the watershed boundaries is presented below in Table B-1, along with rock unit descriptions, relative proportions within the watershed, and the assigned category used in the GLU analysis. Figure 3-3 in the main report shows the generalized geologic categories used in the GLU analysis. These categories represent relative erodibility (i.e., rock strength) of the unit and particle size of the unit's constituent materials (e.g., sand or silt). The relative proportions of the geology GLU categories in the watershed are presented below in Table B-2.

Table B-1. Geologic units within the Santa Rosa Creek watershed.

Geologic unit [1]		Age [1]	Description [1]	% of watershed area [2]	GLU category [3]
Symbol	Explanation				
Qa	Surficial sediments	Holocene	Unconsolidated alluvial gravel, sand, and clay	10.6%	Coarse weak
Qls	Landslide debris	Holocene	Unconsolidated landslide debris	1.9%	Coarse weak
Qm	Marine terrace	Pleistocene	Older marine terraces of unconsolidated cobble-pebble gravel	2.4%	Coarse weak
Tpsl	Pismo Formation	Late Miocene	Marine siltstone or claystone, white, fractured	0.9%	Fine weak
Tps	Pismo Formation	Late Miocene	Marine sandstone, light brown, fine to medium grained, arkosic	0.6%	Coarse competent
Tm	Monterey Formation	Miocene	Marine shale, white weathered, thin-bedded, brittle,	0.03%	Fine weak
Tml	Monterey Formation	Miocene	Marine shale, cream-white to tan, thin-bedded, platy to soft fissile to silty	11.2%	Fine weak
Tt	Monterey Formation	Miocene	Marine tuff, white, very fine-grained	0.1%	Fine weak

Geologic unit [1]			Age [1]	Description [1]	% of watershed area [2]	GLU category [3]
Symbol	Explanation					
Tb	Obispo Formation		Miocene	Basalt, black weathered dark brown, find-grained, massive, somewhat incoherent, locally pillowed, includes intrusive diabase	2.7%	Coarse weak
Tot	Obispo Formation		Miocene	Volcanic tuff and tuff breccia, white to tan	0.4%	Coarse competent
Tr	Rincon Formation		Early Miocene	Marine claystone and siltstone, gray to light brown, vaguely bedded, crumbly	0.7%	Fine weak
Tvq	Vaqueros Formation		Early Miocene / Late Oligocene	Marine sandstone, light gray to light brown, arkosic	2.7%	Coarse competent
Tlc	Lospe Formation		Oligocene	Non-marine green to red conglomerate, sandstone, and claystone with clasts of volcanic rocks and Franciscan detritus (fs and fg)	2.1%	Coarse competent
Tf	Cambria Felsite		Oligocene	Volcanic: hard rhyolite-dacite gray-white felsite with some soft white tuff, poorly bedded	1.2%	Coarse competent
Kss	Unnamed Sedimentary Rocks		Upper Cretaceous	Marine sandstone, arkosic, with some micaceous shale	8.6%	Coarse weak
Ktsh	Toro Formation		Cretaceous	Marine clay shale, dark gray, micaceous, thin layers of fine-grained sandstone	1.1%	Fine weak
sp	Serpentinite		Jurassic-Cretaceous	Metamorphosed ultramafic igneous rocks, blue-green-gray, fractured with slickensided surfaces	2.2%	Coarse weak
fm	Franciscan Assemblage (marine, sedimentary and volcanic rocks)	Mélange	Jurassic-Cretaceous	Mix of sheared rocks, mostly greywacke and argillite, with fragments of fc, fs, fg	47.8%	Coarse weak
fc		Chert	Jurassic-Cretaceous	Chert, brittle, thin-bedded; contorted	0.3%	Coarse weak
fs		Graywacke	Jurassic-Cretaceous	Graywacke sandstone, hard, massive, shattered	1.3%	Coarse weak

Geologic unit [1]			Age [1]	Description [1]	% of watershed area [2]	GLU category [3]
Symbol	Explanation					
fg		Greenstone	Jurassic-Cretaceous	Greenstone altered from basalt, moderately sheared	1.3%	Coarse competent

[1] After Dibblee 2007a, 2007b.
[2] Proportion of rock unit within the total watershed area determined in GIS.
[3] GLU category based on literature information and field observations.

Table B-2. Geology GLU categories within the Santa Rosa Creek watershed.

GLU xategory [1]	% of watershed area [2]
Coarse competent	8.2%
Coarse weak	77.8%
Fine weak	14.0%

[1] GLU category based on literature information and field observations.
[2] Proportion of geology GLU category within the total watershed area determined in GIS.

Land Cover Units

Land cover was based on a data contained within the National Land Cover Database of 2001 (Homer et al. 2004) at 30-m resolution (see Figure 1-6 in the main report). A list of land cover types occurring within the watershed boundaries is presented below in Table B-3, along with relative proportions within the watershed and the assigned category used in the GLU analysis. Figure 3-7 in the main report shows the generalized land cover categories used in the GLU analysis. These categories represent a simplified division of land cover, or vegetation types as they relate to a relative degree of erosion resistance in different landscape units (e.g., forested hillslopes would be less erodible than those covered only with grasses). The relative proportions of the land cover GLU categories in the watershed are presented below in Table B-4.

Table B-3. Land cover classes within the Santa Rosa Creek watershed.

Land cover classes [1]	% of watershed area [2]	GLU category [3]
Developed, open space	6.4%	Developed
Developed, low intensity	1.3%	Developed
Developed, medium intensity	0.4%	Developed
Developed, high intensity	0.01%	Developed
Evergreen forest	6.4%	Forest
Mixed forest	9.5%	Forest
Scrub/shrub	10.6%	Scrub/shrub
Grassland/herbaceous	63.4%	Ag/grass
Pasture/hay	0.1%	Ag/grass
Cultivated crops	1.2%	Ag/grass
Woody wetlands	0.5%	Scrub/shrub
Emergent herbaceous wetland	0.01%	Ag/grass

[1] Source: National Landcover Dataset of 2001 (Homer et al. 2004).
[2] Proportion of land cover category within the total watershed area determined in GIS.
[3] GLU category based on literature information and field observations.

Table B-4. Land cover GLU categories within the Santa Rosa Creek watershed.

GLU category [1]	% of watershed area [2]
Forest	16.0%
Scrub/shrub	11.1%
Ag/grass	64.7%
Developed	8.2%

[1] GLU category based on literature information and field observations.
[2] Proportion of land cover GLU category within the total watershed area determined in GIS.

Hillslope Gradient Units

Hillslope gradients in the watershed were based on elevation data contained within a 10-m resolution digital elevation model (DEM) dataset provided by the USGS. Using this data in a GIS, a histogram of hillslope gradient values were plotted to visualize the distribution of slopes in the watershed (Figure B-1). For the purposes of the GLU analysis, it is necessary to group the slope values into as few classes as possible provided that each class represents unique ranges of relative erosion and slope instability in the watershed. Based on the distribution of slopes and on field observations, the continuous range of hillslope gradients was categorized into three groups: 0-10%, 10-40%, and steeper than 40% (Table B-5; see Figure 3-8 in the main report).

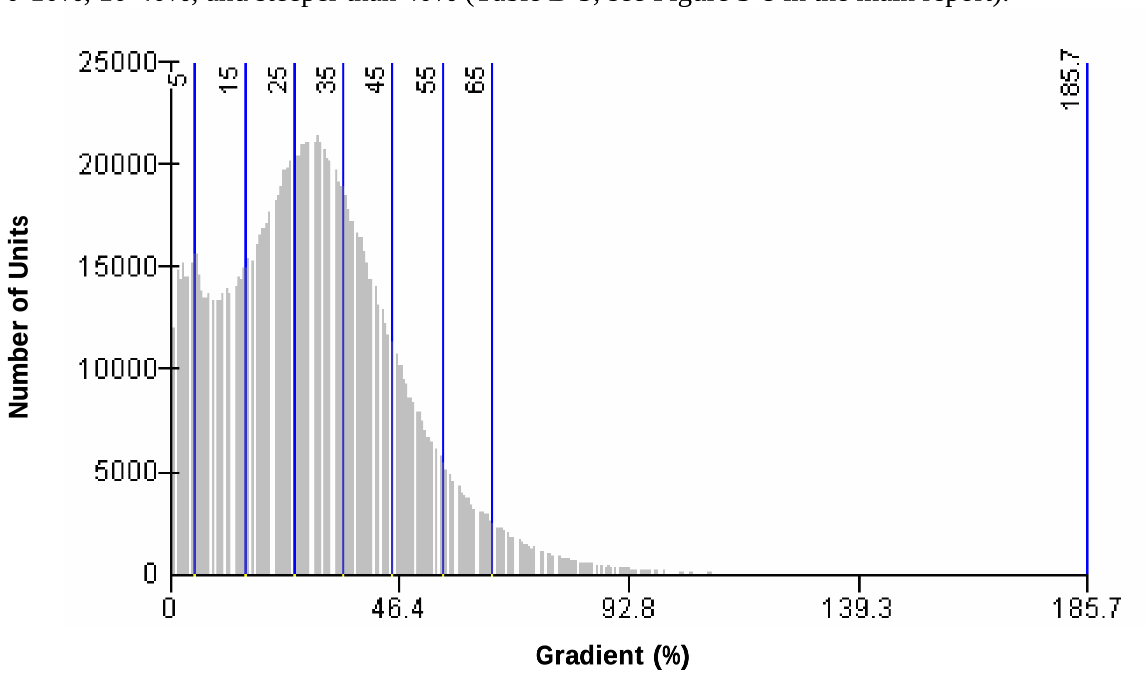

Figure B-1. Histogram of hillslope gradient values in the Santa Rosa Creek watershed.

Table B-5. Hillslope gradient GLU categories within the Santa Rosa Creek watershed.

GLU Category [1]	% of Watershed Area [2]
0-10%	15.3%
10-40%	60.1%
>40%	24.6%

[1] GLU category based on distribution histogram statistics and field observations.
[2] Proportion of hillslope gradient GLU category within the total watershed area determined in GIS.

Appendix C

Channel Reach Descriptions

DESCRIPTIONS OF CHANNEL REACHES

This appendix provides supplementary information on the channel morphology of the stream reaches delineated for the watershed geomorphology assessment. This reach information is based on field assessments made as part of an in-channel geomorphic survey conducted during July 2009. The purpose of the survey was to examine the current conditions in the mainstem Santa Rosa Creek and major tributaries in order to help understand controls on current geomorphic process and help inform the watershed management plan. The geomorphic survey included traversing the mainstem channel and examining geomorphic characteristics and sediment transport dynamics. In addition to general geomorphic information noted during the traverse and estimates of bed particle size, detailed geomorphic data were also collected at 25 locations (15 sites along the mainstem channel at representative locations and 10 sites at major tributaries confluences). The general information and detailed data were compiled with other data sources (e.g., DEM-derived channel network) to develop a comprehensive geomorphic characterization of the channel. The survey locations are shown in Figure C-1 and the geomorphic characterization by channel reach is detailed below. The reaches are shown in Figure 4-6 of the main document.

Upper Zone

The upper-most reach in the Upper Zone (Reach U1) begins at the confluence with Mora Creek and extends 2.4 km downstream to the Unnamed Trib SRC-1 confluence. Throughout the course of this reach, the channel is steep, coarse-bedded, and highly confined by the adjacent valley wall (left bank) and Santa Rosa Creek Rd (right bank). The average reach channel gradient is the steepest of all reaches in the mainstem Santa Rosa Creek subbasin (2.29%), and is strongly influenced by exposed bedrock. Bankfull channel width and depth are relatively low (8–10 m and 0.75–1.0 m, respectively) and the channel bed is moderately entrenched (i.e., several meters below the adjacent, narrow left bank floodplain terrace). The channel transitions from a cascade/plane bed morphology in the steeper upstream end to a pool-riffle morphology at the downstream end where the local channel gradient decreases. The channel bed elevation appears to be relatively stable (as determined from mature vegetation in the active channel) and the bed texture is predominantly poorly-sorted boulder-gravel-cobble (BGC), with a median particle size (D_{50}) between 64 to 128 mm. Channel bars have a similar texture as the bed and are well-vegetated and stable (as determined from mature vegetation on bars), with recent fine sediment deposits on many bars from the last major storm event. Channel banks are composed of bedrock and fine sediment deposits over bedrock, are well-vegetated, and appear to have a low to moderate amount of erosion over the past several decades (based on bank erosion estimates using exposed tree roots at eroding banks and estimated tree age). The reach appears to have some flow throughout the year (summer baseflow at the time of the survey was between 2 to 4 cfs).

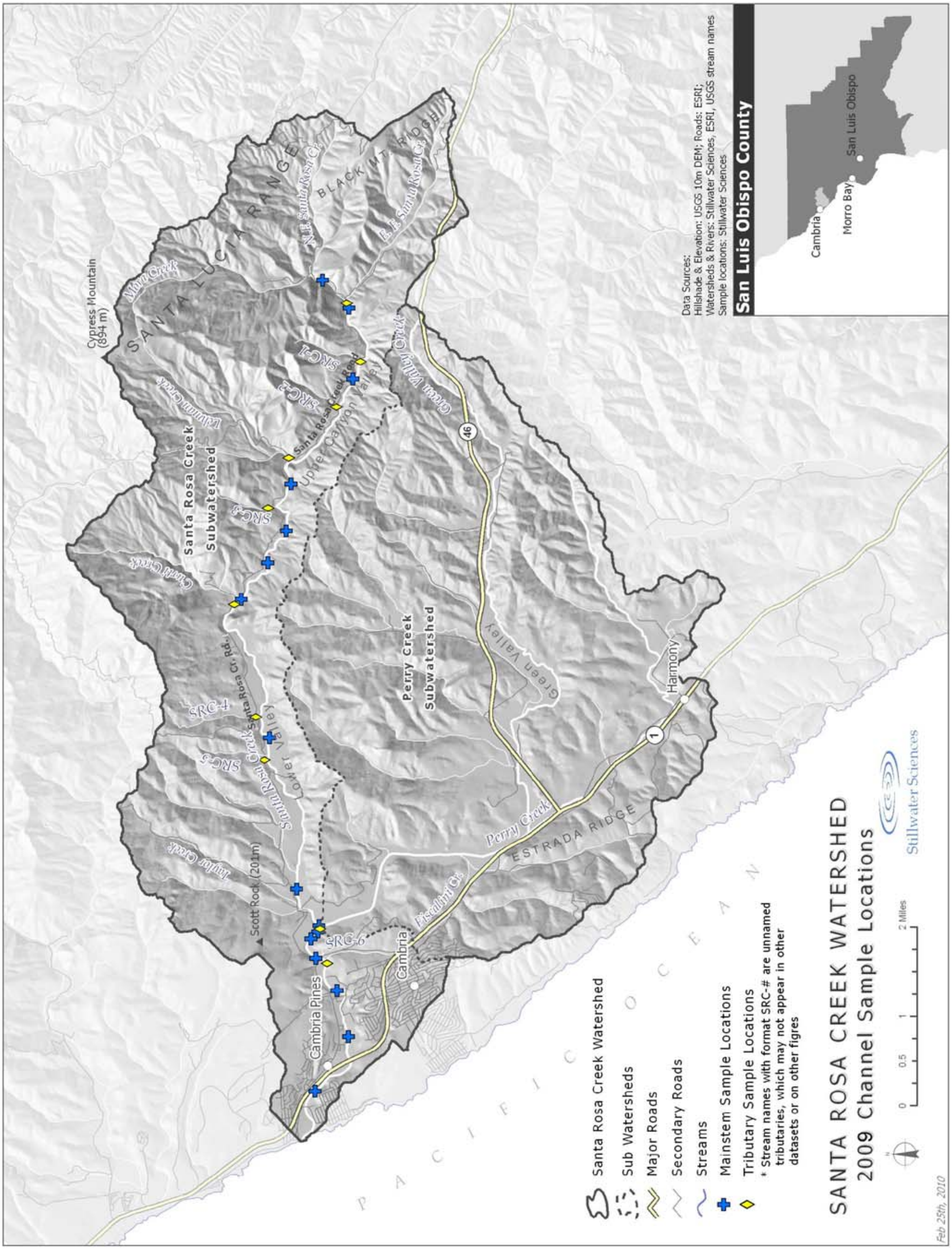

Figure C-1. Stream survey locations along Santa Rosa Creek.

