PESCADERO-BUTANO WATERSHED ASSESSMENT

Final Report

March 5, 2004

ESA Environmental Science Associates

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TABLE OF CONTENTS

PESCADERO-BUTANO WATERSHED ASSESSMENT

Page

Page

Page

APPENDICES

LIST OF MAPS

LIST OF TABLES

Page

LIST OF TABLES (cont.)

LIST OF FIGURES

Page

LIST OF FIGURES (cont.)

Page

LIST OF FIGURES (cont.)

CHAPTER 1

INTRODUCTION AND PURPOSE

The Pescadero-Butano Watershed Assessment was undertaken to assess current habitat conditions for Coho salmon and Steelhead trout in the watershed, and to identify factors limiting the quality and extent of salmonid habitat. The overall goal of the project is to develop a scientific basis for future management plans and actions related to restoration of the watershed and the salmonid fishery. The specific objectives of the project are as follows:

1. Characterize the watershed and identify the areas of remaining high quality salmonid habitat, that should receive high priority for conservation and restoration treatments;

2. Identify the factors and anthropogenic processes limiting the quality of salmonid habitat in the watershed, and water quality generally.

3. Identify the most cost-effective treatments for improving salmonid habitat, and the areas where these should be employed.

Historically, both Pescadero Creek and Butano Creek, as well as several tributary streams, supported runs of Steelhead trout and Coho salmon. Steelhead are still present, but there have been only sparse reports of Coho salmon in the watershed in recent years. Both streams are listed under the federal Clean Water Act as impaired water bodies for sediment. It should be noted that this assessment is not intended to substitute for, nor to form the basis for the development of Total Maximum Daily Loads (TMDL) for the basin, though the study may be useful to others undertaking their development.

The Pescadero-Butano watershed has been the subject of several past studies, as well as actions and efforts by local residents to investigate and solve problems associated with the streams, including flooding, landsliding, impaired water quality, and the declining fish population. The Pescadero-Butano Watershed Assessment builds on past studies, and includes several discrete new studies. These include a land use history (Chapter 3); a hydrologic analysis of the watershed, focusing on the USGS stream gauging record (Chapter 4) and a study of the changes in stream bed elevation at several County road bridges (Chapter 5); a geomorphic study of the watershed, including an analysis of sediment sources and erosion rates since 1937 (Chapter 6) and current geomorphology of stream channels (Chapter 7); and an assessment of current ecological conditions, focusing on the quality of salmonid spawning and rearing habitat, and specific impairments to salmonid habitat (Chapter 8). All of these studies are synthesized and conclusions are presented in Chapter 2.

Concurrently with this study, Environmental Science Associates is undertaking a separate study of conditions in Pescadero Marsh. That study, which focuses on the changes brought about by restoration work undertaken by the California Department of Parks and Recreation in the 1990s, is scheduled for publication in the spring of 2004. Several references are made in this report to as-yet unpublished findings of the Pescadero Marsh study.

The Pescadero-Butano Watershed Assessment has been carried out under the auspices of the Monterey Bay National Marine Sanctuary Foundation, with funding provided by the California State Water Resources Control Board and the United States EPA, through a Clean Water Act Section 319h grant. The study, including the scope of work, the Quality Assurance Project Plan, and this assessment report, have been overseen by a Technical Advisory Committee (TAC), who have guided the study and reviewed draft documents (see Chapter 9 for the TAC's membership).

The Assessment would not have been possible without the support and cooperation of the Pescadero community and other individuals, organizations, and agencies interested in the welfare of the watershed. The idea of a comprehensive watershed assessment has been discussed in the community for many years. Prior to commencement of this study, the San Mateo County Resource Conservation District and Environmental Science Associates held a series of public meetings in which the aim and scope of the assessment was refined and aligned with the community's interests. Many in the community have continued to provide support to the project, by providing their time, their experience, accounts of their personal and family histories, and access to their land. The authors of this report sincerely hope that this report will be of use in assisting the community in conserving and restoring the salmon and Steelhead fishery, while continuing the long-standing land uses of agriculture, forestry, recreation, and open space, and preserving the rural character of the watershed.

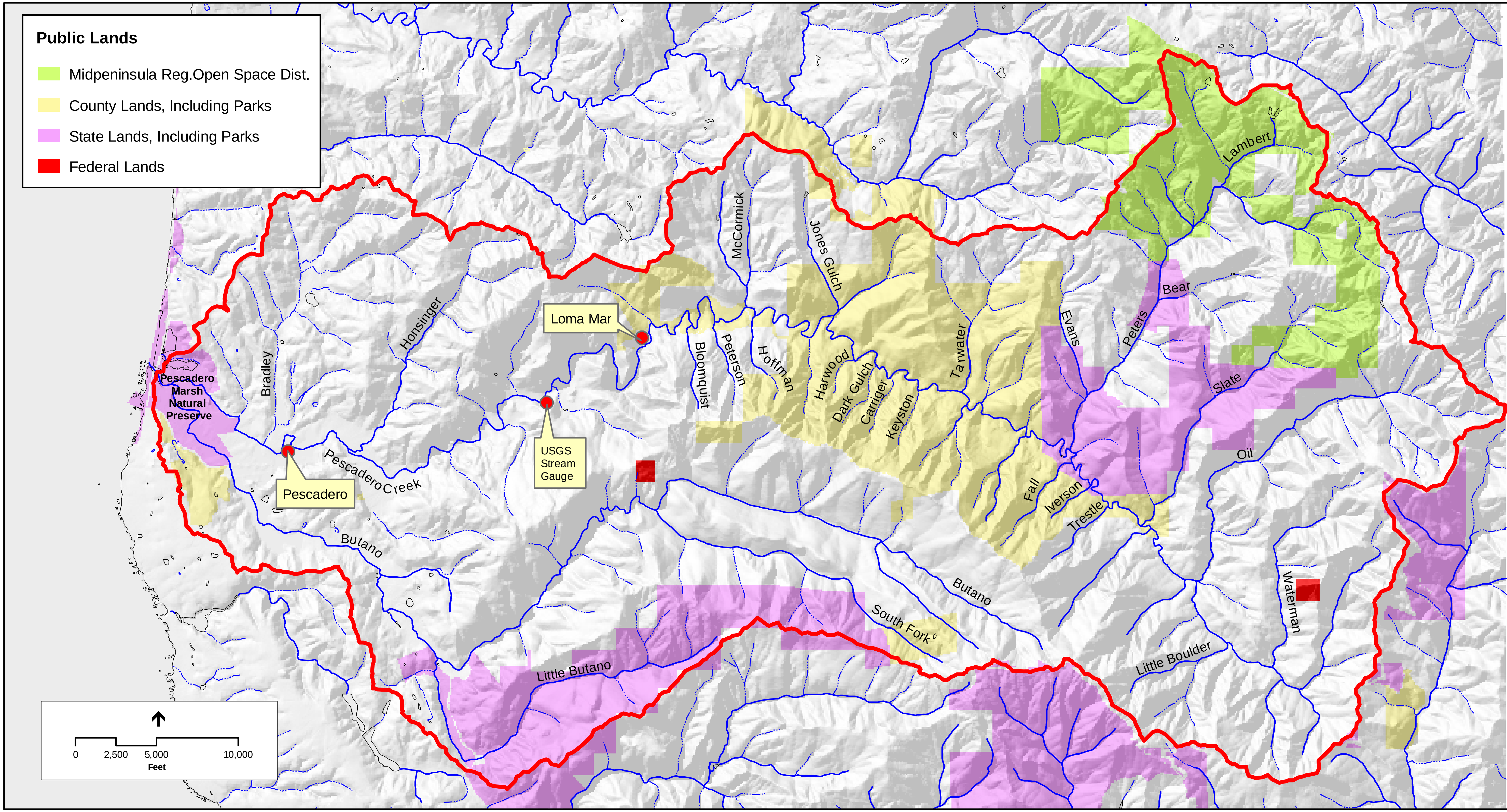
CHAPTER 2

OVERVIEW, CONCLUSIONS, AND RECOMMENDATIONS

The Pescadero-Butano watershed is the largest coastal watershed between the Golden Gate and the San Lorenzo River. The watershed's two principal streams, Pescadero Creek and Butano Creek, which have their confluence in Pescadero Marsh, drain 81 square miles of the Santa Cruz Mountains and the coastal valleys, hills, and terraces around the town of Pescadero (Map 2-1). The San Andreas Fault lies just to the east of the watershed, and the San Gregorio Fault runs through the western portion of the watershed. The tectonic forces of this region, of which these two faults are expressions, give rise to a very rapid rate of uplift, as well as extensive folding, fracturing, and deformation of the bedrock. A variety of rock types crop out in these mountains, including marine sandstones, shale, and mudstones, basalt and other volcanics (see Map 6-1 in Chapter 6). These rock types have different physical properties that result in a range of susceptibility to erosion. The steepness of the mountains, and the power exerted on them by the intense rainstorms that strike the area about every 20 years, produce high natural rates of erosion. When the land is disturbed through human activities such as clearing of the forest cover, cultivation or overgrazing of the delicate grassland hillsides, modification of stream channels, removal of riparian vegetation, or road building and other grading activities; or through natural processes such as fires and earthquakes, it becomes much more susceptible to a variety of erosional processes. Chapter 6 demonstrates that a large portion of the erosion that has occurred in the watershed since 1937 is associated with land management practices.

Pescadero Creek, Butano Creek, and their main tributaries lie in deep, heavily wooded canyons. As these streams have evolved with the mountains that they drain, their channels have formed to move the products of erosion that they receive – sediment, soil, and debris – rapidly and effectively. Before the forest cover was extensively removed in the middle of the 20th century, these streams were shaded, with frequent, stable pools created by fallen trees, bedrock outcrops, and boulders, and an abundant, if not steady, supply of gravel. With cool stream temperatures and reliable flows through the summer[1], they provided excellent habitat for salmon and trout, and both Pescadero Creek and Butano Creek were renowned sports fishing streams for vacationing San Franciscans in the late 19th century, as described in Chapter 3.

[1] As one Technical Advisory Group (TAC) reviewer points out, one school of thought holds that removal of forest cover increases total water yield and may actually increase summer base flows, through reductions in interception and evapotranspiration by the forest trees. Early timber harvest practices commonly included disposal of slash in stream channels and use of stream channels for transport of logs. These practices resulted in greatly increased volume of woody debris in stream channels and the creation of huge log jams, some of which became barriers to fish migration. Many stream restoration projects, beginning in the 1960s or earlier, focused on removal of log jams and other deposits of woody debris from stream channels. In some instances, these restoration efforts were overzealous, and resulted in a loss of this important geomorphic and habitat element from which many streams are still recovering.



SOURCE: USGS data sets from Bay Area Regional Database; parcels from San Mateo County Department of Public Works

Map 2-1
The Pescadero-Butano Watershed

Because of its isolation, development in the watershed was slow through the 19th and early 20th centuries. During this period, most human activity was in the lowlands and coastal terraces, and consisted first of raising livestock, and later row crop agriculture, limited production of timber products – mostly shingles, and tourism. The middle of the 20th Century was the time of greatest change. During the period of 1930-1960, Highway 1 and other major roads through the watershed were built or improved; most of the coniferous forests were clearcut; farming became increasingly mechanized, and farmed land was extended up the coastal hills and into previously uncleared lowlands; Pescadero Marsh was diked and drained[2]; and portions of the watershed were subdivided and developed as rural communities, vacation homes, and small ranches.