East Fork Santa Rosa Creek enters Reach U1 approximately midway through the reach and is one of the few tributaries in the reach that appears to be a notable source of sediment. At the confluence with Santa Rosa Creek, East Fork Santa Rosa Creek has a relatively moderate channel gradient (1–2%), is moderately entrenched (3–6 m), and appears to have no summer baseflow (as determined from the lack of flow during the summer 2009 field visit). The tributary delivers sediment ranging in size from silt/sand to boulders, but the depositional bar at the mouth suggests the load is predominantly BGC (D_{50} between 64 to 128 mm). The tributary currently appears to be a moderate source of coarse sediment and a low source of fine sediment to the mainstem Santa Rosa Creek, however sediment delivery from the tributary is currently influenced by LWD-induced sediment deposition beginning ~30 m upstream from the confluence. It is not known, the length of time that this hydraulic control has been affecting sediment deposition or how far upstream East Fork Santa Rosa Creek the depositional zone extends.

In spite of it's relatively small drainage area (0.6 km^2), Unnamed Trib SRC-1 appears to be a relatively important source of sediment to mainstem Santa Rosa Creek within Reach U1. Unnamed Trib SRC-1 is a short, steep channel (gradient >5%) on the south-facing hillslopes that appears to have no summer baseflow. Like most Santa Rose Creek tributaries draining south-facing hillslopes, the channel goes through a culvert under Santa Rosa Creek Road before entering mainstem Santa Rosa Creek. Upstream of the culvert, the channel is predominantly depositional but is incised 0.5–1 m. Downstream of the culvert, the channel is unstable and has several headcuts. The tributary delivers sediment ranging in size from silt/sand to boulders, but the sediment load appears to be predominantly CG (D_{50} between 32 to 64 mm). The tributary currently appears to be a moderate source of coarse sediment and a low source of fine sediment.

Downstream of Reach U1, the channel enters a lower gradient, less confined reach that extends downstream for approximately 2.1 km (Reach U2). The average reach channel gradient is relatively steep compared to the other mainstem Santa Rosa Creek reaches (1.17%), although it is approximately one-half the value for Reach U1. Similar to Reach U1, channel gradient throughout the entire reach is strongly influence by exposed bedrock. The decreased channel confinement contributes to a wider bankfull channel than upstream (12–14 m), however bankfull depth is similar to upstream values (0.75–1.0 m). The channel bed is moderately entrenched (but less entrenched than upstream) and has a pool-riffle morphology throughout the reach. The bed elevation appears to be stable and somewhat aggradational (as determined from mature vegetation in the active channel) and the channel bed texture is predominantly cobbley-gravel (CG) and more well-sorted than upstream (D_{50} between 32 to 64 mm). Channel bars have a similar texture as the bed, are well-vegetated and appear stable/aggrdational and more mobile than bars in upstream reach. Channel banks are predominantly composed of bedrock, are well-vegetated, and appear relatively stable but somewhat more erosional than banks upstream. The reach appears to have flow throughout the year and has a summer baseflow discharge similar to Reach U1 (between 2 to 4 cfs).

Unnamed Trib SRC-2 enters the mainstem Santa Rosa Creek in the middle of Reach U2 and appears to be a primary source of sediment to mainstem Santa Rosa Creek within the reach. At the confluence with Santa Rosa Creek, Unnamed Trib SRC-2 has a relatively steep channel (gradient of 2–4%) with no summer baseflow. Similar to the other south-facing valley wall tributaries, the channel goes through a culvert under Santa Rosa Creek Road before entering mainstem Santa Rosa Creek. Upstream of the culvert, the channel has a relatively narrow riparian buffer (low herbaceous vegetation and some mature trees) and appears to be eroding through a recent sediment deposit. Downstream of the culvert, the channel has several headcuts and is incised 2–3 m. The tributary delivers sediment ranging in size from silt/sand to fine gravel, but the sediment load appears to be predominantly fine gravel (Gf) (D_{50} between 2 to 4 mm). The tributary currently appears to be a low source of coarse sediment and a moderate source of fine sediment.

The channel then transitions to a 3.3 km long reach that is characterized by a meandering channel and a more erosional bed (i.e., sediment supply-limited conditions) than upstream reaches (Reach U3). The average reach channel gradient is relatively steep compared to the other mainstem Santa Rosa Creek reaches (1.16%) and is essentially the same as Reach U2. Channel gradient is strongly influenced by both bedrock exposures and bend-induced sediment deposition along the entire reach. Bankfull width throughout this reach is very similar to the bankfull width for Reach U2 (estimates range from 11 to 15 m), however bankfull depth is slightly greater (estimates range from 1.0 to 1.25 m). The channel bed is moderately entrenched (but is more entrenched than Reach U2) and the channel has a pool-riffle morphology in the lower gradient, less confined sections and plane bed morphology in the steeper, more confined sections. Pools within this reach have more fine sediment accumulation than seen upstream and are up to 50 m in length. The channel bed appears to be somewhat incising and channel bed texture is predominantly poorly-sorted CG (D_{50} between 32 to 64 mm). Channel bars have a finer texture than the channel bed (CG with a D_{50} between 16 to 32 mm) and range from well-vegetated and stable to moderately stable and more mobile/depositional. Several vegetated bars at the downstream end of the reach have recent fine sediment deposits. Channel banks are predominantly composed of alluvial deposits (finer and coarse sediment) with bedrock exposures, are well vegetated, and appear moderately stable. Bank erosion estimates range from 0.3 to 0.6 m in the last 30–40 years to 0.6–1.3 m in the past 40–50 years (based on vegetation indicators). The reach appears to have flow throughout the year and has a summer baseflow discharge similar to the upstream reaches (between 2 to 4 cfs).

Lehman Creek is the most upstream major tributary (i.e., large watershed area and high sediment load) draining all of the south-facing hillslopes along mainstem Santa Rosa Creek (downstream of Mora Creek) and enters the mainstem Santa Rosa Creek towards the upstream end of Reach U3. At the confluence with Santa Rosa Creek, Lehman Creek has a relatively steep channel gradient (3–4%), is moderately entrenched, and has a relatively high summer baseflow compared to other tributaries (~5 cfs). The tributary delivers sediment ranging in size from silt/sand to boulders, but the relatively large depositional bar at the mouth suggests that the load is predominantly BCG (D_{50} between 32 to 64 mm). Lehman Creek currently appears to be a high source of coarse sediment and a moderate to low source of fine sediment to the mainstem Santa Rosa Creek.

Unnamed Trib SRC-3 enters the mainstem Santa Rosa Creek in the middle of Reach U3 and appears to be the secondary source of tributary-derived sediment in the reach. Unnamed Trib SRC-3 drains a steep, south-facing catchment and has a relatively moderate channel gradient (2–3%) and high degree of channel entrenchment (~10 m) at the confluence with Santa Rosa Creek. The tributary also has mature riparian vegetation close to the confluence and no summer baseflow. There appears to be historic bank failures adjacent to the road culvert under Santa Rosa Creek Rd associated with the road crossing. The tributary delivers sediment ranging in size from silt/sand to cobbles, but the load appears to be predominantly CG (D_{50} between 16 to 32 mm). Unnamed Trib SRC-3 currently appears to be a low to moderate source of both coarse and fine sediment to mainstem Santa Rosa Creek.

Downstream of Reach U3, the channel then enters a somewhat more confined reach that extends 1.8 km downstream to Mammoth Rock (Reach U4). The average reach channel gradient is relatively steep compared to the other mainstem Santa Rosa Creek reaches (1.20%) but is essentially the same as Reach U3. Channel gradient is strongly influence by the Mammoth Rock bedrock outcrop and associated channel meander at the downstream end of the reach. Bankfull width throughout this reach is very similar to estimates for both Reaches U2 and U3 (estimates range from 11 to 12 m) and bankfull depth is similar to estimates for Reach U3 (estimates range from 1.0 to 1.25 m). The channel bed is moderately entrenched (but less entrenched than Reach U3) and channel morphology can be classified as glide/run, as there is no distinct morphologic structure or depositional bars. The channel bed texture is predominantly well-sorted CG (D_{50} between 32 to 64 mm). The bed sediment is somewhat indurated (i.e., cemented) and downstream hydraulic control induced by Mammoth Rock makes this an aggradational reach. Channel banks are predominantly composed of alluvium deposits (finer and coarse sediment) with bedrock exposures, are well-vegetated, and appear relatively stable. Summer baseflow is infiltrated into the channel bed at the upstream end of the reach and re-emerges at the downstream end of the reach where the channel becomes confined by Mammoth Rock.

Curti Creek is the most downstream major tributary draining the south-facing hillslopes along mainstem Santa Rosa Creek (downstream of Mora Creek) and enters mainstem Santa Rosa Creek in the middle of Reach U4. At the confluence with Santa Rosa Creek, Curti Creek has a relatively steep channel gradient (ranging from 2 to 4% at the mouth to 4 to 8% 50 m upstream), is moderately entrenched (~3 m) with lower inset terraces, and has no summer baseflow. The tributary delivers sediment ranging in size from silt/sand to boulders, but the relatively large depositional bar at the mouth suggest that the load is predominantly CG (D_{50} between 32 to 64 mm). Sediment storage upstream of the Santa Rosa Creek Rd culvert is relatively high. The considerable amount of embeddeness by finer sediment and mature vegetation on the bar surface suggests that the bar is stable/depositional. Curti Creek currently appears to be a high source of coarse and fine sediment to the mainstem Santa Rosa Creek.

Middle Zone

Downstream of Mammoth Rock, the channel confinement decreases and the channel enters the Middle Zone. The upper-most reach in the Middle Zone is within a broad alluvial and is valley that allows active thalweg migration. The average reach channel gradient is moderate compared to the other mainstem Santa Rosa Creek reaches (0.80%) and is strongly influenced by exposed bedrock and channel confinement at the downstream end of the reach. The channel bed is very entrenched (~10 m below adjacent terrace) and is organized into a quasi pool-riffle morphology in short steeper sections, but generally lacks a coherent morphology throughout most of the reach. The channel bed texture is predominantly poorly-sorted GC (D_{50} between 32 to 64 mm). Channel banks are composed of alluvium except along sections at the upstream and downstream ends of the reach where the channel is up against bedrock along the right bank. Where channel banks are composed of alluvium, the banks are actively eroding and are a local supply of fine sediment. Summer baseflow is infiltrated into the channel bed at the upstream end of the reach and re-emerges at the downstream end of the reach where the channel becomes more confined.

Unnamed Trib SRC-4 enters the mainstem Santa Rosa Creek towards the downstream end of Reach M1 and appears to be the primary source of tributary-derived within the reach. At the confluence with Santa Rosa Creek, Unnamed Trib SRC-4 has a relatively steep channel (gradient of 2–4%), is highly incised (~5 m below the adjacent terrace), and has no summer baseflow. Local channel gradient is strongly influenced by the bridge the channel passes through before the confluence with Santa Rosa Creek, and the channel is currently incising through the sediment deposit upstream of the bridge. Observations of the current channel condition and location within the adjacent floodplain suggest that the channel has moved east towards the toe of the adjacent valley wall sometime in the past century. The tributary delivers sediment ranging in size from silt/sand to boulders, but the sediment load appears to be predominantly very coarse gravel (Gvc) (D_{50} between 32 to 64 mm. The tributary currently appears to be a moderate source of coarse sediment and a low source of fine sediment.

At the downstream extent of Reach M1, the channel transitions to a 2.4 km long reach that is characterized by a moderately confined, meandering channel (Reach M2). The average reach channel gradient is somewhat less than Reach M1 but still moderate compared to the other mainstem Santa Rosa Creek reaches (0.62 %) and is strongly influence by exposed bedrock and meander-induced deposition. The channel is very entrenched (~10 m below adjacent terrace) and has a pool-riffle morphology with low terraces that are up to 1 m above the channel bed. Bankfull width estimates along the reach range from 12 to 14 m and bankfull depth estimates range from 0.75 to 1 m. The channel bed elevation appears to be relatively stable/aggradational and the bed texture is predominantly well-sorted GC, with the D_{50} between 32 to 64 mm range. Channel bars are generally somewhat finer than the bed (Gc with a D_{50} between 16 to 32 mm) and vary in degrees of mobility (i.e., bars range from well-vegetated to bare). Several bars with established vegetation have recent fine sediment deposits. Channel banks are composed of bedrock and fine-grained alluvium and are predominantly well-vegetated. Meander bends through this reach have a relatively high bank erosion rate compared to the rest of the reach (estimates from vegetation indicators are as high as 0.75 m in the past 10–20 years) and provide a local supply of fine sediment. Summer baseflow through this reach is somewhat lower than in upstream reaches (summer baseflow at the time or the survey was between 1 to 2 cfs).

Unnamed Trib SRC-5 enters mainstem Santa Rosa Creek in the middle of Reach M2 and appears to be the primary source of tributary-derived sediment within the reach. Unnamed Trib SRC-5 drains a small south-facing catchment and has no summer baseflow. Channel morphology and sediment delivery dynamics are strongly influenced by an old (80–100 years old) road culvert the channel passes through before the confluence with Santa Rosa Creek. Upstream of the culvert, the channel has a relatively moderate gradient (~1 %) and the channel appears stable (as determined from mature riparian vegetation established on the channel bed). Downstream of the culvert, the channel is approximately 8–10 m below the culvert elevation, has a relatively moderate gradient (~1 %), and has banks that are actively eroding. Similar to Unnamed Trib SRC-4, the channel appears to have changed course some time in the past. The tributary delivers sediment ranging in size from silt/sand to coarse cobble, but the sediment load appears to be predominantly medium (D_{50} between 8 to 16 mm). The channel appears to be a moderate supply of both coarse and fine sediment.

The channel then transitions to a moderately confined and entrenched reach that extends 2.4 km to the Perry Creek confluence (Reach M3). The average reach channel gradient through this reach is somewhat steeper than Reach M2, but still moderate compared to the other mainstem Santa Rosa Creek reaches (0.75 %). In-channel bedrock exposure and bend-induced deposition are the primary controls on reach-average channel gradient throughout reach. Local influences on channel gradient and sediment depositional/transport dynamics include the Fistillini Restoration site, a large in-channel LWD structure downstream of the Taylor Creek confluence, and the Fish Ladder. The channel is moderately entrenched for most of the reach (~2–5 m below adjacent terrace) and has a pool-riffle morphology with several long glide/run sections. Bankfull width estimates along the reach range from 9 to 11 m and bankfull depth estimates range from 1 to 1.25 m. The channel bed elevation appears to be relatively stable/aggradational and the bed texture is predominantly well-sorted cobble-gravel (D_{50} between 32 to 64 mm). Channel bars range from coarser-grained stable bars with mature vegetation to finer-grained mobile bars with little to no vegetation cover. Depositional bars can be relatively large compared to upstream reaches, particularly at channel bends. Similar to upstream reaches, bars with established vegetation have recent fine sediment deposits. Channel banks are predominantly composed of fine-grained alluvium, are well-vegetated, and appear relatively stable. Summer baseflow at the time of the survey is estimated to have been between 1 to 2 cfs.

Perry Creek is the largest tributary entering mainstem Santa Rosa Creek and is therefore a primary source of sediment to Reach M3. At the confluence with Santa Rosa Creek, Perry Creek has a relatively low channel gradient (<1%), is very entrenched (8–10 m below the adjacent terrace), and has no summer surface flow yet appears to be discharging subsurface water to mainstem Santa Rosa Creek during the summer (as suggested by the deep pool at the confluence). Approximately 600-m upstream of the confluence is a 2-m high knickpoint that appears to be a result of historic channel re-alignment and re-grading. In general, the tributary has a relatively fine sediment load that includes sediment ranging in size from silt to fine gravel. The very large depositional bar at the mouth suggests that the load is predominantly very fine gravel (Gvf) (D_{50} between 2 to 4 mm). Perry Creek currently appears to be a low source of coarse sediment and a high source of fine sediment to the mainstem Santa Rosa Creek.

Lower Zone

Downstream of the Perry Creek confluence, the gradient decreases and the channel enters the Lower Zone. The upper-most reach (Reach L1) extends 2.9 km downstream from the Highway 1 bridge through Cambria Pines and is characterized by a confined meandering channel. The average reach channel gradient through this reach is relatively low (0.33 %) and less than one-half the gradient of the upstream reach. In-channel bedrock exposure and bend-induced deposition strongly influence reach-average channel gradient throughout reach. The channel is moderately entrenched and has a pool-riffle morphology with several long glide/run sections. Bankfull width estimates along the reach range from 12 to 19 m and bankfull depth estimates range from 1 to 1.25 m. The channel bed elevation appears to be relatively stable for the most part, with localized areas of scour and deposition resulting from localized channel confinement and in-channel bridge infrastructure. The channel bed texture is predominantly poorly-sorted cobble-gravel (D_{50} between 32 to 64 mm), although there are several areas where the bed is composed of poorly-sorted sandy gravel (D_{50} ranging between 4 to 8 mm and 16 to 32 mm). Channel bars have a similar texture as the channel bed and range from relatively mobile bars with little vegetation cover to relatively static bars with mature vegetation established. Vegetated bars at the downstream end of the reach have recent fine sediment deposits. Channel banks are composed of bedrock and fine-grained alluvium, are well-vegetated, and appear moderately stable throughout. Bank erosion estimates range from <0.3 m in the past 20–30 years to >0.6 m in the past 10 years. At the downstream end of the reach, rip rap has been placed at bank toes to help deflect flow in an effort to prevent localized bank erosion. Summer baseflow at the time of the survey is estimated to have been between 1 to 2 cfs at the upstream end of the reach and becoming less downstream as the flow infiltrated into the channel bed.

Unnamed Trib SRC-6 drains a steep, relatively small north-draining catchment (0.8 km^2) that enters mainstem Santa Rosa Creek towards the upstream end of Reach L1 and is the dominant tributary sediment source in the reach. At the confluence with Santa Rosa Creek, Unnamed Trib SRC-6 has a relatively moderate slope that becomes steep at the channel mouth (1–2 %), is moderately entrenched (1–2 m below the adjacent terrace), and has no summer baseflow. Local tributary channel gradient and sediment transport/deposition dynamics are strongly influenced by in-channel LWD approximately 20 m upstream of the confluence. The large bar at the mouth appears to have been deposited in the recent past, causing the tributary channel to change course and the confluence to migrate approximately 10 m downstream. Observations of the channel bed upstream of the confluence and the large bar at the confluence suggest that the tributary has a load ranging from silt/sand to boulders, with a current sediment load that is predominantly very coarse gravel (D_{50} between 32–64 mm). Coarse sediment buried beneath the large depositional bar suggests that the tributary load may have been coarser in the past. Unnamed Trib SRC-6 currently appears to be a high source of both coarse and fine sediment to the mainstem Santa Rosa Creek.

The channel then transitions to a lower gradient depositional reach that flows through Cambria Pines and extends 2.5 km downstream to the channel mouth (Reach L2). The average reach channel gradient through this reach is the lowest in the Santa Rosa Creek subbasin (0.29 %) and is influenced by tidal elevation and at the mouth. The channel is moderately entrenched and becomes less confined downstream of Cambria Pines near the mouth. Bankfull width estimates along the reach range from 20 to 22 m and bankfull depth estimates range from 1.25 to 1.5 m. The channel bed has a pool-riffle morphology and currently appears aggradational, with the channel bed being at a similar elevation as adjacent bars. The channel bed texture is predominantly well-sorted very coarse gravel (D_{50} between 16 to 32 mm), transitioning from coarser sediment upstream to finer sediment downstream. Channel bars have a similar texture to the channel bed and are relatively large compared to upstream reaches, indicating a considerable amount of sediment storage within this reach. Overall, the channel bars appear mobile, but most are covered in young vegetation that has established since the last major storm event. Channel banks are composed of fine-grained alluvium, are well-vegetated, and appear moderately stable throughout (estimates range from 0.3 to 0.6 m in the past 20 years). The reach appears to remain dry during the summer (i.e., there was no baseflow within the reach at the time of the survey in summer 2009).

Appendix B

Santa Rosa Creek BMI Sampling

(provided as separate document)

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SANTA ROSA CREEK
BENTHIC MACROINVERTEBRATE (BMI)
ASSESSMENT REPORT

San Luis Obispo, CA
June 2010

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1 INTRODUCTION

1.1 Project Overview

This Benthic Macroinvertebrate Assessment Report is part of the Santa Rosa Creek Watershed Management Plan, a project funded by a California Department of Fish and Game (CDFG) grant received by Greenspace-The Cambria Land Trust. The purpose of the project is to obtain a more comprehensive assessment of the Santa Rosa Creek watershed and to evaluate the ecological processes and impacts affecting the water quality and stream habitat for southern Steelhead Salmon (*Oncorhynchus mykiss*).

This report is organized in six sections: Section 1 - the Introduction discusses the purpose and advantages of evaluating a stream's health by assessing the benthic macroinvertebrates (BMI) of a stream, Section 2 - describes the BMI Sampling Methods, Section 3 - Water Quality and Physical Measurements, Section 4 -makes clear the Results of the lab analysis, Section 5 - Discussion, and finally Section 6 - the References used.

1.2 Purpose for the Bioassessment of Santa Rosa Creek

The water quality of a stream can be measured using physical, chemical, and biological information. Ambient or surface water information such a temperature, pH, and dissolved oxygen are commonly used to assess the water quality of a stream. However, benthic macroinvertebrate sampling data has been recognized as an important diagnostic tool for assessing water quality and biological conditions of stream habitat. The methods are employed in stream monitoring programs of the United States Environmental Protection Agency, California Water Board, California Department of Fish and Game and other local advocacy groups.

The distribution of benthic macroinvertebrates is dependent on seasonal variations in the weather and food availability. Seasonal weather variations affect the instream conditions of a stream such as the volume, velocity and temperature of the water (Plotnikoff et al, 1997). Food sources can originate within the stream (algae) and food falls into the stream from outside sources (sticks, leaves, twigs). The presence of benthic macroinvertebrates communities corresponds to a certain habitat in which they can survive (Plotnikoff et al, 1997).

Stream benthic macroinvertebrates respond to impacts related to pollution, sedimentation, or other small changes in their habitat. The numbers, composition, and distribution of these benthic macroinvertebrate organisms can be a strong indicator to quality of the stream's habitat.

These benthic macroinvertebrates are known as a primary food source for the southern steelhead salmon *(Oncorhynchus mykiss*). BMI assessment will provide valuable insight into potential limiting factors for steelhead productivity.

1.3 Why Benthic Macroinvertebrate are Used to Measure Stream Quality

- The benthic macroinvertebrate community is very diverse. Each species has its own structural or functional characteristics and requires a unique and specialized living habitat. Some need specific water temperatures, substrate composition, or a specific food source to survive. Stream degradation can be show by the presence or absence of certain percentages of specialized species.
- Some benthic macroinvertebrates are very sensitive to pollution, sedimentation, and other small changes in their habitat. This vulnerability makes them useful in determining the types and source of impacts affecting a stream.
- The life span of some species of benthic macroinvertebrates can be up to several years. This long life span can provide clues to the quality of the habitat over a period of time.
- Most benthic macroinvertebrates are stationary organisms. Therefore, they cannot move away from the source of pollution and impacts.

2 BMI SAMPLING METHODS

On May 5, 6, and 7th 2010, Central Coast Salmon Enhancement collected benthic macroinvertebrates (BMI) utilizing an abridged version of the California Water Board's Surface Water Ambient Monitoring Program (SWAMP) bioassessment protocol (Ode, 2007). The collection of benthic macroinvertebrates samples was accompanied by the collection of associated physical habitat and ambient water quality data.

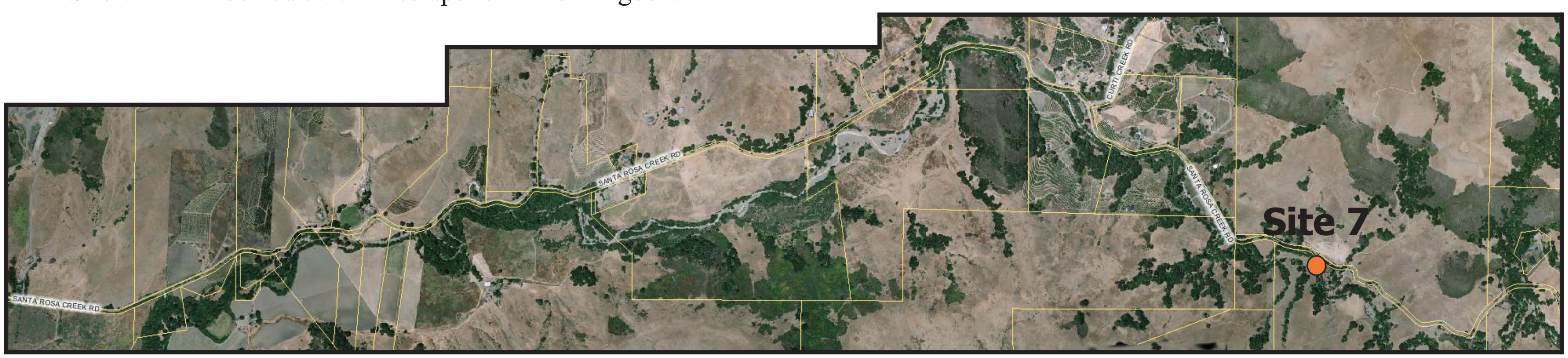
2.1 Site Selection

Seven sites with the presence of riffle habitat were sampled along the lower 7 miles of Santa Rosa Creek. Site selection was determined in part by personal communication with Mary Adams of the Central Coast Regional Water Quality Control Board's Ambient Monitoring Program (CCAMP) and Jennifer Nelson of the California Department of Fish and Game, both of whom have experience on the Santa Rosa Creek. Physical accessibility and permission for access from the landowners also played a role in site selection. The sites chosen for sampling reflect a variety of land uses and human influences including urbanization, agriculture, and ranching.

The sites start 0.3 miles upstream from the Santa Rosa Creek lagoon (where the creek empties into the Pacific Ocean) and continues upstream to the last site at 7 miles. Six of the sites are located below the so-called "Narrows" including four sites within the town of Cambria (Figure 2.1)

Figure 2.1 Santa Rosa Creek BMI Sampling Sites

Site 1.	Located .3 miles upstream from lagoon.
Site 2.	Located 1 mile upstream from lagoon.
Site 3.	Located 1.5 miles upstream from lagoon.
Site 4.	Located 1.8 miles upstream from lagoon.
Site 5	Located 2.75 miles upstream from lagoon.
Site 6	Located 3.25 miles upstream from lagoon.



Site 7	Above the “Narrows”, located 7 miles upstream from lagoon.

2.2 Habitat and Reach Identification

The benthic macroinvertebrate (BMI) sampling event took place at base flow conditions using SWAMP's targeted riffle composite (TRC) procedure (Ode, 2007). A stream reach of 450 feet of riffle habitat was defined at each site. Riffles are the shallower portions of stream habitat characterized by water that flows over rocks creating a mild to moderate turbulence in the surface water (Ode, 2007). Riffles are commonly used for BMI sampling because they are considered the "richest" habitat and usually offer the highest diversity of benthic macroinvertebrates (Ode, 2007). All sampling took place at riffles no deeper than 2 feet of water.

Each 450 feet reach was randomly divided into eight transects, the only criteria being the presence of riffle habitat. The sampling began at the lower most end of the reach at the first sizeable riffle location and progressed upstream, so as to not disturb the substrate of the upstream sampling locations. Contamination of the downstream sampling sites with sediment and disturbed BMI could result if the sampling did not occur in an upstream direction.

2.3 Sampling Procedure

At each transect, a sampling location was determined closely upstream where a D-frame net with mesh size of 0.5 micrometers was used to collect the sample. The D-frame net was placed flat on the substrate where a one square foot sample was taken. Organisms in the sampling location were first removed from the larger rocks and then the substrate within the sampling area was disturbed by hand for 60 seconds. Care was taken to ensure that all sample material flowed downstream and was captured by the net.

Sample material from each transect was placed into one sample jar. A site's BMI sample is a composite of these eight individual transect samples. Each sample was preserved in 95% ethanol for lab analysis.

2.4 Sample Sorting

All seven BMI samples were sent to J. Thomas King BioAssessment Services (P.O. Box 0752 Folsom, CA 95763) for identification using the required chain of custody forms. The samples were randomly sub-sampled and sorted to 600 individual organisms per sample.

2.5 Taxonomic Identification of Benthic Macroinvertebrates

For each subsample, organisms were identified to the Safit level 1 standard taxonomic effort (Rodgers et al, 2006) by a qualified taxonomist.

Safit level 1 standard taxonomic effort identifies most organisms to the genus level, except chironomids, which are identified to subfamily. The non-insects such as segmented worms are identified to Class level (Oligochatea).

The sorted identified organisms labeled with scientific name, date, and the site location were returned to Central Coast Salmon Enhancement. Also, included was an individual taxonomic list for each site, and spreadsheets of data including raw taxa, formulated taxa, commonly reported biometric values (DeShon1995, Barbour et al 1996b, Fore et al 1996, Smith and Voshell 1997), and calculations for the Southern California Index of Biological Integrity (So Cal-IBI) scores (Ode et al, 2005) (Appendix B).

3 WATER QUALITY AND PHYSICAL HABITAT MEASUREMENTS

Water quality measurements and the assessment of the stream's habitat characteristics were recorded in association with the BMI sampling at each site. Together this data can provide an overall framework for assessing the biotic, physical and chemical conditions of a stream reach (Ode, 2007). These physical characteristics can be influenced by a small change to riparian habitat or by adjacent land uses. They can provide supporting data in the evaluation of the type and perhaps the source of stream pollution or degradation.

The chemical and physical data measured was documented on SWAMP's field forms (Appendix A). Several of the data modules were subtracted and were considered unnecessary for the specific objectives of this project. A minimum of two photographs were taken at each transect. One facing upstream and one facing downstream from the center of the transect. Any additional information (not included on the field forms) was recorded in detailed field notes.

3.1 Water Chemistry Measurements

Ambient water quality data was collected at the beginning of each reach. This included the stream's water temperature, pH, dissolved oxygen, and velocity. The water chemistry data was collected using Vernier's LabQuest.

3.2 Physical Measurements

The physical measurements included wetted width of the stream, depth of water, stream bottom substrate measurements, presence of organic matter, and cobble embeddedness.