The level of disturbance is much less now. As demonstrated in Chapter 6, the rate of erosion appears to have decreased, and stream conditions are adequate to support salmonids in much of the watershed. Nevertheless, the effects of last century's disturbances are still apparent, and current land management continues to have a lesser, but cumulatively significant, effect on stream resources.

THE 1955 FLOOD

The 1955 'Christmastime" storm and flood was, at that time, the largest in memory of long-time Pescadero area residents. The storm caused extensive landslides, flooded the town of Pescadero, and had a lasting effect on the landscape of the entire watershed.

The United States Geological Survey (USGS) gauging record on Pescadero Creek indicates that, within a short time of the 1955 flood, the elevation of the bed of Pescadero Creek at the gauging site had increased by about one and a half feet. Though other explanations are possible, it appears that the landslides and other mass wasting features (debris slides, debris flows and torrents, earthflows, gullies) triggered by the 1955 storm deposited a huge amount of sediment into the stream system, which aggraded the stream bed in the vicinity of the gauge, and probably throughout much of the stream system. Several winters prior to 1955 had produced no major storm events (the last storm of consequence had occurred in 1940), but during this period large portions of the watershed had been subjected to intensive, unregulated logging using heavy equipment (Figures 2-1, 2-2, and 2-3). It is likely, therefore, that the watershed was "primed" for massive erosion: the effects of road, skid trail, and landing construction; soil compaction from heavy equipment operations; canopy removal; and slash disposal still lay on the hillslopes and in the stream channels as disturbed and exposed soil, altered drainage patterns, and debris accumulations. At the same time, a growing population, rural subdivisions, and intensification and extension of agriculture during and after World War II, all contributed to disturbance of the watershed, and made it more susceptible to the damaging effects of a large storm.

2 See Viollis, 1979, and the forthcoming Pescadero Marsh study report for a detailed account of levee construction in Pescadero Marsh.

Figure 2-1: South slope of Pescadero Creek, logged in 1929. Photo taken June 24, 1930. From collection in the National Archives, Washington, D.C. Photo appears in Viollis, 1979.

Figure 2-2: Looking south near Pescadero Creek. Photo taken June 24, 1930. From collection in the National Archives, Washington, D.C. Photo appears in Viollis, 1979.

Figure 2-3: Looking south near Pescadero Creek. Photo taken June 24, 1930. From collection in the National Archives, Washington, D.C. Photo appears in Viollis, 1979.

The effects of the 1955 storm are apparent in an airphoto series from 1956. The mass wasting features mapped from this airphoto series (see Map 6-6 in Chapter 6) are clustered in the logged-over lands of the upper Pescadero and middle Butano watersheds, and in the coastal hills. While the lack of tree cover in these areas biases the mapping – since mass wasting features are much more visible from the air where there is no tree cover – there is also no doubt a relationship between the forest and ground disturbance that the photos record, and the instability of the land. The results of our on-the-ground surveys of erosion features in sample plots revealed numerous erosion features that appear to date back to the 1955 storm and to logging and agricultural practices of that era.

If our interpretation of the gauging station record is correct, the bed of Pescadero Creek at the station aggraded about one and a half feet in the immediate aftermath of the storm. Yet, by 1958, the apparent elevation of the streambed at the USGS gauge had fallen to about the same elevation it had prior to the storm. The apparent rapidity with which the streambed elevation recovered after the 1955 storm may be attributed to two characteristics of this watershed: the prevalence of low density, weak rocks that make up much of the watershed’s geology; and the deeply confined stream channels of the middle and upper watershed.

Much of the geology of the Pescadero-Butano watershed consists of mudstone, shale, and sandstone (see Map 6-1 in Chapter 6; see also Ellen and Wentworth, 1995 for description of bedrock units). Santa Cruz mudstone, one of the most common rock types, is very light and friable; once exposed, it breaks down quickly into a fine-grained silt (Owens, 2003). Other predominant rock types, including Butano Sandstone and the sandstones, mudstones, siltstones, and shales of the Purisima formation, also are weak and fine-grained. As stream sediments, the lighter rock types are easily mobilized and transported. The weaker rock types break down quickly into their constituent grain particles (much of the larger gravel-sized sediments in Pescadero Creek appear to be derived from the relatively limited areas of volcanic rock in the upper Pescadero watershed) [3]. The resulting fine sediments may be transported as a stream's suspended load, and can move very quickly through the system, even in moderately high flows.

Much of Pescadero Creek (upstream of Loma Mar), Butano Creek, and their tributaries, consist of deeply incised or confined channels. Pescadero Creek above Loma Mar is for the most part a broad-bottomed, steep-banked stream with limited flood plain development that, in the summer, meanders between alternating and mid-stream gravel bars. During floods, the channel fills rapidly with the rising flows, and the creek behaves like a gigantic sluice box, rapidly and efficiently sorting, breaking, and transporting sediments.

The three to four winters following the 1955 storm were relatively light, with the exception of the April 2, 1958 storm, which produced stream flow with a return period of about 14 years. These smaller events were probably sufficient to bring additional fine materials into the stream channels, but not to trigger much additional mass wasting. They were, however, apparently enough to weather and transport not only the additional fines they washed into the streams, but much of the massive sediment load from the 1955 storm – at least as far as the lowlands.