The wetted width is the portion of the channel that is inundated with water (Ode, 2007). This distance between the sides of the channel where surface water is no longer present was measured using a stadia rod.

Each transect was then divided into five equidistant points (Left bank, Left Center, Center, Right

Center, and Right Bank). At each point, a substrate and water depth measurement was taken. The Wolman pebble count technique (Wolman, 1954) was used for estimating particle size distribution. Particle size frequency and distribution can provide valuable information about instream habitat conditions that can effect the distributions of benthic macroinvertebrates (Ode, 2007). Benthic macroinvertebrates are dependent on specific substrate conditions within the riffle habitat. The substrate needs to be a variety of sizes with a percentage of cobbles. Land uses that can disturb the substrate composition will be evident in the benthic macroinvertebrate organisms collected there (Ode, 2007).

The presence or absence of organic matter such as decaying leaves (but not algae) was noted at each of the five points along the transect. Coarse particulate organic matter can be a general indicator of the amount of food supply that is available at a site (Ode, 2007).

At each transect, cobble embeddedness was also measured. Five random cobbles were pulled from the streambed and an estimate of percent embeddendness of each was determined. Substrate embeddedness or the degree to which fine particles fill interstitial spaces on a streambed has a significant impact on the environment of benthic macoinvertebrates (Ode, 2007).

3.3 Visual Estimates and Habitat Scoring Method

In addition to the physical measurement, visual estimates and habitat scoring methods were used to assess the complexity of the instream habitat, riparian vegetation, bank stability, and the human influences at each transect. These semi-qualitative visual estimates assist in summarizing the overall characteristic and quality of the stream habitat.

3.3.1 Riparian Vegetation

At each transect a 30 x 30 foot section of both the left and the right sides of the stream bank habitat were visually assessed using categorical scoring charts. The riparian vegetation was divided into three zones according to height, 1) groundcover (< 0.5 m), 2) lower canopy (0.5-5m), and 3) upper canopy (> 5m)(Ode, 2007). Within each zone, the density of the vegetation was given a score between 0 and 4, with 0 being absent of vegetation (0%) and 4 being a very heavy density (greater than 75%). Riparian vegetation has a strong influence on the quality of a stream habitat. It can be a direct or indirect source of food, provide protection from bank erosion, and act as a buffer between the stream channel and adjacent land uses (Ode, 2007).

3.3.2 Instream Habitat Complex and Bank Stability

The instream habitat complexity was evaluated by scoring the areal coverage of nine different stream features such as algae, macrophytes, boulders, wood debris, undercut banks, overhanging vegetation, live tree roots and artificial structures (Ode, 2007). The scoring ranged from 0 to 4, with 0 being absent (0%) and 4 being a very heavy presence (greater than 75%). Visual estimates were done within a zone of 30 feet upstream and 30 feet downstream of the transect and included features within the stream as well as along the banks. Assessing the instream habitat complexity provides important information about the general condition and complexity of the stream channel as well as quantify fish concealment habitat (Ode, 2007).

Stability of both the right and left banks were also scored. The banks along a zone of 30 feet upstream and 30 feet downstream of each transect were visually assessed as being eroded, vulnerable, or stable. Bank stability influences the amount of sedimentation that might occur that can cause degradation to the stream's habitat.

3.3.3 Human Influences

At each transect, a 30 ft x 30 foot riparian area centered along the transect was divided into three zones 1) Left bank, 2) Center channel, and 3) Right bank (Ode, 2007). The presence and location of 14 human influence categories were recorded within each of the zones. These 14 human influence categories are 1) walls and riprap, 2) buildings, 3) pavement, 4) roads and railroads, 5) pipes, 6) trash, 7) lawn or park, 8) row crops, 9) pasture, 10) logging activity, 11) mining activity, 12) vegetation management, 13) bridges, and 14) orchard or vineyard. The influence of human activities and adjacent land uses are a critical concern to the quality of a stream's habitat. Recording the impacts and the locations at which they occur can often help explain the results in the BMI analysis (Ode, 2007).

4 RESULTS

4.1 Biometric Values

Biometric values were calculated for each of the seven samples (Appendix B). Each biometric is a characteristic of the stream's macroinvertebrate community that changes in some predictable way relative to a stressor (Fore, 1996). These biometrics are used as a diagnostic tool and are useful in evaluating stream health and for comparing conditions between sites, with other past sampling events, and other Southern California streams.

There are four types (or measures) of biometrics, each biometric responds in its own particular way to impacts to the environment due to pollution or other small physical changes.

1) Richness measures are the total number of individual taxa in a sample. It is an indicator of diversity and suggests an ecosystem that is able to support a variety of benthic macroinvertebrates.
2) Composition is the measure of a percentage (or relative abundance) of particular taxa in a sample. This measure is intended to show the overall make-up of the sample and the relative contribution of the populations to the total biological community.

3) Tolerance/Intolerance measures can be the number of individual taxa sensitive to disturbance or the percentage of tolerant to sensitive taxa. This biometric indicates the relative sensitivity to disturbances.

4) Functional Feeding Groups measures the proportions of different types of feeding among the taxa. This biometric provides information on the balance of feeding strategies among the benthic macroinvertebrate community.

Table 4.1 is a list of the biometrics used for water quality analysis of the Santa Rosa Creek (compiled from DeShon1995, Barbour et al 1996b, Fore et al 1996, Smith and Voshell 1997). Each biometric has a brief description and indicates how the metric would change in response to a disturbance.

Table 4.1

Biometric Descriptions and Response to Impairment
(compiled from DeShon 1995, Barbour et al. 1996, Fore et al. 1996, Smith and Voshell 1997).

BMI Metric	Description	Response to Impairment [1]
Richness Measures		
1. Taxonomic	Total number of individual taxa.	Decrease
2. EPT [2]	Number of taxa in the orders Ephemeroptera (mayfly), Plecoptera (stonefly) and Trichoptera (caddisfly)	Decrease
3. Ephemeroptera	Number of mayfly taxa	Decrease
4. Plecoptera	Number of stonefly taxa	Decrease
5. Trichoptera	Number of caddisfly taxa	Decrease
6. Coleoptera [2]	Number of beetle taxa	Decrease
7. Predator [2]	Number of predator taxa	Decrease
Composition Measures		
8. EPT Index (%)	Percent composition of mayfly, stonefly and caddisfly individuals	Decrease
9. Sensitive EPT Index (%)	Percent composition of mayfly, stonefly and caddisfly individuals with CTVs less than 4.	Decrease
8. Shannon Diversity Index	General measure of sample diversity that incorporates richness and evenness (Shannon and Weaver 1963).	Decrease
10. Non-insect Taxa (%) [2]	Percentage of taxa not within the class Insecta	Increase
Tolerance/Intolerance Measures		
11. California Tolerance Value (CTV)	CTVs between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) and intolerant (lower values).	Increase
12. Intolerant Organisms (%) [2]	Percentage of organisms that are highly intolerant to water and/ or habitat quality impairment as indicated by CTVs of 0, 1 or 2.	Decrease
13. Tolerant Taxa (%) [2]	Percentage of taxa that are highly tolerant to water and/ or habitat quality impairment as indicated by CTVs of 8, 9 or 10.	Increase
Functional Feeding Groups (FFG)		
14. % Collector-gatherers (cg)	Percentage of macroinvertebrates that collect or gather material.	Increase
15. % Collector-filterers (cf)	Percentage of macroinvertebrates that filter suspended material from the water column.	Increase
16. % Collectors [2]	Percentage of macroinvertebrates that collect and filter suspended material from the water column.	Increase
17. % Scrapers (sc)	Percentage of macroinvertebrates that graze upon periphyton.	Variable
18. % Predators (p)	Percentage of macroinvertebrates that prey on living organisms.	Decrease
19. % Shredders (sh)	Percentage of macroinvertebrates that shred leaf litter.	Decrease
20. % Others (ot)	Percentage of macroinvertebrates that occupy an FFG not described above.	Variable
Other		
21. Abundance	Estimate of the number of organisms in a sample based on the proportion of organisms subsampled.	Variable

[1] The responses indicated are generalized and can follow natural gradients associated with elevation, water temperature and substrate composition.

[2] Metrics used for southern coastal California index of biotic integrity

4.2 Calculated Data

The following (Table 4.2) is the calculated biometric values and Southern California Index of Biological Integrity scores for the seven sampling sites on the Santa Rosa Creek. The complete data set including the raw taxa, formulated taxa, and calculated data can be found in Appendices B-D. Also, additional past data from the Central Coast Regional Water Quality Control Board's Ambient Monitoring Program (CCAMP) can be found in Appendix E for Site 1 and Site 6, referred to as Windsor and Ferrasci, respectively, in CCAMP.

Table 4.2 **Santa Rosa Creek Calculated Metrics Data**

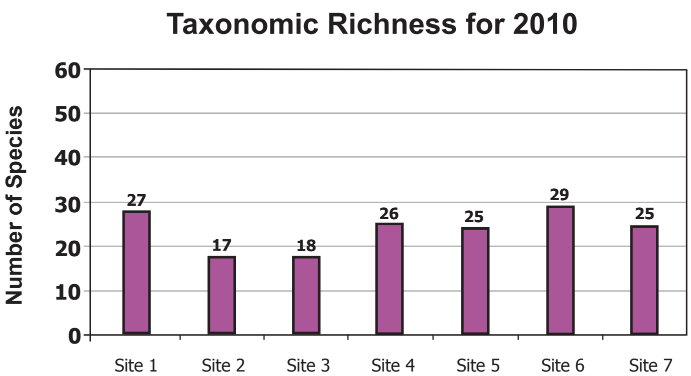
Metrics							
Richness:	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Taxonomic	27	17	18	26	25	29	25
EPT*	9	7	8	10	11	11	12
Ephemeroptera	3	2	3	4	4	4	5
Plecoptera	0	1	0	1	0	0	2
Trichoptera	6	4	5	5	7	7	5
Coleoptera*	4	2	2	3	3	4	4
Predator*	13	4	7	12	9	10	8
Composition:							
EPT Index (%)	49	51	41	40	42	26	25
Sensitive EPT Index (%)	3.0	1.5	3.0	3.9	5.5	6.4	5.9
Shannon Diversity	1.9	1.4	1.3	1.8	1.9	2.3	2.1
Dominant Taxon (%)	43	48	49	36	33	32	38
Non-Insect Taxa (%)*	26	29	28	23	28	21	20
Tolerance:							
Tolerance Value	5.3	5.3	5.3	5.3	5.1	5.1	5.2
Intolerant Organisms (%)*	3.0	1.6	3.0	3.9	5.5	6.4	5.9
Tolerant Organisms (%)	6.6	1.6	0.7	4.4	4.9	6.9	8.6
Tolerant Taxa (%)*	26	18	22	23	24	17	16
Functional Feeding Groups:							
Collector-Gatherers (%)	49	52	37	42	40	29	28
Collector-Filterers (%)	26	36	50	37	32	33	38
Collectors (%)*	76	88	87	79	71	62	66
Scrapers (%)	9	5	9	9	16	18	15
Predators (%)	15	6	3	12	11	16	16
Shredders (%)	0.2	0.3	0.0	0.0	0.5	3.1	2.2
Other (%)	0.2	0.8	1.3	0.2	0.6	0.9	0.7
IBI Score**	**51**	**34**	**37**	**51**	**50**	**63**	**60**
Estimated Abundance:							
Composite sample (8 ft^2)	846	1130	2310	2820	1170	420	1580
Site (BMIs/ft^2)	106	141	289	353	146	52	198
Site (BMIs/m^2)	1139	1521	3109	3795	1575	560	2126

* Metrics used in SoCal B-IBI

** IBI scores range from 0 (poor) to 100 (very good). Scoring criteria described by Ode et al. 2005.

4.3 Evaluation of Biometric Values

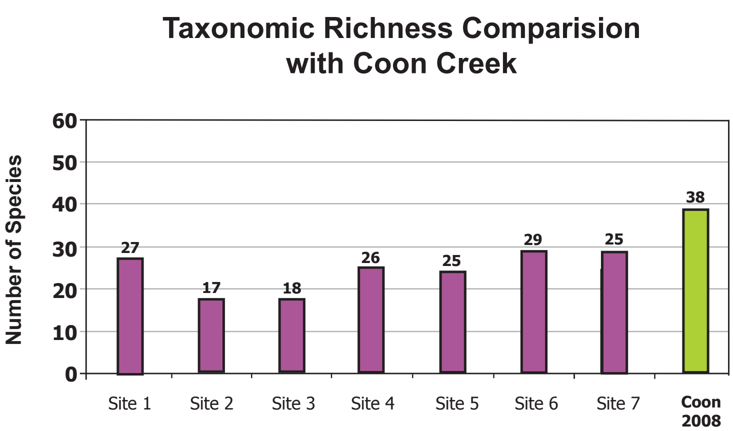
Figure 4.1



4.3.1 Richness Measures

The taxonomic richness metric identifies the total number of individual species found in the samples**.** It is an indicator of diversity and suggests an ecosystem that is healthy enough to support a wide variety of benthic macroinvertebrates. A decrease in this value indicates a lower diversity. Site 2 and Site 3 had the lowest values (17 and 18) and sites further upstream such as Site 6 had higher diversity of species (29).

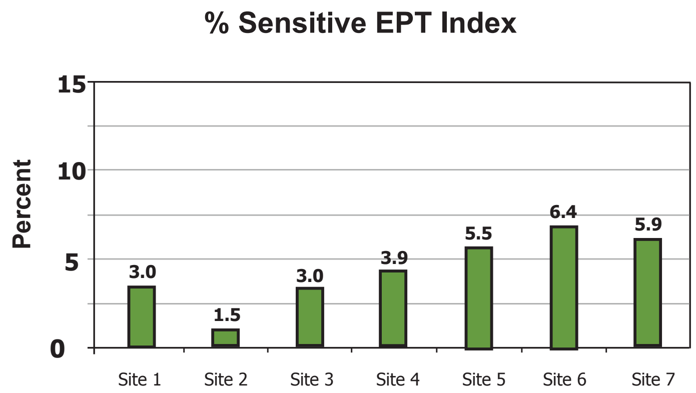
Figure 4.2



Coon Creek, located in southern San Luis Obispo County at Montana de Oro State Park, can be used as a base comparison. It is considered to have high quality habitat with adjacent land uses of mostly pristine open space and agriculture. There are few impacts due to urbanization along Coon Creek. As seen here, the taxonomic richness value for Coon Creek in 2008 (MBNEB, 2008) is much higher (38) than the Santa Rosa Creek values (17-29). A decrease in taxonomic richness shows a response by the BMI community to disturbance.

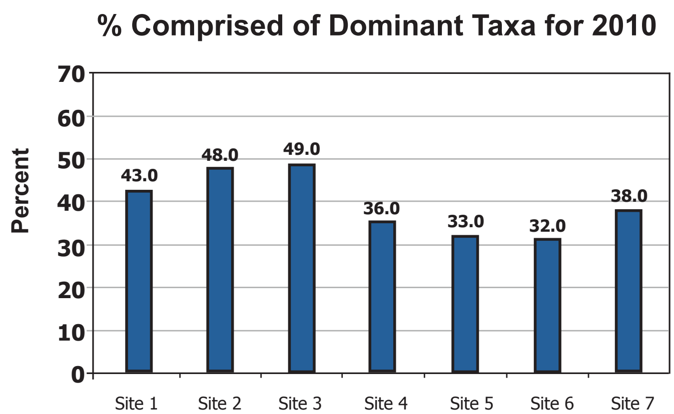
4.3.2 Composition Measures

Figure 4.3



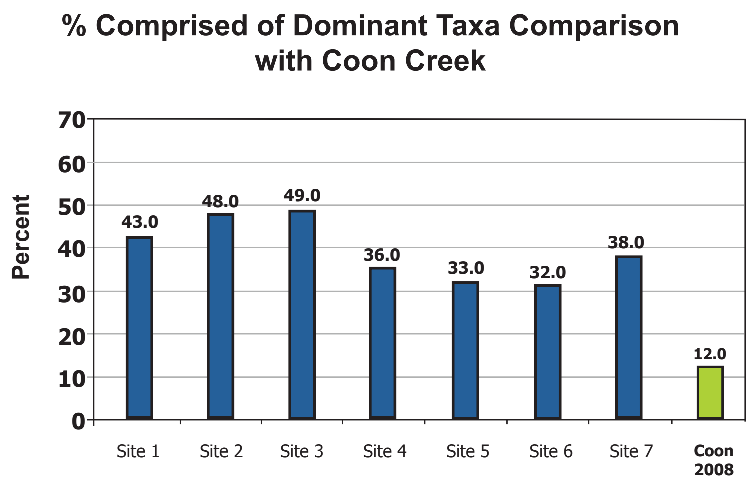
% Sensitive EPT Index metric is the percentage of three pollution sensitive species Ephemeroptera (mayflies), Plecoterea, (stoneflies) and Trichoptera (caddisflies). A stream with good water quality would have higher values for % Sensitive EPT Index. The four lower Santa Rosa creek sites ranged in values from 1.5% to 3.9%.

Figure 4.4



The % Dominant Taxa metric identifies the portion of the third, second, and single most dominant species in the sample. A stream with excellent water quality can support a greater number of taxa, each in moderate percentages of 20-30% or less (Plotnikoff, 1997). If the values for dominant taxa are 40% or greater, it's an indication of instability in the macroinvertebrate community and that a stressor is present (Plotnikoff, 1997). The three sites lower in the watershed all had higher percentages (43% to 49%) of dominant taxa compared to the other sites.

Figure 4.5



Again in comparison with Coon Creek, the Santa Rosa Creek sites have higher values for the percentage of the sample comprised of dominant taxa. The numbers range from 32.0% - 48.0% compared to Coon Creek's 12.0% (MNEB, 2008).

4.3.4 Functional Feeding Group Measures

% Scrappers taxa metric identifies the portion of macroinvertebrates that graze upon periphyton. The greater number of taxa indicates a higher level of primary productivity in the benthic macroinvertebrate community. Site 1 (9%), Site 2 (5%), Site 3 (9%) and Site 4 (9%) all showed lower values in % Scrappers compared to sites Site 5 (16%), Site 6 (18%), and Site 7 (15%), located higher upstream in the watershed.

% Shredder taxa metric is the percentage of macroinvertebrates that shred leaf litter. This metric reflects macroinvertebrate habitats with high retention of organic matter and the presence of allochthonous sources of food such as overhanging leaves and sticks. The values where much higher for sites Site 6 (3.1%) and Site 7 (2.2%) compared to Sites 3 and 4 where no taxa where identified in the samples.

4.4 Evaluation of Southern California Index of Biotic Integrity Scores

For each site, a standardized Southern California Index of Biotic Integrity (So Cal-IBI) score was determined. The So Cal-IBI has been adopted as a diagnostic tool for stream health and is the collective sum of seven uncorrelated biometric values. These being 1) the number of Coleoptra taxa, 2) the number of Ephemeroptera, Plecoterea, Trichoptera (EPT) taxa, and 3) the number of Predator taxa, 4) the percentage of sensitive individuals, 5) the percentage of Collector individuals, 6) the percentage of tolerant taxa, and 7) the percentage of non-insect taxa. (Table 4.3). The So Cal IBI is a "condition" score that expresses the health of site in a single qualitative number. It ranges from 0 to 100, with 0 representing an environment of very poor quality with low diversity and 100 being a very healthy environment with high diversity.

Table 4.3 Scoring Ranges for Seven Component Metrics in the SoCal B-IBI
(Ode, P.R., A.C. Rehn and J.T. May, 2005).

Metric Score	% CF+CG	% Non-Insect Taxa	% Tolerant Taxa	Coleoptera Taxa	Predator Taxa	% Intolerant Individuals	EPT Taxa
10	0-51	0-8	0-5	>5	>12	32-100	>16
9	52-55	9-13	6-8		12	29-31	15-16
8	56-60	14-18	9-11	5	11	26-28	14
7	61-66	19-23	12-15	4	10	22-25	12-13
6	67-71	24-28	16-18		9	19-21	10-11
5	72-76	29-33	19-21	3	8	15-18	9
4	77-81	34-38	22-25	2	7	12-14	7-8
3	82-86	39-43	26-28		6	8-11	5-6
2	87-91	44-48	29-32	1	5	5-7	4
1	92-95	49-53	33-36		4	1-4	2-3
0	96-100	54-100	37-100	0	0-3	0	0-1

The following tables 4.4 through 4.10 show the seven uncorrelated metric values and the final Southern California Index of Biological Integrity Scores for the seven sampling site on the Santa Rosa Creek.

Table 4.4

Site 1
05-06-10

	Value	Score
Beetle Taxa	4	7
EPT Taxa	9	5
Predator Taxa	13	10
% Collector Individuals	76	5
% Sensitive Individuals	3	1
% Non-Insect Taxa	26	5
% Tolerant Taxa	26	3
Raw Score		36
Final SoCal IBI Score	51	

FAIR WATER QUALITY

Table 4.5

Site 2
05-07-10

	Value	Score
Beetle Taxa	2	4
EPT Taxa	7	4
Predator Taxa	4	1
% Collector Individuals	88	3
% Sensitive Individuals	2	1
% Non-Insect Taxa	29	5
% Tolerant Taxa	18	6
Raw Score		24
Final SoCal IBI Score	34	

POOR WATER QUALITY

Table 4.6

Site 3
05-07-10

	Value	Score
Beetle Taxa	2	4
EPT Taxa	8	4
Predator Taxa	7	4
% Collector Individuals	87	3
% Sensitive Individuals	3	1
% Non-Insect Taxa	28	5
% Tolerant Taxa	22	5
Raw Score		26
Final SoCal IBI Score	37	

POOR WATER QUALITY

Table 4.7

Site 4
05-07-10

	Value	Score
Beetle Taxa	3	5
EPT Taxa	10	5
Predator Taxa	12	9
% Collector Individuals	79	5
% Sensitive Individuals	4	2
% Non-Insect Taxa	23	6
% Tolerant Taxa	23	4
Raw Score		36
Final SoCal IBI Score	51	

FAIR WATER QUALITY

Table 4.8

Site 5
05-06-10

	Value	Score
Beetle Taxa	3	5
EPT Taxa	11	6
Predator Taxa	9	6
% Collector Individuals	71	7
% Sensitive Individuals	6	2
% Non-Insect Taxa	28	5
% Tolerant Taxa	24	4
Raw Score		35
Final SoCal IBI Score	50	

FAIR WATER QUALITY

Table 4.9

Site 6
05-05-10

	Value	Score
Beetle Taxa	4	7
EPT Taxa	11	6
Predator Taxa	10	7
% Collector Individuals	62	9
% Sensetive Individuals	6	2
% Non-Insect Taxa	21	7
% Tolerant Taxa	17	6
Raw Score		44
Final SoCal IBI Score	63	

GOOD WATER QUALITY

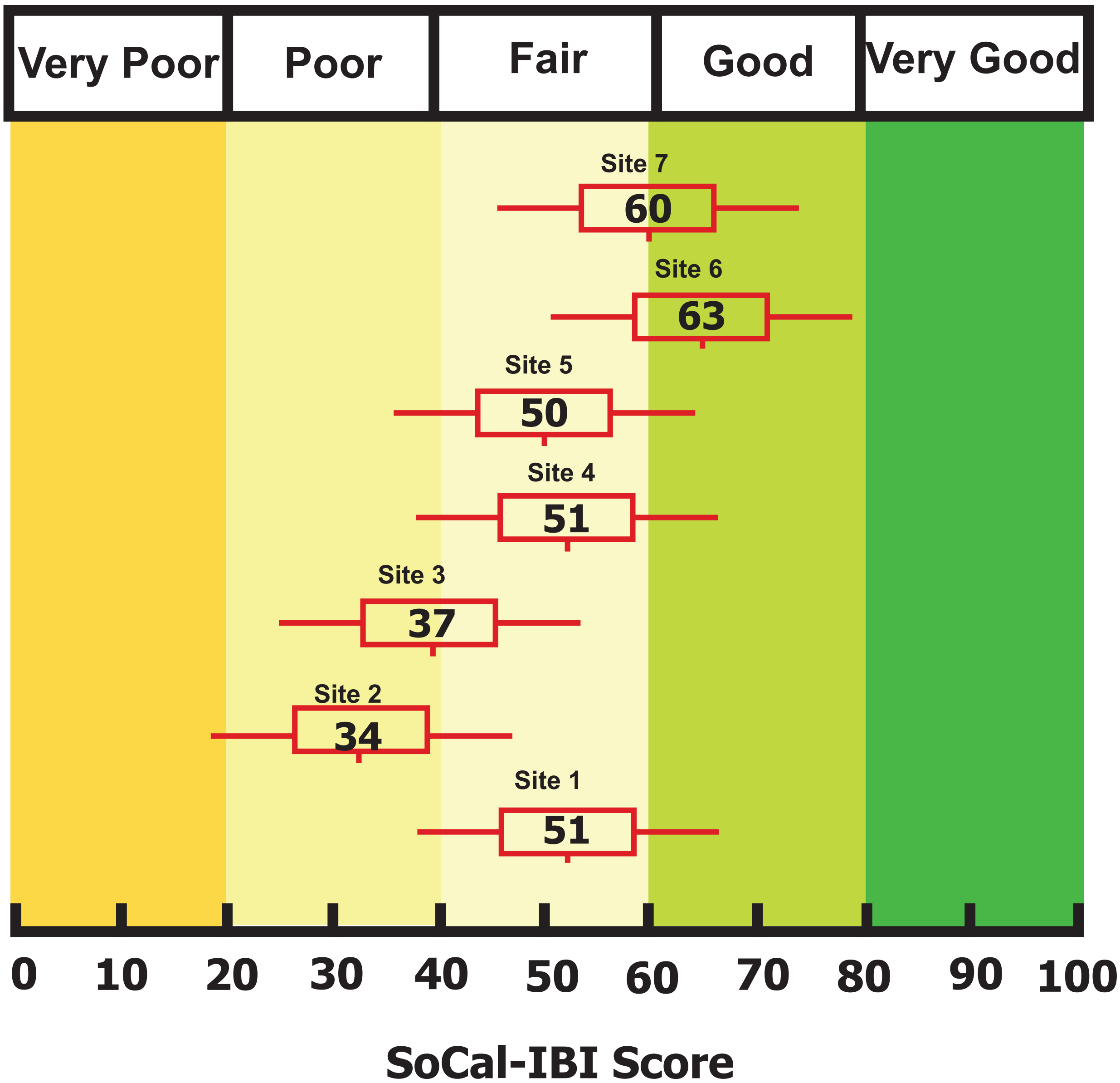
Table 4.10

Site 7
05-05-10

	Value	Score
Beetle Taxa	4	7
EPT Taxa	12	6
Predator Taxa	8	5
% Collector Individuals	66	8
% SensItive Individuals	6	2
% Non-Insect Taxa	20	7
% Tolerant Taxa	16	7
Raw Score		42-
Final SoCal IBI Score	60	

GOOD WATER QUALITY

Table 4.11 A comparison of the final Southern California Index of Biological Integrity Scores for sites on Santa Rosa Creek.



5 DISCUSSION

The Southern California Index of Biotic Integrity (So Cal-IBI) scores for the Santa Rosa Creek sites range from 34 (Site 2) to a moderate value of 63 (Site 6). The water quality ranges from Poor to Moderately Good.

Site 2 (34) and Site 3 (37) had the two lowest scores and were determined to have poor water quality. All the sites adjacent to the town of Cambria receive urban runoff, which can affect the benthic macroinvertebrate community. Any increase in impervious surfaces near the Santa Rosa Creek will cause impacts to both the physical habitat and water quality of Santa Rosa Creek. Also, in the habitat scoring data for these sites, the presence and location of human influences was much higher. There was more evidence of urbanization in the creek bed such as rip-rap, concrete, and trash.

The two sites, Site 6 (63) and Site 7 (60), upstream from Cambria, were determined to have Moderately Good water quality. These sites are not as affected by urban runoff but may possibly be impacted by their adjacent lands uses of agriculture and ranching.

Another result of this study was to verify if the food supply in the Santa Rosa Creek is adequate to sustain populations of the southern steelhead salmon (*Oncorhynchus mykiss*). The taxonomic lists for each site proved to have large populations of *Baetis* (mayflies) and *Simulium* (blackfly) populations. These benthic macroinvertebrates are known as a valuable food source for salmonid populations.

This study should be valued as a baseline and used as a foundation for the establishment of a biomonitoring program of Santa Rosa Creek in the future. This kind of monitoring program would be helpful in keeping track of the impacts of increased urbanization, or other changes in land uses along the Santa Rosa Creek. This data can be helpful in identifying areas of the Santa Rosa Creek that are in need of restoration and used to help monitor the success of the restoration efforts at those sites.

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Appendix A
California Water Board's Surface Water Ambient Monitoring Program's (SWAMP) Field Forms

APPENDIX A

SWAMP Field Forms

(Ode, 20007)

SWAMP Stream Habitat Characterization Form *Revision Date: March 3rd, 2010*

REACH DOCUMENTATION	Standard Reach Length (wetted width ≤ 10 m) = 150 m Distance between transects = 15 m Alternate Reach Length (wetted width >10 m) = 250 m Distance between transects = 25 m	
Project Name:	Date: / / 2010	Time:
Stream Name:	Site Name/ Description:	
Site Code:	Crew Members:	
Latitude (actual – decimal degrees): °N		
Longitude (actual – decimal degrees): °W	GPS Device:	

AMBIENT WATER QUALITY MEASUREMENTS						*turbidity and silica are optional; calibration date required*	
Temp (°C)		pH				Turbidity (ntu)	
		cal. date				cal. date	
Dissolved O^2 (mg/L)							
cal. date		cal. date				cal. date	

REACH LENGTH	
Actual Length (m) *(see reach length guidelines at top of form)*	
Explanation:	

NOTABLE FIELD CONDITIONS (check one box per topic)						
Evidence of recent rainfall (enough to increase surface runoff)	NO		minimal		>10% flow increase	
Evidence of fires in reach or immediately upstream (<500 m)	NO		< 1 year		< 5 years	
Dominant landuse/ landcover in area surrounding reach	Agriculture		Forest		Rangeland	
	Urban/ Industrial		Suburb/Town		Other	

ADDITIONAL COBBLE EMBEDDEDNESS MEASURES (carry over from transect forms if needed; measure in %)	1	2	3	4	5	6	7	8	9	10	11	12	13
	14	15	16	17	18	19	20	21	22	23	24	25	

Page 1

SWAMP Stream Habitat Characterization Form — *Revision Date: March 3rd, 2010*

Site Code:	Site Name:		Date: __ __ / __ __ / 2010
Wetted Width (m):	Bankfull Width (m):	Bankfull Height (m):	**TRANSECT 1**

Transect Substrates

Position	Dist from LB (m)	Depth (cm)	mm/ size class	% Cobble Embed.	CPOM	Microalgae Thickness Code	Macroalgae Attached	Macroalgae Unattached	Macrophytes
Left Bank					P A		P A D	P A D	P A
Left Center					P A		P A D	P A D	P A
Center					P A		P A D	P A D	P A
Right Center					P A		P A D	P A D	P A
Right Bank					P A		P A D	P A D	P A