Pescadero Creek maintains a moderate range of gradient until it reaches Pescadero Marsh (see Map 7-1 in Chapter 7). The elevation of the bed at the Stage Road Bridge, for example, is about 10 feet above mean sea level. By the time sediment arrives from the upper watershed at the alluvial reach of the stream, which begins around the USGS gauge, it consists primarily of small gravel, sand, and silt. Further downstream, by the time the stream enters State Park land around the end of Water Lane, the material is finer still (see Chapter 7). Pescadero Creek therefore has the ability to transport sediment – especially the fine material that it carries in its lower reaches – all the way to the ocean. This can be seen in the bed material that presently makes up the channel: even in the reach just upstream of its confluence with Butano Creek at Grassy Point in Pescadero Marsh, the bed of Pescadero Creek is composed of sand and small gravel.

Butano Creek, on the other hand, has a very low gradient after it emerges from its canyon, at about the Cloverdale Road bridge (see Map 7-1 in Chapter 7). The course of Butano Creek follows the San Gregorio Fault through the fault's rift valley to Pescadero Marsh. The lower course of Butano Creek has thus been extended several miles, but the drop in elevation has not changed. The Butano Creek watershed is composed almost entirely of sandstone, mudstone, and

[3] As one TAC reviewer points out, although the Butano and Purisima Formation rocks are generally relatively friable and easily erodible when they are bare, they are variable in strength properties. They also contain local beds and lenses of conglomeratic sandstone that may be a source of gravel in streambeds.

shale, including a relatively large seam of the highly erodible Santa Margarita Sandstone. While the upper part of the stream, above the falls, contains boulders and exposed bedrock in its bed, the bed of the lower reach, where the stream parallels Cloverdale Road, is made up of very fine material – the products of erosion and weathered sediment that accumulates in the nearly flat gradient of the creek's lower reach. This is most evident in the vicinity of the Pescadero Road Bridge (Cook, 2003), and in the Alder Patch upstream and downstream of the bridge, where a heavy accumulation of fine material has apparently raised the bed of the stream several feet, resulting in a sluggish, braided channel. This condition has no doubt been exacerbated by the Pescadero Road Bridge itself, which constricts the channel and reduces its flood (and sediment) conveyance capacity (Swanson, 1999). Pescadero resident William Cook has prepared a report that details the history of changes in lower Butano Creek. Cook maintains that, in addition to the constriction caused by the bridge, flooding has also been exacerbated by the partial filling of the floodplain by the construction of Pescadero Road and the fire station; and by the dense vegetation and beaver dams in the lower course of the stream below the bridge (Cook, 2003).

The effects of the 1955 storm on Butano Creek were, if anything, even more dramatic than those on Pescadero Creek. In July, 1955, field notes by an anonymous Department of Fish and Game biologist[4] included the following description of Butano Creek: "…a very nice stream for salmon and trout reproduction.…" The main threat to the fishery noted was from the "web of diversion irrigation." In 1954, Fish and Game biologist Leo Shapovalov noted "…a minor problem of siltation from logging operations by Santa Cruz Lumber Company" in the upper watershed. He noted that much of the stream bottom in the higher reaches of the creek was composed of bedrock, with the lack of spawning gravel a limit to the productivity of the fishery. Shapovalov described Butano Creek as a "…cool, well-shaded small stream flowing through redwoods except in its lower 2-3 miles, which is open, delta-like country. It might provide some trout fishing, but steelhead have never been too plentiful because of the Falls."

After the storm, a 1958 stream survey by Ken Middleton and Ron Regnart of the Department of Fish and Game found very different conditions. They described the channel bottom as consisting of, "…mud in the vicinity of the mouth, sand predominant in the rest of the stream, 2-4 inches deep. Gravel and rubble next in abundance. Spawning considered poor due to heavy sand deposition." They attributed the heavy accumulation of sand to lumber operations in the upper watershed "for the past 3 years," and noted that the most intensive lumbering operations had been occurring at the junction of the north and south forks, where fallen trees and slash, "…completely hide the stream." Conditions had not changed much by 1964, when a stream survey by Fish and Game biologist Glenn Brackett reported abundant fines and little good spawning habitat: "Steam channels have a deep layer of silt, and the sandy-silty bottom is constantly shifting." In South Butano Creek, Brackett estimated that the bed composition included 22 percent sand, 40 percent silt, and 10 percent organic debris.

4 This and the following references to Fish and Game surveys and field notes are from Robert Zatkin's compilation of information from Department of Fish and Game files on San Mateo County streams, published as, *San Mateo County Streams: Compendium of Information,*13 volumes, 2002.

Professor Robert Curry of U.C. Santa Cruz and several of his colleagues in a 1985 study of the hydrology of Pescadero Marsh provide further evidence of the relative difference in the behavior of Pescadero and Butano Creeks in response to the 1955 storm (Curry et al, 1985). Their analysis of core samples taken from several locations around the marsh reveal that, between 1955 and 1984, Butano Creek had deposited up to five feet of sediment in its floodplain above and within the Marsh, while Pescadero Creek had deposited only about two feet. Furthermore, they observed that the area of deposition for Butano Creek was much larger than for Pescadero Creek, meaning that the total volume of material deposited by Butano Creek was many times that for Pescadero Creek. They assumed a similar rate of hillslope erosion in the two watersheds, but conjectured that Butano Creek carried a much larger amount of sediment due primarily to material scoured out of the banks and stream bed below Butano Falls. Their conjecture is substantiated by our survey of the bed of Butano Creek at the Cloverdale Road Bridge (see Chapter 5), which indicates that the elevation of the bed of the stream at that location fell by nearly five feet between the time the bridge was built in 1963 and our survey in 2003.

Another source of the sediment deposited in the lower course of Butano Creek is the extensive gullying of the coastal hills. Gullying appears to have begun in earnest with the 1955 storm, and continues to contribute large quantities of sediment to the lower courses of both Pescadero and Butano Creeks[5].