Note: Substrate sizes can be recorded either as direct measures of the median axis of each particle or one of the size class categories listed on the supplemental page (direct measurements preferred)

Microalgae Thickness Codes
0 = No microalgae present, Feels rough, not slimy;
1 = Present but not visible, Feels slimy;
2 = Present and visible but <1mm; Rubbing fingers on surface produces a brownish tint on them, scraping leaves visible trail.
3 = 1-5mm;
4 = 5-20mm;
5 = >20mm;
UD = Cannot determine if microalgae present, substrate too small or covered with silt (formerly Z code).
D = Dry, not assessed

RIPARIAN VEGETATION (facing downstream)
0 = Absent (0%); 1 = Sparse (<10%); 2 = Moderate (10-40%); 3 = Heavy (40-75%); 4 = Very Heavy (>75%)

Vegetation Class	Left Bank	Right Bank
Upper Canopy (>5 m high)		
Trees and saplings >5 m high	0 1 2 3 4	0 1 2 3 4
Lower Canopy (0.5 m-5 m high)		
All vegetation 0.5 m to 5 m	0 1 2 3 4	0 1 2 3 4
Ground Cover (<0.5 m high)		
Woody shrubs & saplings <0.5 m	0 1 2 3 4	0 1 2 3 4
Herbs/ grasses	0 1 2 3 4	0 1 2 3 4
Barren, bare soil/ duff	0 1 2 3 4	0 1 2 3 4

INSTREAM HABITAT COMPLEXITY
0 = Absent (0%); 1 = Sparse (<10%); 2 = Moderate (10-40%); 3 = Heavy (40-75%); 4 = Very Heavy (>75%)

Filamentous Algae	0 1 2 3 4
Aquatic Macrophytes/ Emergent Vegetation	0 1 2 3 4
Boulders	0 1 2 3 4
Woody Debris >0.3 m	0 1 2 3 4
Woody Debris <0.3 m	0 1 2 3 4
Undercut Banks	0 1 2 3 4
Overhang. Vegetation	0 1 2 3 4
Live Tree Roots	0 1 2 3 4
Artificial Structures	0 1 2 3 4

DENSIOMETER READINGS (0-17) *count covered dots*

Center Left	
Center Upstream	
Center Right	
Center Downstream	
Optional	
Left Bank	
Right Bank	

HUMAN INFLUENCE (circle only the closest to wetted channel)
0 = Not Present; **B** = On Bank; **C** = Between Bank & 10m from Channel; **P** = >10m+<50m from Channel; **Channel** (record Yes or No)

	Left Bank	Channel	Right Bank
Walls/ Rip-rap/ Dams	P C B 0	Y N	0 B C P
Buildings	P C B 0	Y N	0 B C P
Pavement/ Cleared Lot	P C B 0		0 B C P
Road/ Railroad	P C B 0	Y N	0 B C P
Pipes (Inlet/ Outlet)	P C B 0	Y N	0 B C P
Landfill/ Trash	P C B 0	Y N	0 B C P
Park/ Lawn	P C B 0		0 B C P
Row Crop	P C B 0		0 B C P
Pasture/ Range	P C B 0		0 B C P
Logging Operations	P C B 0		0 B C P
Mining Activity	P C B 0	Y N	0 B C P
Vegetation Management	P C B 0		0 B C P
Bridges/ Abutments	P C B 0	Y N	0 B C P
Orchards/ Vineyards	P C B 0		0 B C P

BANK STABILITY (score zone 5m upstream and 5m downstream of transect between bankfull - wetted width)

Left Bank	eroded	vulnerable	stable
Right Bank	eroded	vulnerable	stable

TAKE PHOTOGRAPHS (check box if taken & record photo code)

Downstream (**optional**) ☐

Upstream (**required**) ☐

Page 2

SWAMP Stream Habitat Characterization Form *Revision Date: March 3rd, 2010*

Flow Habitat Type	DESCRIPTION
Cascades	Short, high gradient drop in stream bed elevation often accompanied by boulders and considerable turbulence
Falls	High gradient drop in elevation of the stream bed associated with an abrupt change in the bedrock
Rapids	Sections of stream with swiftly flowing water and considerable surface turbulence. Rapids tend to have larger substrate sizes than riffles
Riffles	Shallow sections where the water flows over coarse stream bed particles that create mild to moderate surface turbulence; (< 0.5 m deep, > 0.3 m/s).
Runs	Long, relatively straight, low-gradient sections without flow obstructions. The stream bed is typically even and the water flows faster than it does in a pool; (> 0.5 m deep, > 0.3 m/s). A **step-run** is a series of runs separated by short riffles or flow obstructions that cause discontinuous breaks in slope
Glides	A section of stream with little or no turbulence, but faster velocity than pools; (< 0.5 m deep, < 0.3 m/s)
Pools	A reach of stream that is characterized by deep, low-velocity water and a smooth surface; (> 0.5 m deep, < 0.3 m/s)

Size Class Code	Size Class Range	Size Class Description	Common Size Reference
RS	> 4 m	bedrock, smooth	larger than a car
RR	> 4 m	bedrock, rough	larger than a car
XB	1 - 4 m	boulder, large	meter stick to car
SB	25 cm - 1.0 m	boulder, small	basketball to meter stick
CB	64 - 250 mm	cobble	tennis ball to basketball
GC	16 - 64 mm	gravel, coarse	marble to tennis ball
GF	2 – 16 mm	gravel, fine	ladybug to marble
SA	0.06 – 2 mm	sand	gritty to ladybug
FN	< 0.06 mm	fines	not gritty
HP	< 0.06 mm	hardpan (consolidated fines)	
WD	NA	wood	
RC	NA	concrete/ asphalt	
OT	NA	other	

BANK STABILITY	
Although this measure of the degree of erosive potential is subjective, it can provide clues to the erosive potential of the banks within the reach. Assign the category whose description best fits the conditions in the area between the wetted channel and bankfull channel (see figure below)	
Eroded	Banks show obvious signs of erosion from the current or previous water year; banks are usually bare or nearly bare
Vulnerable	Banks have some vegetative protection (usually annual growth), but not enough to prevent erosion during flooding
Stable	Bank vegetation has well-developed roots that protect banks from erosion; alternately, bedrock or artificial structures (e.g., concrete/ rip-rap) prevent bank erosion

CPOM/ COBBLE EMBEDDEDNESS

CPOM: Record presence (P) or absence (A) of coarse particulate organic matter (>1.0 mm particles) within 1 cm of each substrate particle

Cobble Embeddedness: Visually estimate % embedded by fine particles (record to nearest 5%)

ADDITIONAL COBBLE EMBEDDEDNESS MEASURES (carry over from transect forms if needed; measure in %)	1	2	3	4	5	6	7	8	9	10	11	12	13
	14	15	16	17	18	19	20	21	22	23	24	25	

Appendix B
Lab Documentation and Santa Rosa Creek Metrics Data

APPENDIX B

Lab Documentation

Date of preparation: May 31, 2010
Prepared by: Tom King
Project: Santa Rosa Creek Bioassessment
Project Manager: Virginia Brown, Central Coast Salmon
Background:

1) Benthic samples collected in the spring season of 2010 by Virginia Brown using the SWAMP targeted riffle sampling strategy.

2) Benthic samples processed by BioAssessment Services.
a) Identifier: Tom King
b) Subsampler: Monica Murray

3) 600 (±5%) invertebrates were subsampled and identified to standard taxonomic level (STL) I specified by the Southwest Association of Freshwater Invertebrate Taxonomists (http://www.waterboards.ca.gov/swamp.
a) STL exceptions: chironomids identified to subfamily/tribe instead of family and less precise identifications for empidid pupae.
b) 600 (±5%) organisms subsampled. One sample, Fiscalini #1, contained less than 600 organisms.

4)Chironomids converted to family for metric calculations and generation of coastal southern California B-IBI.

5)Tolerance values and functional feeding group designations from CAMLnet 27 January 2003 revision.

6)Piercer herbivore, omnivore, macrophyte herbivore and parasite functional feeding groups converted. to “other” category for metric calculation.

*Ode, P.R., A.C. Rehn and J.T. May. 2005. A quantitative tool for assessing the integrity of southern coastal Calirornia streams.
Environmental Management Vol. 35, No. 1, pp. 1□13. Springer Science+Business Media, Inc.

SANTA ROSA CREEK METRICS DATA

Metrics **Richness:**	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Taxonomic	27	17	18	26	25	29	25
EPT*	9	7	8	10	11	11	12
Ephemeroptera	3	2	3	4	4	4	5
Plecoptera	0	1	0	1	0	0	2
Trichoptera	6	4	5	5	7	7	5
Coleoptera*	4	2	2	3	3	4	4
Predator*	13	4	7	12	9	10	8
Composition:							
EPT Index (%)	49	51	41	40	42	26	25
Sensitive EPT Index (%)	3.0	1.5	3.0	3.9	5.5	6.4	5.9
Shannon Diversity	1.9	1.4	1.3	1.8	1.9	2.3	2.1
Dominant Taxon (%)	43	48	49	36	33	32	38
Non-Insect Taxa (%)*	26	29	28	23	28	21	20
Tolerance:							
Tolerance Value	5.3	5.3	5.3	5.3	5.1	5.1	5.2
Intolerant Organisms (%)*	3.0	1.6	3.0	3.9	5.5	6.4	5.9
Tolerant Organisms (%)	6.6	1.6	0.7	4.4	4.9	6.9	8.6
Tolerant Taxa (%)*	26	18	22	23	24	17	16
Functional Feeding Groups:							
Collector-Gatherers (%)	49	52	37	42	40	29	28
Collector-Filterers (%)	26	36	50	37	32	33	38
Collectors (%)*	76	88	87	79	71	62	66
Scrapers (%)	9	5	9	9	16	18	15
Predators (%)	15	6	3	12	11	16	16
Shredders (%)	0.2	0.3	0.0	0.0	0.5	3.1	2.2
Other (%)	0.2	0.8	1.3	0.2	0.6	0.9	0.7
IBI Score**	**51**	**34**	**37**	**51**	**50**	**63**	**60**
Estimated Abundance:							
Composite sample (8 ft^2)	846	1130	2310	2820	1170	420	1580
Site (BMIs/ft^2)	106	141	289	353	146	52	198
Site (BMIs/m^2)	1139	1521	3109	3795	1575	560	2126

* Metrics used in SoCal B-IBI

** IBI scores range from 0 (poor) to 100 (very good). Scoring criteria described by Ode et al. 2005.

Appendix C
Santa Rosa Creek Taxa List

APPENDIX C

SANTA ROSA CREEK TAXA LIST

Phylum / Class / Order / Family / Final ID	CTV[1]	FFG[2]	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Arthropoda									
Insecta									
Coleoptera									
Dryopidae									
Helichus	5	sh							1
Dytiscidae									
Agabus	8	p	1			1			
Sanfillipodytes	5	p	5			1	4	4	2
Stictotarsus	5	p	6					1	21
Elmidae									
Dubiraphia	6	cg		2			2		
Optioservus	4	sc	39	19	32	38	73	48	71
Zaitzevia	4	sc			1				
Haliplidae									
Peltodytes	5	mh						2	
Diptera									
Ceratopogonidae									
Bezzia/ Palpomyia	6	p	3		1	1		1	
Chironomidae									
Chironomini	6	cg	3		1	1	3	3	
Orthocladiinae	5	cg	6	17	6	17	18	34	5
Tanypodinae	7	p	4	2		1	2		2
Tanytarsini	6	cg	6	1	2	5	1	3	
Empididae									
Empididae	6	p						2	
Neoplasta	6	p	1			2	1	1	
Muscidae									
Muscidae	6	p	1						
Simuliidae									
Simulium	6	cf	153	215	294	221	187	134	228
Stratiomyidae									

SANTA ROSA CREEK TAXA LIST (continued)

Phylum Class Order Family Final ID	CTV[1]	FFG[2]	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Caloparyphus/Euparyphus	8	cg	5			11	3	15	41
Tanyderidae									
Tanyderidae	1	?		1					
Tipulidae									
Cryptolabis	3	sh						1	9
Ephemeroptera									
Baetidae									
Baetis	5	cg	263	293	210	205	205	60	99
Caenidae									
Caenis	7	cg							1
Ephemerellidae									
Drunella	0	cg				1			
Ephemerella	1	cg	11		1	12	8	2	17
Heptageniidae									
Ecdyonurus criddlei	4	sc	8	1	3	9	4	2	7
Leptohyphidae									
Tricorythodes	4	cg						2	1
Leptophlebiidae									
Paraleptophlebia	4	cg					1		
Hemiptera									
Naucoridae									
Ambrysus	5	p				1			
Odonata									
Coenagrionidae									
Argia	7	p	2			1		2	
Plecoptera									
Chloroperlidae									
Suwallia	1	p				1			
Nemouridae									
Malenka	2	sh		1					2

SANTA ROSA CREEK TAXA LIST (continued)

Phylum Class Order Family Final ID	CTV[1]	FFG[2]	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Pteronarcyidae									
Pteronarcys	0	om							2
Trichoptera									
Brachycentridae									
Micrasema	1	mh					1	2	
Glossosomatidae									
Agapetus	0	sc	6	8	16	10	24	19	10
Hydropsychidae									
Cheumatopsyche	5	cf			1	1	5	1	
Hydropsyche	4	cf	4	3	2	4	4	4	1
Hydroptilidae									
Ochrotrichia	4	ph	1	4	8	1	3		2
Philopotamidae									
Wormaldia	3	cf	2			2			
Psychomyiidae									
Tinodes	2	sc						2	
Rhyacophilidae									
Rhyacophila	0	p	1		1		1	2	4
Sericostomatidae									
Gumaga	3	sh	1	1			3	12	1
Arachnoidea									
Acari									
Hydryphantidae									
Protzia	8	p	2				3	1	
Hygrobatidae									
Atractides	8	p	16	5	1	8	7	7	5
Hygrobates	8	p				1			
Lebertiidae									
Lebertia	8	p	10	2	1	2	6		4
Mideopsidae									

SANTA ROSA CREEK TAXA LIST (continued)

Phylum / Class / Order / Family / Final ID	CTV[1]	FFG[2]	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Mideopsis	5	p							2
Sperchontidae									
Sperchon	8	p	4	3	1	4	10	1	1
Sperchonopsis	8	p			1				
Torrenticolidae									
Torrenticola	5	p	41	28	14	48	36	47	56
Annelida									
Hirudinea									
Arhynchobdellida									
Erpobdellidae									
Erpobdellidae	8	p					1		
Oligochaeta									
Oligochaeta	5	cg	1	1		1	1	3	
Mollusca									
Bivalvia									
Veneroida									
Sphaeriidae									
Pisidium	8	cf	2						
Gastropoda									
Hypsogastropoda									
Hydrobiidae									
Hydrobiidae	8	sc						5	
			608	607	597	611	617	423	595

[1] California Tolerance Value based on a scale from 0 (intolerant) to 10 (tolerant).

[2] Functional Feeding Group:
collector-gatherer (cg); collector-filterer (cf); scraper (sc); predator (p); shredder (sh)
Note: omnivore (om), piercer herbivore (ph), parasite (pa) and macrophyte herbivore (mh) placed into other (ot) category for metric calculations

Appendix D
Santa Rosa Creek BMI Calculations

APPENDIX D

SANTA ROSA CREEK CALCULATIONS

			Site 1	Site 2	Site 3	Site 4	Site 6	Site 5	Site 7
Final ID	CTV	FFG	3012	3015	3013	3014	3009	3011	3010
Helichus	5	sh							1
Agabus	8	p	1			1			
Sanfillipodytes	5	p	5			1	4	4	2
Stictotarsus	5	p	6				1		21
Dubiraphia	6	cg		2				2	
Optioservus	4	sc	39	19	32	38	48	73	71
Zaitzevia	4	sc			1				
Peltodytes	5	ot					2		
Bezzia/ Palpomyia	6	p	3		1	1	1		
Chironomidae	6	cg	19	20	9	24	40	24	7
Empididae	6	p					2		
Neoplasta	6	p	1			2	1	1	
Muscidae	6	p	1						
Simulium	6	cf	153	215	294	221	134	187	228
Caloparyphus/Euparyp	8	cg	5			11	15	3	41
Tanyderidae	1	ot		1					
Cryptolabis	3	sh					1		9
Baetis	5	cg	263	293	210	205	60	205	99
Caenis	7	cg							1
Drunella	0	cg				1			
Ephemerella	1	cg	11		1	12	2	8	17
Ecdyonurus criddlei	4	sc	8	1	3	9	2	4	7
Tricorythodes	4	cg					2		1
Paraleptophlebia	4	cg						1	
Suwallia	1	p				1			
Malenka	2	sh		1					2

SANTA ROSA CREEK CALCULATIONS (continued)

			Site 1	Site 2	Site 3	Site 4	Site 6	Site 5	Site 7
Pteronarcys	0	ot							2
Micrasema	1	ot					2	1	
Agapetus	0	sc	6	8	16	10	19	24	10
Cheumatopsyche	5	cf			1	1	1	5	
Hydropsyche	4	cf	4	3	2	4	4	4	1
Ochrotrichia	4	ot	1	4	8	1		3	2
Wormaldia	3	cf	2			2			
Tinodes	2	sc					2		
Rhyacophila	0	p	1		1		2	1	4
Gumaga	3	sh	1	1			12	3	1
Ambrysus	5	p				1			
Argia	7	p	2			1	2		
Protzia	8	p	2				1	3	
Atractides	8	p	16	5	1	8	7	7	5
Hygrobates	8	p				1			
Lebertia	8	p	10	2	1	2		6	4
Mideopsis	5	p							2
Sperchon	8	p	4	3	1	4	1	10	1
Sperchonopsis	8	p			1				
Torrenticola	5	p	41	28	14	48	47	36	56
Erpobdellidae	8	p						1	
Oligochaeta	5	cg	1	1		1	3	1	
Pisidium	8	cf	2						
Hydrobiidae	8	sc					5		
			608	607	597	611	423	617	595

SANTA ROSA CREEK CALCULATIONS (continued)

	Site 1	Site 2	Site 3	Site 4	Site 6	Site 5	Site 7
Taxonomic Richness	27	17	18	26	29	25	25
EPT Taxa	9	7	8	10	11	11	12
Ephemeroptera Taxa	3	2	3	4	4	4	5
Plecoptera Taxa	0	1	0	1	0	0	2
Trichoptera Taxa	6	4	5	5	7	7	5
EPT Index (%)	49	51	41	40	26	42	25
Sensitive EPT Index (%)	3.0	1.5	3.0	3.9	6.4	5.5	5.9
Shannon Diversity	1.9	1.4	1.3	1.8	2.3	1.9	2.1
Dominant Taxon (%)	43	48	49	36	32	33	38
Tolerance Value	5.3	5.3	5.3	5.3	5.1	5.1	5.2
ntolerant Organisms (%)	3.0	1.6	3.0	3.9	6.4	5.5	5.9
Tolerant Organisms (%)	6.6	1.6	0.7	4.4	6.9	4.9	8.6
Collector-Gatherers	49	52	37	42	29	40	28
Collector-Filterers	26	36	50	37	33	32	38
Scrapers	9	5	9	9	18	16	15
Predators	15	6	3	12	16	11	16
Shredders	0.2	0.3	0.0	0.0	3.1	0.5	2.2
Other	0.2	0.8	1.3	0.2	0.9	0.6	0.7
	100	100	100	100	100	100	100

SANTA ROSA CREEK CALCULATIONS (continued)

			Site 1	Site 2	Site 3	Site 4	Site 6	Site 5	Site 7
SoCal B-IBI metrics							Values:		
Coleoptera Richness			4	2	2	3	4	3	4
EPT Richness			9	7	8	10	11	11	12
Predator Richness			13	4	7	12	10	9	8
Collectors (%)			76	88	87	79	62	71	66
tolerant Individuals (%)			3	2	3	4	6	6	6
Non-Insect Taxa (%)			26	29	28	23	21	28	20
Tolerant Taxa (%)			26	18	22	23	17	24	16
							Scores:		
Coleoptera Richness			7	4	4	5	7	5	7
EPT Richness			5	4	4	5	6	6	6
Predator Richness			10	1	4	9	7	6	5
Collectors (%)			5	3	3	5	9	7	8
tolerant Individuals (%)			1	1	1	2	2	2	2
Non-Insect Taxa (%)			5	5	5	6	7	5	7
Tolerant Taxa (%)			3	6	5	4	6	4	7
Total x 1.43	1.43	**IBI:**	**51**	**34**	**37**	**51**	**63**	**50**	**60**
C			fair	poor	poor	fair	good	fair	good
Estimated Abundance									
Composite sample (8 ft^2)			846	1130	2310	2820	420	1170	1580
Site (BMIs/ft^2)	8		106	141	289	353	52	146	198
Site (BMIs/m^2)	0.09288		1139	1521	3109	3795	560	1575	2126

Appendix E
Central Coast Regional Water Quality Control Board's Ambient Monitoring Program (CCAMP) Past Data for Windsor and Ferrasci

Note: The CCAMP data was collected using the California Stream Bioassessment Procedure. The protocol and sorted sampling sizes are different than the California Water Board's Surface Water Ambient Monitoring Program's (SWAMP) bioassessment protocol which was used for the seven Santa Rosa Creek sites in this study. TheCCAMP data was not standardized to the SWAMP protocol and therefore is not compared to results of this study. It is included here to capture previously collected BMI data for the watershed.

APPENDIX E

CCAMP'S BMI DATA

		Total Taxa	EPT Index (%)	EPT Taxa	Number Amphipoda Individuals	Number Baetidae Individuals	Number CF + CG Individuals	Number CF + CG Taxa
Windsor 5/1/2001	CSBP-Transects Benthics- 9 900count	36	26	9	0	202	487	10
Windsor 3/29/2002	CSBP-Transects Benthics- 9 900count	28	3	3	3	0	449	9
Windsor 3/25/2003	CSBP-Transects Benthics- 9 900count	38	20	9	4	20	316	14
Windsor 4/8/2004	CSBP-Transects Benthics- 9 900count	37	17	9	39	26	557	11
Windsor 5/4/2005	Margin-Ctr-Margin	11	1	2	0	0	488	5
Windsor 5/4/2005	Multi-Habitat	18	1	2	0	1	479	7
Ferrasci 3/25/2003	CSBP-Transects Benthics- 9 900count	38	14	11	0	14	351	11
Ferrasci 3/25/2003	CSBP-Transects Benthics- 9 900count	45	59	16	0	180	386	15

CCAMP'S BMI DATA

	Number Chironomidae Individuals	Number Chironomidae Taxa	Number Chironominae Taxa	Number Coleoptera Taxa	Number Collector Filterer Individuals	Number Collector Filterer Taxa	Number Collector Gatherer Individuals	Number Collector Gatherer Taxa	Number Corbicula Individuals	Number Crustacea + Mollusca Individuals	Number Crustacea Individuals
Windsor 5/1/2001	167	1	0	8	19	1	468	9	0	64	64
Windsor 3/29/2002	121	1	0	4	2	1	447	8	0	29	19
Windsor 3/25/2003	52	1	0	6	4	1	312	13	0	14	13
Windsor 4/8/2004	46	1	0	4	0	0	557	11	0	76	62
Windsor 5/4/2005	142	1	0	1	0	0	488	5	0	0	0
Windsor 5/4/2005	332	1	0	2	1	1	478	6	0	0	0
Ferrasci 3/25/2003	288	1	0	4	12	2	339	9	0	2	2
Ferrasci 3/25/2003	32	1	0	5	13	2	373	13	0	2	0

CCAMP'S BMI DATA

	Number Diptera Individuals	Number Diptera Taxa	Number Elmidae Individuals	Number Elmidae Taxa	Number Ephemerellidae Taxa	Number Ephemeroptera Individuals	Number Ephemeroptera Taxa	Number EPT Individuals	Number Gastropoda Individuals	Number Glossosomatidae Individuals
Windsor 5/1/2001	225	7	12	2	1	205	3	240	0	22
Windsor 3/29/2002	164	8	4	1	0	1	1	24	10	0
Windsor 3/25/2003	83	8	4	1	2	121	6	183	1	1
Windsor 4/8/2004	53	6	3	1	0	126	6	155	14	0
Windsor 5/4/2005	149	3	1	1	0	2	1	4	0	0
Windsor 5/4/2005	340	6	2	1	0	1	1	7	0	0
Ferrasci 3/25/2003	453	12	7	1	1	20	5	124	0	30
Ferrasci 3/25/2003	147	10	60	2	2	276	8	519	0	38

CCAMP'S BMI DATA

	Number Grazer Individuals	Number Grazer Taxa	Number Hydropsychidae Individuals	Number Hydropsychidae Taxa	Number Hydroptilidae Individuals	Number Individuals per Reach	Number Individuals per Replicate	Number Intolerant Diptera Individuals	Number Intolerant Ephemeroptera Individuals	Number Intolerant EPT Taxa
Windsor 5/1/2001	0	0	0	0	0	911	911	29	3	6
Windsor 3/29/2002	0	0	0	0	0	893	893	0	0	1
Windsor 3/25/2003	0	0	0	0	0	913	913	5	18	4
Windsor 4/8/2004	0	0	0	0	7	891	891	5	22	2
Windsor 5/4/2005	0	0	0	0	0	499	499	0	0	0
Windsor 5/4/2005	0	0	0	0	0	502	502	1	1	1
Ferrasci 3/25/2003	0	0	1	1	5	906	906	1	2	4
Ferrasci 3/25/2003	0	0	0	0	1	887	887	8	62	7

CCAMP'S BMI DATA

	Number Intolerant Individuals	Number Intolerant Scraper Individuals	Number Intolerant Taxa	Number Intolerant Trichoptera Individuals	Number Mollusca Individuals	Number Mollusca Taxa
Windsor 5/1/2001	66	22	7	22	0	0
Windsor 3/29/2002	1	0	1	1	10	1
Windsor 3/25/2003	24	1	6	1	1	1
Windsor 4/8/2004	28	0	5	0	14	4
Windsor 5/4/2005	0	0	0	0	0	0
Windsor 5/4/2005	2	0	2	0	0	0
Ferrasci 3/25/2003	36	30	5	30	0	0
Ferrasci 3/25/2003	166	38	9	45	2	1

CCAMP'S BMI DATA

	Number Oligochaeta Taxa	Number Orthocladiinae Taxa	Number Other FFG Individuals	Number Other FFG Taxa	Number Perlodidae Individuals	Number Philopotamidae Individuals	Number Plecoptera Individuals	Number Plecoptera Taxa	Number Predator Individuals	Number Predator Taxa
Windsor 5/1/2001	1	0	4	3	7	0	12	4	383	19
Windsor 3/29/2002	1	0	1	1	0	0	0	0	380	12
Windsor 3/25/2003	1	0	2	1	0	0	0	0	526	18
Windsor 4/8/2004	1	0	10	2	0	0	1	1	285	17
Windsor 5/4/2005	1	0	0	0	0	0	0	0	8	4
Windsor 5/4/2005	1	0	0	0	0	0	0	0	15	9
Ferrasci 3/25/2003	1	0	6	2	2	0	3	2	344	18
Ferrasci 3/25/2003	1	0	7	2	36	0	51	2	221	20

CCAMP'S BMI DATA

	Number Rhyacophilidae Individuals	Number Scraper Individuals	Number Scraper Taxa	Number Sensitive EPT Individuals	Number Shredder Individuals	Number Shredder Taxa	Number Simuliidae Individuals	Number Tolerant Individuals	Number Trichoptera Individuals	Number Trichoptera Taxa	Percent Amphipoda
Windsor 5/1/2001	0	34	3	38	3	1	19	157	23	2	0
Windsor 3/29/2002	0	14	2	23	45	3	2	144	23	2	0
Windsor 3/25/2003	0	6	3	78	63	2	4	262	62	3	0
Windsor 4/8/2004	0	18	6	51	21	1	0	186	28	2	4
Windsor 5/4/2005	0	1	1	2	2	1	0	4	2	1	0
Windsor 5/4/2005	0	2	1	7	6	1	1	8	6	1	0
Ferrasci 3/25/2003	0	39	3	100	166	4	11	196	101	4	0
Ferrasci 3/25/2003	0	101	5	302	172	3	11	137	192	6	0

CCAMP'S BMI DATA

	Percent Baetidae	Percent Burrowers	Percent CF + CG Individuals	Percent CF + CG Taxa	Percent CF Taxa	Percent CG Taxa	Percent Chironomidae	Percent Chironomidae Taxa	Percent Chironominae Taxa	Percent Clinger Taxa	Percent Collector-Filterers
Windsor 5/1/2001	22	41	53	28	3	25	18	3	0	48	2
Windsor 3/29/2002	0	81	51	32	4	29	14	4	0	17	0
Windsor 3/25/2003	2	14	35	37	3	34	6	3	0	28	0
Windsor 4/8/2004	3	17	63	30	0	30	5	3	0	16	0
Windsor 5/4/2005	0	90	98	45	0	45	28	9	0	12	0
Windsor 5/4/2005	0	95	95	39	6	33	66	6	0	20	0
Ferrasci 3/25/2003	2	71	39	29	5	24	32	3	0	33	1
Ferrasci 3/25/2003	20	10	44	33	4	29	4	2	0	41	1

CCAMP'S BMI DATA

	Percent Collectors Gatherers	Percent Corbicula	Percent Crustacea	Percent Diptera	Percent Diptera Taxa	Percent Dominant Taxon	Percent Elmidae	Percent Ephemeroptera	Percent Ephemeroptera Taxa	Percent EPT Taxa	Percent Gastropoda
Windsor 5/1/2001	51	0	7	25	19	22	1	23	8	25	0
Windsor 3/29/2002	50	0	2	18	29	33.6	0	0	4	11	1
Windsor 3/25/2003	34	0	1	9	21	15.8	0	13	16	24	0
Windsor 4/8/2004	63	0	7	6	16	36	0	14	16	24	2
Windsor 5/4/2005	98	0	0	30	27	67.5	0	0	9	18	0
Windsor 5/4/2005	95	0	0	68	33	66.1	0	0	6	11	0
Ferrasci 3/25/2003	37	0	0	50	32	21.3	1	2	13	29	0
Ferrasci 3/25/2003	42	0	0	17	22	19.5	7	31	18	36	0

CCAMP'S BMI DATA

	Percent Glossosomatidae	Percent Grazer Taxa	Percent Grazers	Percent Hydropsychidae	Percent Hydroptilidae	Percent Intolerant	Percent Intolerant Diptera	Percent Intolerant Ephemeroptera	Percent Intolerant Scrapers	Percent Intolerant Taxa (0-2)
Windsor 5/1/2001	2	0	0	0	0	8	3	0	3	20
Windsor 3/29/2002	0	0	0	0	0	0	0	0	0	4
Windsor 3/25/2003	0	0	0	0	0	3	1	2	0	16
Windsor 4/8/2004	0	0	0	0	1	3	1	2	0	14
Windsor 5/4/2005	0	0	0	0	0	0	0	0	0	0
Windsor 5/4/2005	0	0	0	0	0	0	0	0	0	11
Ferrasci 3/25/2003	3	0	0	0	1	4	0	0	3	13
Ferrasci 3/25/2003	4	0	0	0	0	19	1	7	4	20