A possible explanation for these observations is that sediment entering Butano Creek in the 1955 storm caused the creek bed to aggrade by several feet. Then, in the years after the storm, much of the stream incised back to or below its former elevation. Changes in runoff from timber operations and residential development in the watershed may have caused an intensification of runoff during storms, which may have resulted in portions of the creek incising to a lower elevation than before widespread disturbance in this watershed. Another possible explanation for this incision is tectonic uplift, either from the 1906 earthquake or from smaller, more recent events. A third explanation, though one that currently is unsubstantiated, stems from the possibility that the present lower course of Butano Creek, at the western edge of the valley, may be an artificial channel, and that the creek may have been relocated at the time of agricultural clearing of the area along Cloverdale Road prior to World War II.

Whatever the reason for channel incision, Butano Creek, because of its low gradient, small drainage area, and the natural and built constrictions in its lower channel, does not have the ability to transport all of its sediment load to its mouth, and the material is instead deposited on the floodplains during floods, and in the stream channel, at and below the Alder Patch, at other times. Pescadero Creek, by contrast, has the ability to transport its sediment load all the way to

[5] Long-time Pescadero resident and farmer Noel Dias noted in a personal communication that when the coastal hills were being actively farmed (see discussion of flax farming in Chapter 3), the farmers took care to remediate any rills or small gullies before they had a chance to develop. The conditions for gully development may be associated with use of the coastal hills for agriculture, but may be more directly attributable to large storm events that coincided with the abandonment of agriculture in the hills. Regarding gully development in the coastal hills, see Mitchell Swanson et al, "An example of rapid gully initiation and extension by subsurface erosion: coastal San Mateo County, California." Geomorphology, 2 (1989), pp. 393-403.

the sea, enabling it to recover quickly from major storms and to maintain a remarkably stable bed elevation over time, as shown in our bridge surveys (Chapter 5).

Fish and Game surveys from the 1960s and 1970s indicate that Pescadero Creek's fishery, at least in the upper watershed, also recovered relatively quickly from the 1955 storm. A 1962 survey by Glen Brackett and Richard Burge, from Loma Mar to just above Iverson Creek (in what is now Portola Redwoods State Park) noted that "…40 percent of the creek may be used for spawning." They observed that the stream bed consisted of gravel mixed with moderate amounts of sand and silt. Several other surveys of Pescadero Creek tributaries, including Peters Creek, Oil Creek, Slate Creek, Tarwater Creek, Little Boulder Creek, and Fall Creek, noted in all instances – except Tarwater Creek – siltation that the observers attributed to timber operations, as well as large accumulations of woody debris. In all these streams, however, the surveyors noted good spawning and rearing habitat. Similar observations were made in the 1960's of Little Butano Creek, which had been relatively unaffected by logging operations, and Honsinger Creek. These reports contrast with a 1963 survey by Brackett of the lower part of Pescadero Creek, from the marsh to the downstream boundary of Memorial Park. He found the best spawning areas were above the "Loma Mar Bridge" (the lower Wurr Road Bridge?). Below this point he noted "great quantities" of sand and silt and poor spawning habitat.

It is also interesting to note the results of a July, 1977 survey of the mainstem of Pescadero Creek from Memorial Park to the lagoon, which found extensive siltation of the streambed: the surveyors noted that the bed had 1-2 inches of silt deposited on the surface in most places, and overall was made up of 50 percent sand, 40 percent silt, and only 10 percent gravel and larger sediment from Memorial Park to stream mile 5.3 (a length of 5.8 miles). From there to the lagoon the bed was made up of 50 percent sand, 30 percent silt, 10 percent coarser material, and 10 percent organic debris. These observations were made toward the end of the 1975-77 drought, the driest period on record. There simply may not have been sufficient flows in the two or three years previous to the survey to transport even very fine material.

THE WATERSHED BEFORE AND AFTER 1982

The January 3-5, 1982 storm was of a similar magnitude to the 1955 storm, and probably had a similar effect on the watershed. The USGS notes that the 1982 storm triggered 18,000 fast-moving debris flows and numerous slower-moving landslides and earth flows in the San Francisco Bay region, causing 25 deaths and $66 million in property damage (USGS, 1997). The USGS mapped debris flows and large landslides resulting from the storm, and found high concentrations of debris flows in several areas of the Pescadero-Butano watershed: in the area between Bradley Creek and Honsinger Creek (up to 20 individual debris flows per square kilometer); in the Butano basin, centered just upstream of the confluence of South Fork Butano Creek and Butano Creek (up to 22.1 per square kilometer); and in the area west of the lower course of Butano Creek (up to 27.2 per square kilometer) (Ellen and Wieczorek, 1988, plate 8). The storm also triggered a large landslide, consisting of translational debris slides, at least nine of which coalesced into two debris flow tracks in the upper tributaries of Fall Creek, in Pescadero Creek County Park (Ellen and Wieczorek, 1988, plate 8 and Table 8-4).

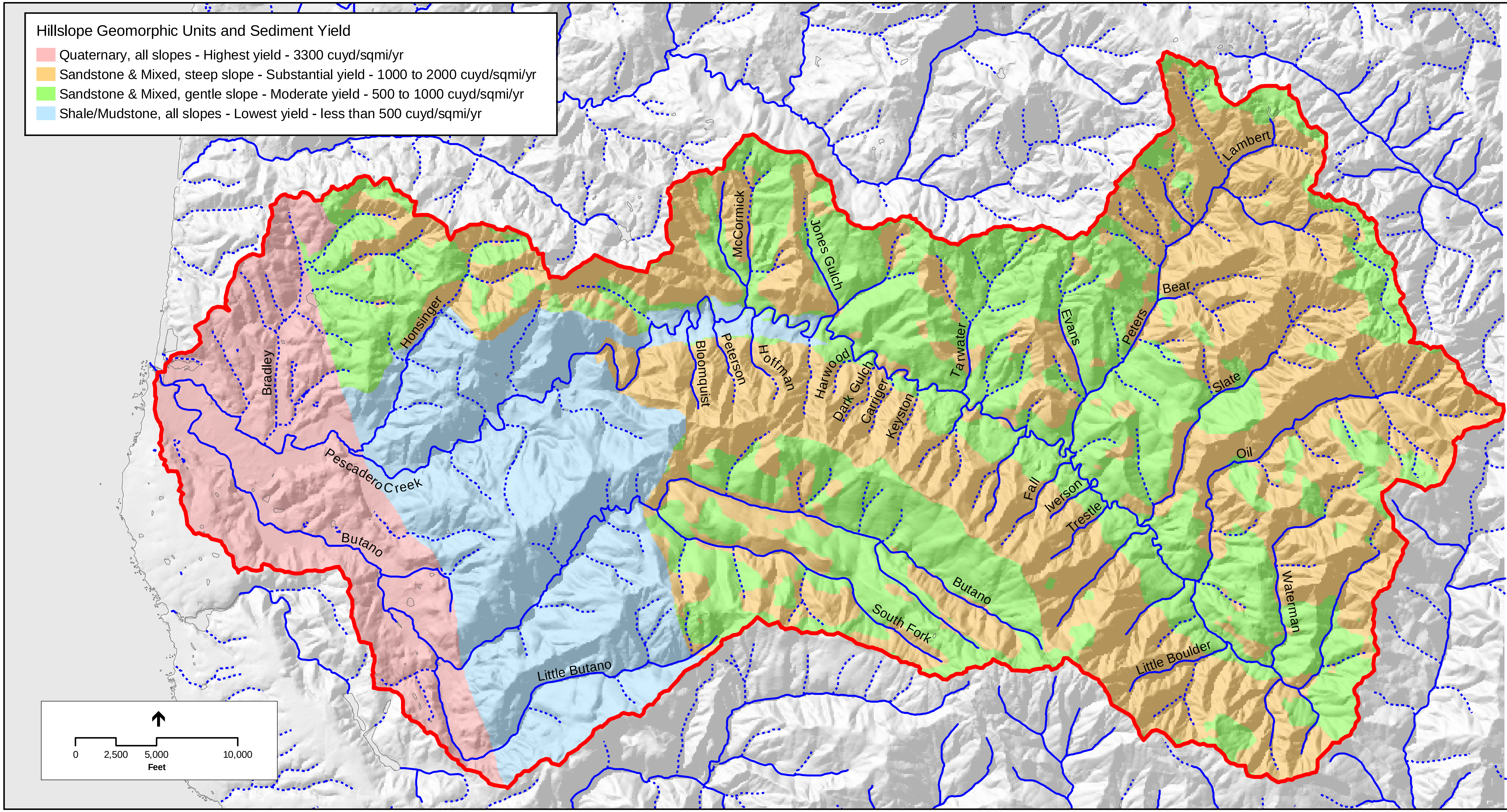
The USGS stream gauge flow measurement record is missing for the years from 1972 through 1987, so it was not possible to conduct an assessment of changes in stream bed elevation as we did for the 1950s. Furthermore, the California Department of Fish and Game seems not to have conducted stream surveys in the Pescadero-Butano watershed during the 1980s (there are no stream survey reports from this time period in Robert Zatkin's previously referenced compilation). The only piece of physical evidence that we have that suggests a similar response of the stream channel is a 1986 survey of the Anderson Bridge, below Loma Mar. That survey (see Chapter 5) indicates that the elevation of the thalweg (the deepest part of the channel – the low-flow channel) was 1.3 feet higher in 1986 than when the bridge was built in 1937. By the time of our survey in the fall of 2003, the elevation of the thalweg had lowered by 2.6 feet compared to the 1986 survey. This suggests, but certainly does not prove, that the bed of Pescadero Creek aggraded and then incised in response to the 1982 storm, in a similar manner to its response to the 1955 storm.

Neither would it be surprising if the 1982 storm did have a similar effect on the watershed. As noted above, the 1982 storm produced flows in Pescadero Creek of a similar magnitude to 1955. One long-time resident recalls that in the town of Pescadero, the 1982 flood waters were "a little bit higher" than in 1955 (see Chapter 3). Furthermore, while the California Forest Practices Act became law in 1974, its full implementation took several years. By 1982, logging had declined in the watershed, but was still the predominant land use in the upper Pescadero and Butano basins, as it continues to be today. The recently harvested timberlands would not yet have begun to benefit from improved logging practices, and, as in 1955, there had been no major storms for the past several years. As they were prior to the 1955 storm, the hill slopes and stream channels may have been "loaded" with material ready to move downslope and downstream, once the hillslopes became saturated with rain and the channels filled with floodwaters.

The February, 1998 storm produced the largest flow recorded at the USGS gauge since it began continuous operation in 1951. Long-time residents who experienced all three floods agree that the 1998 flood produced higher water in town than the 1955 or 1982 storm (see Chapter 3). The record of stream measurements taken at the USGS gauge in the months and years following the 1998 storm shows no 1955-like response of the elevation of the stream bed (Chapter 4). There was a small increase in elevation in the year 2000, but no dramatic, immediate change as we see in the record from the 1950s. This may indicate that there is less easily mobilized sediment stored on the hillslopes and in the stream channels than there was at the time of the 1955 and 1982 storms, and that the watershed is recovering from the widespread disturbances of the last century. The results of the sediment source analysis conducted for this study, presented in Chapter 6, indicate a trend toward lower sediment yield rates.