CCAMP'S BMI DATA

	Percent Intolerant Trichoptera	Percent Mollusca	Percent Non Baetis Fallceon Ephemeroptera	Percent Non Hydro Cheumato Trichoptera	Percent Non-Gastropoda Scrapers	Percent Non-Hydropsyche Hydropsychidae	Percent Non-Insecta Taxa
Windsor 5/1/2001	3	0	0	2	4	0	31
Windsor 3/29/2002	0	1	0	3	0	0	46
Windsor 3/25/2003	0	0	12	7	1	0	34
Windsor 4/8/2004	0	2	14	3	0	0	41
Windsor 5/4/2005	0	0	0	0	0	0	27
Windsor 5/4/2005	0	0	0	1	0	0	44
Ferrasci 3/25/2003	3	0	1	11	4	0	26
Ferrasci 3/25/2003	5	0	11	22	11	0	24

CCAMP'S BMI DATA

	Percent of Intolerant Ephemeroptera	Percent of Intolerant Trichoptera	Percent of IntolerantTrichoptera	Percent Oligochaeta Taxa	Percent Omnivore Taxa	Percent Orthocladiinae Taxa	Percent Other FFG	Percent Other FFG Taxa
Windsor 5/1/2001	1	96	3	3	2.8	0	0	8
Windsor 3/29/2002	0	4	34	4	3.6	0	0	4
Windsor 3/25/2003	15	2	12	3	0	0	0	3
Windsor 4/8/2004	18	0	36	3	0	0	1	5
Windsor 5/4/2005	0	0	68	9	0	0	0	0
Windsor 5/4/2005	100	0	28	6	0	0	0	0
Ferrasci 3/25/2003	10	30	1	3	2.6	0	1	5
Ferrasci 3/25/2003	22	23	0	2	0	0	1	4

CCAMP'S BMI DATA

	Percent Perlodidae	Percent Philopotamidae	Percent Plecoptera	Percent Plecoptera Taxa	Percent Predator Taxa	Percent Predators	Percent Rhyacophildae	Percent Scraper Taxa	Percent Scrapers	Percent Shredder Taxa
Windsor 5/1/2001	1	0	1	11	53	42	0	8	4	3
Windsor 3/29/2002	0	0	0	0	43	43	0	7	2	11
Windsor 3/25/2003	0	0	0	0	47	58	0	8	1	5
Windsor 4/8/2004	0	0	0	3	46	32	0	16	2	3
Windsor 5/4/2005	0	0	0	0	36	2	0	9	0	9
Windsor 5/4/2005	0	0	0	0	50	3	0	6	0	6
Ferrasci 3/25/2003	0	0	0	5	47	38	0	8	4	11
Ferrasci 3/25/2003	4	0	6	4	44	25	0	11	11	7

CCAMP'S BMI DATA

	Percent Shredders	Percent Simuliidae	Percent Tolerant	Percent Tolerant Taxa (8-10)	Percent Trichoptera	Percent Trichoptera Taxa	Sensitive EPT Index (%)	Shannon Diversity	Simpsons Index	Taxonomic Richness	Tolerance Value
Windsor 5/1/2001	0	2	19	17	3	6	4	2.5	0	36	5.44
Windsor 3/29/2002	5	0	16	36	3	7	3	2.25	0	28	5.52
Windsor 3/25/2003	7	0	29	29	7	8	9	2.64	0	38	5.95
Windsor 4/8/2004	2	0	21	28	3	5	6	2.32	0	37	5.54
Windsor 5/4/2005	0	0	1	18	0	9	0	0.84	1	11	5.31
Windsor 5/4/2005	1	0	2	33	1	6	1	0.96	1	18	5.68
Ferrasci 3/25/2003	18	1	22	18	11	11	11	2.64	0	38	5.42
Ferrasci 3/25/2003	19	1	15	20	22	13	34	2.87	0	45	4.28

Appendix C

Public Meeting Questionnaire

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Santa Rosa Creek Watershed
Tell Us What You Think

We greatly appreciate your assistance! Please, fill out this form as completely as you can and place in Public Comment Box before leaving. Then, take a <u>raffle ticket</u> and put one half in the bowl to be eligible for the drawing. (If you need more space for answers, please use the other side of the page.)

1. What are your concerns about the creek and watershed?

2. Do you know of an area in the creek that is in need of maintenance? *Example: bank stabilization, erosion, or trash pickups.*

3. Would you share any stories or historic photos you might have about steelhead or unusual occurrences that that have occurred related to Santa Rosa Creek? We can contact you if you prefer to provide contact info.

4. Please rank the following items in terms of your assessment of their importance with 1 as highest priority and 5 as lowest priority. There are two blank boxes to write in your own priorities.

	1	2	3	4	5
Improve water quality	1	2	3	4	5
Improve water quantity	1	2	3	4	5
Restore and protect riparian habitat for native plants and animals	1	2	3	4	5
Improve natural conditions for people living in the watershed	1	2	3	4	5
Foster community stewardship of, and education about, the watershed such as volunteering for projects	1	2	3	4	5
Reduce sediment delivery into the creek	1	2	3	4	5
	1	2	3	4	5

Contact Information (optional)

Name: ______________________________

Street Address: ______________________________

City: ____________________ Zip: ____________________

Phone ____
Email: ____
Interest Representing: ____

- Mailing List
- Volunteer
- Water Monitoring
- Special Events – creek clean up

Santa Rosa Creek Watershed
Compiled Questionnaire Information
Public Meeting January 19, 2010

1. What are your concerns about the creek and watershed?
   - Improving quality of resources through cooperation of community/landowners
   - Ag run-off, human caused pollution, illegal dumping, invasive species, sewage impacts
   - That it becomes a healthy system that supports wildlife and public enjoyment of the environment
   - Restore and maintain creek, tributaries and lagoon for steelhead and other wildlife
   - Deforestation, defoliation, top-soil erosion, earth subsidence, deterioration of air and water resources
   - Hope for cooperative effort that results in a healthy watershed
   - Balanced use between Santa Rosa and San Simeon Creeks
   - Use, pollution
   - Taking too much water out and loss of healthy habitat
   - Public health; maintain healthier habitat conditions; viability for diverse species; over-development
   - Sustainable management of water for environment and people; enhance the productivity of ecosystem services of SR Creek Watershed
   - Want more water flow and better water quality to support more wildlife
   - That there be enough water for all of us
   - Interfering with creek hydrology; desal; erosion
   - Steelhead; mercury
   - Sediment load/erosion; hydrologic roughness
   - Amount of overgrowth that has been allowed to remain along the banks; this is going to cause another flood when it all backs up behind Windsor Bridge
   - Overpopulation; building near the creek banks

2. Do you know of an area in the creek that is in need of maintenance? *Example: bank stabilization, erosion, or trash pickups.* If so, please indicate location.
   - Along Fiscalini Ranch Reserve; periodic trash pick up; invasive species removal along streambanks
   - Ferasci Bridge is a barrier to steelhead use; bridge should be reconstructed to allow passage
   - Maintenance is what degrades wildlands
   - Along Hwy. 1 to Burton Dr. trash, weeds, erosion near Hwy. 1 Bridge

- Burton Drive Bridge erosion under and around bridge; sediment falling from steep hillsides on Burton Dr. and increased grading activity on the Rodeo grounds

3. Would you share any stories or historic photos you might have about steelhead or unusual occurrences that that have occurred related to Santa Rosa Creek? We can contact you if you prefer to provide contact info.

   We may contact people who offered stories/photos directly.

4. Please rank the following items in terms of your assessment of their importance with 1 as high priority and 5 as low priority. First number is priority rank; second number is how many responded to that ranking.

Protect stream side archeological sites*	1/1	2	3	4	5
Improve water quality	1/14	2/4	3/1	4/1	5/0
Increase water quantity	1/9	2/5	3/4	4/2	5/0
Restore and protect riparian habitat for native plants and animals	1/11	2/6	3/2	4/0	5/2
Improve natural conditions for people living in the watershed for recreational activities	1/0	2/3	3/10	4/3	5/4
Increase education about the importance of the watershed	1/10	2/6	3/3	4/0	5/1
Foster community stewardship of the watershed such as through volunteering for projects	1/9	2/5	3/4	4/0	5/2
Reduce sediment delivery into the creek	1/12	2/1	3/5	4/2	5/0
Stop fire district campaign*	1/1	2	3	4	5
Monitor water quality (chemical) at least 4 times each year*	1/1	2	3	4	5
Clear sides of banks*	1/1	2	3	4	5
Steelhead enhancement*	1/1	2	3	4	5

*write-ins
Total submitted = 21

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Appendix D

Funding Resources

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California Department of Fish and Game Fisheries Restoration Grant Program (FRGP)

http://www.dfg.ca.gov/fish/Administration/Grants/FRGP/

FRGP was established in 1981 in response to rapidly declining populations of wild salmon and steelhead trout and deteriorating fish habitat in California. This competitive grant program has invested over $180 million to support projects from sediment reduction to watershed education throughout coastal California. Contributing partners include the California Department of Fish and Game (CDFG), federal and local governments; tribes, water districts, fisheries organizations, watershed restoration groups, the California Conservation Corps, AmeriCorps, and private landowners.

San Luis Obispo County Fish and Game Commission Fines Committee

Contact: Robert Cone (805) 781-5024

Each year as part of its budget process, the San Luis Obispo County Board of Supervisors approves a lump sum budget for the Fish and Game Fine Commission. The committee meets to develop a detailed listing of recommended projects for the coming fiscal year. The listing is then submitted to the Board for approval.

CalTrans Environmental Enhancement and Mitigation Program (EEM)

http://www.dot.ca.gov/hq/LocalPrograms/EEM/homepage.htm

EEM is provided by Streets and Highways Code Section 164.56 and authorizes the allocation of up to $10 million each year for grants to mitigate the environmental impacts of modified or new public transportation facilities.

San Luis Obispo Integrated Regional Water Management Plan (IRWMP)

http://www.slocountywater.org/site/Frequent%20Downloads/Integrated%20Regional%20Water%20Management%20Plan/index.htm

The Integrated Regional Water Management (IRWM) Program is intended to promote and practice integrated regional water management to ensure sustainable water uses, reliable water supplies, better water quality, environmental stewardship, efficient urban development, protection of agriculture, and a strong economy.

Wildlife Conservation Board Habitat Enhancement and Restoration Program (HERP)

http://www.wcb.ca.gov/HERP/grants.html

After the Wildlife Conservation Board (WCB) was created by the Wildlife Conservation Law of 1947, it was given the authority to acquire and restore California lands to protect wildlife values and to provide wildlife-oriented public access. The Habitat Enhancement and Restoration Program (HERP) was WCB's first program and incorporated all restoration projects until new restoration programs were first initiated in 1990. Over the last 20 years, there have been at least eight specific new programs added to the WCB's mandate that fund and target certain types of habitat restoration projects that historically fell under the HERP. While the program is not as active as it once was, it still effectively covers important habitat enhancement and restoration projects that fall outside the criteria of the other habitat restoration programs.

California State Coastal Conservancy
http://scc.ca.gov/category/grants/

To achieve its goals, the Coastal Conservancy may award grants to public agencies and nonprofit organizations that qualify under Section 501(c)(3) of the United States Internal Revenue Code and whose purposes are consistent with Division 21 of the California Public Resources Code (commencing with section 31000). Some examples of the kinds of projects the Coastal Conservancy may fund include trails and other public access to and along the coast, natural resource protection and restoration in the coastal zone or affecting coastal areas, restoration of coastal urban waterfronts, protection of coastal agricultural land, and resolution of land use conflicts.

U.S. Fish and Wildlife Service Fisheries Operational Needs System Database for National Fish Passage Program Funds
Contact: Donald Ratcliff (209) 334-2968 ext. 409

Millions of culverts, dikes, water diversions, dams, and other artificial barriers have been constructed to impound and redirect water for irrigation, flood control, electricity, drinking water, and transportation--all changing natural features of rivers and streams. In 1999, the U.S. Fish and Wildlife Service initiated the National Fish Passage Program to work with others to address this problem. The Program uses a voluntary, non-regulatory approach to remove and bypass barriers to aquatic species movement. The Program addresses the problem of passage barriers on a national level, working with local communities and partner agencies to restore natural flows and fish migration. The Program is administered by National and Regional Coordinators, and delivered by Regional Fish and Wildlife Management Assistance Offices.

U.S. Fish and Wildlife Service Partners in Fish and Wildlife Program
http://www.fws.gov/partners

The mission of the Partners Program is to efficiently achieve voluntary habitat restoration on private lands through financial and technical assistance for the benefit of Federal Trust Species.

National Oceanic and Atmospheric Administration (NOAA) Southwest Region
http://www.habitat.noaa.gov/funding/southwest.html

NOAA Restoration Center's Community-based Restoration Program invests funding and technical expertise in high-priority habitat restoration projects that instill strong conservation values and engage citizens in hands-on activities. Through the program, NOAA, its partners, and thousands of volunteers are actively restoring coastal, marine, and migratory fish habitat across the nation. The NOAA Restoration Center staff helps to identify potential projects, strengthen the development and implementation of habitat restoration activities within communities, and generate long-term national and regional partnerships to support community-based restoration efforts across a wide geographic area.

Upper Salinas-Las Tablas Resource Conservation District
http://us-ltrcd.org/

The Upper Salinas-Las Tablas Resource Conservation District (RCD) serves the local community with its programs in watershed management, restoration, research and education and works with public and private landowners to conserve natural resources throughout the Upper Salinas River Watershed and surrounding environments. The RCD can coordinate with the USDA Natural Resources Conservation Service to bring cost-share programs to a project in order to make restoration projects cost effective.

Private Foundations

Fund For Wild Nature	http://www.fundwildnature.org/
Doris Duke Charitable Foundation Wildlife Action Opportunities Fund	http://www.wcs.org/wildlifeopportunity
Lindbergh Foundation	http://www.lindberghfoundation.org/
Disney Wildlife Conservation Fund	http://www.dwcf-rfp.com/
Waste Management	http://www.wm.com/community/giving.asp
Environmental Grantmakers Association	http://www.ega.org/funders/index.php
Acorn Foundation	http://www.commoncounsel.org/AcornFoundation
California Watershed Funding Database	http://www.calwatershedfunds.org/
Directory of Watershed Resources	http://www.efc.boisestate.edu/watershed/
Conservation grants	http://www.conservationgrants.com/water.htm
EPA Catalog of Federal Funding Sources for Watershed Protection	http://cfpub.epa.gov/fedfund/
Databases of Funding Opportunities	http://www.epa.gov/owow/funding/databases.html
Ben and Jerry's Foundation	http://www.benjerry.com/company/foundation/
Gordon and Betty Moore Foundation	http://www.moore.org/
Henry P. Kendall Foundation	http://www.kendall.org/index_flash.html
Rivers Foundation	http://riversfoundation.org/rfa/about/
Norcross Wildlife Foundation	http://www.norcrossws.org
Frost Foundation	http://www.frostfound.org/Pages/grantapp.html
Fish America	http://www.fishamerica.org/grants/index.html
American Rivers	http://www.americanrivers.org/our-work/restoring-rivers/dams/noaa-grants-program.html
Global Restoration Network	http://www.americanrivers.org/our-work/restoring-rivers/dams/noaa-grants-program.html
Trout Unlimited	http://www.tucalifornia.org