EROSION AND SEDIMENT DELIVERY THEN AND NOW

Erosion in the Pescadero-Butano watershed is estimated at an average of 2,000 yds^3/mi^2/year over the period 1937 to 2002 (Chapter 6). Sediment delivery, that is, the amount of eroded sediment that enters stream channels, is estimated at an average of 1,700 yds^3/mi^2/year over the same time period. The relative amounts of both erosion and sediment delivery from the various terrain types



SOURCE: USGS data sets from Bay Area Regional Database; Pacific Watershed Associates

Map 2-2

Hillslope Geomorphic Units and Sediment Yield in the watershed quantified in this study are in line with expectations, with more highly erodible geologic units and steeper areas generally producing the largest quantities of sediment (Map 2-2).

Erosional features associated with land management account for the majority of sediment delivery volumes from the watershed: we estimate that approximately 90 percent of all sediment entering stream channels is from erosion features that are associated with some kind of human land use (see Table 6-12 in Chapter 6). In order of importance, roads, agricultural including grazing, and timber harvest land use associations account for the largest percentage of the total sediment delivery (see Table 6-13 in Chapter 6). Intensive land use practices have contributed to accelerated, human-caused erosion throughout the watershed, resulting in increased sediment loading of the streams. Over the past 50 years, subsequent sediment transport within the upland stream channels has, in all likelihood, contributed to aggradation, sedimentation, and flooding in the lowlands of the watershed.

Analysis of aerial photos (Chapter 6) indicates that commercial timberlands accounted for a large amount of sediment during the earlier years covered in this investigation. The 1956 air photo set revealed widespread occurrence of mass movements in timberlands that had been subjected to clear-cutting and use of tractors for log skidding. Mass movements were much less widespread in these areas on both the 1982 and 2000 air photo sets that we examined. It is likely that improved land management practices are the central factor in reducing erosion and sediment delivery on commercial timberlands. Field observations indicate, however, that there may be substantial quantities of sediment still stored in smaller streams in timberlands previously subjected to tractor logging. Consequently, the areas underlain by sandstone and mixed lithology, which constitute much of the forested area of the watershed, may continue to produce relatively large quantities of sediment for some time.

The area of the watershed west of the San Gregorio Fault accounts for a significant proportion of the erosion and sediment delivery documented in Chapter 6. While the bulk of this area lacks forest canopy cover and may be naturally more susceptible to erosion, it has also seen some of the most intensive land management activities, particularly cropping and grazing. Much of the erosion was initiated prior to 1956, but continues today. Most mass movements and gullying in this area occur in relatively steep hillslope areas.

STREAM CHANNELS TODAY: GEOMORPHOLOGY AND FISH HABITAT

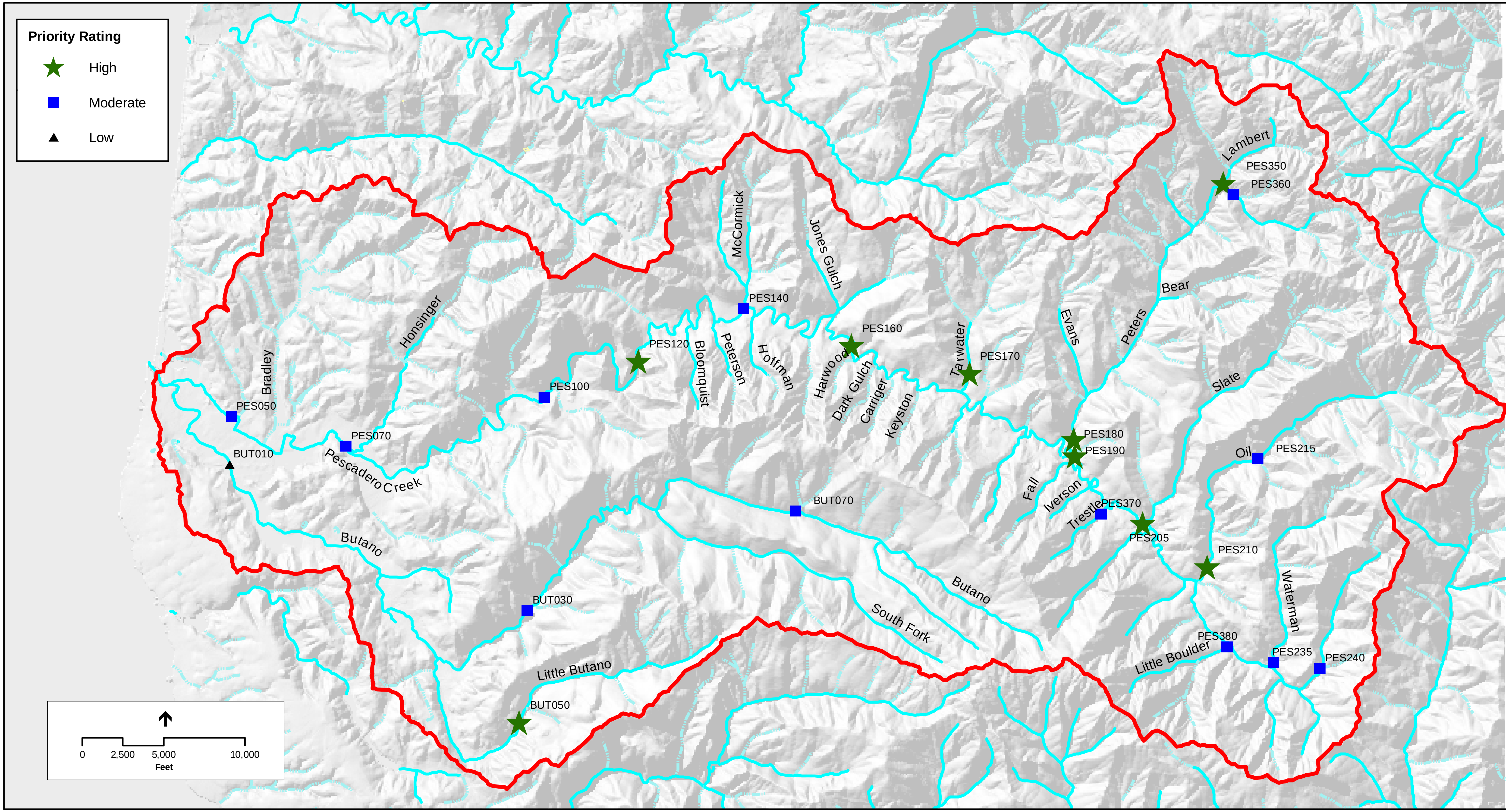
As described in Chapter 7, there appears to be substantial variation in sediment supply entering the stream system through smaller drainage basins (less than 6 square miles or 10 square kilometers), but in the larger streams, the cumulative inflow from smaller basins creates a relatively uniform and abundant supply of sediment stored in stream channels. This is seen in a relatively consistent distribution of gravel bars in channels with drainage areas greater than 6 square miles. A surprisingly consistent sediment size distribution is found throughout the Pescadero Creek channel network, extending even into the steeper headwater channels with small drainage areas where coarser sediment size distributions might be expected. Hence, even in relatively small channels high in the watershed, sediment sizes on the bed are frequently suitable for spawning by salmonids. Given that even within the steeper stream reaches there are areas of relatively low channel slopes -- well within the range utilized by steelhead -- migration barriers may be a primary factor limiting the extent of available steelhead habitat. In contrast, Butano Creek bed material consists of both very coarse material and very fine material, with a lower proportion of gravel between the extremes. Unlike Pescadero Creek's watershed where a relatively large variety of bedrock types are found, the Butano basin contains primarily fine-grained sedimentary rocks that tend to weather to fine gravel, sand and silt sizes, and produce relatively little coarse gravel. Hence, good quality spawning habitat is more limited in Butano Creek than in Pescadero Creek.

Large woody debris (LWD) is likely to be less abundant in the watershed than prior to European settlement, due to logging activities and stream management that included LWD removal over the past century. It is likely that, prior to the large-scale mechanized logging that began around 1930, very large redwoods lined stream channels throughout much of the upper watershed, providing extremely long-lasting LWD that was not easily mobilized.

LWD abundance varies significantly from reach to reach, as is typical in forested watersheds. Relatively mature stands of conifers in public parks adjacent to stream channels in the Pescadero-Butano watershed are likely to provide significant LWD inputs that would be expected to improve pool habitat (cover and depth) over the coming decades. Live trees -- mostly hardwoods -- growing within the stream channels provide a source of LWD available over the short-term.

Channel and floodplain morphology in the lower reaches of Pescadero and Butano Creeks, or the 'Marsh' reaches, are influenced by tidal processes. The marsh reaches exhibited distinctive morphological characteristics compared to the rest of the watershed, including greater channel width, higher entrenchment ratios, and lower ratios of bankfull depth to floodplain height. Moreover, these channel reaches exhibit finer sediment size distributions, suggesting relatively more frequent episodes of overbank flooding and deposition compared to other parts of the watershed. Although our field measurements did not detect a significant change in channel slope, periods of high tide that coincide with flood flows, as well as seasonal lagoon formation, would be expected to reduce the water surface slope and therefore the energy gradient of the stream in this area. This creates a strongly depositional environment, which is a normal feature of an alluvial river as it approaches a fixed base level such as the sea. The growth of dense riparian vegetation along channel banks would tend to enhance this effect.

These same common stream features are reflected in the quality of the watershed's fisheries habitat, as indicated in Chapter 8. Overall, most of the sites surveyed in the Pescadero basin provide adequate habitat for salmonid spawning and rearing (Map 2-3), including suitable spawning gravels, frequent pools, good riparian forest growth, a favorable population of benthic macroinvertebrates, and adequate water quality (especially temperature) and flows. Few barriers to fish migration, other than natural falls, were seen by our field crews or noted in previous surveys, except in small tributaries and high in some larger tributaries. The common habitat impairments, which may also be considered factors limiting the productivity of the fishery, include a lack of cover, related to the infrequency of large woody debris; abundant fines, and



SOURCE: USGS data sets from Bay Area Regional Database; Sampling points from San Francisco Bay Regional Water Quality Control Board and Environmental Science Associates

Map 2-3
Fisheries Habitat Ratings

shallow pools (which itself is related to the abundance of fine sediment and the lack -- or rather the infrequency -- of large woody debris).

CONCLUSIONS AND RECOMMENDATIONS

As stated in Chapter 1, the specific objectives of the Pescadero-Butano Watershed Assessment are as follows:

1. Characterize the watershed and identify the areas of remaining high quality salmonid habitat, that should receive high priority for conservation and restoration treatments;

2. Identify the factors and anthropogenic processes limiting the quality of salmonid habitat in the watershed, and water quality generally.

3. Identify the most cost-effective treatments for improving salmonid habitat, and the areas where these should be employed.

Regarding the first objective: adequate, but generally not excellent steelhead trout spawning and rearing habitat exists throughout a relatively large area of the watershed that is accessible to anadromous fish. The lack of deep, sheltered pools and undercut banks in the reaches we surveyed, however, indicates that there is little suitable habitat for coho salmon. The best salmonid habitat that we observed is found in the upper Pescadero basin, including the upper mainstem of Pescadero Creek itself (upstream of Loma Mar), and in the following tributary streams: Tarwater Creek, Peters Creek, Slate Creek, and Oil Creek. We have assigned these areas a High Priority for conservation and restoration, as indicated in Map 2-4. This designation means that these areas should receive highest priority for conservation and restoration of fisheries habitat; that relatively little improvement in existing conditions is required to optimize the quality of habitat; and that minor improvements can be expected to provide substantial benefit.

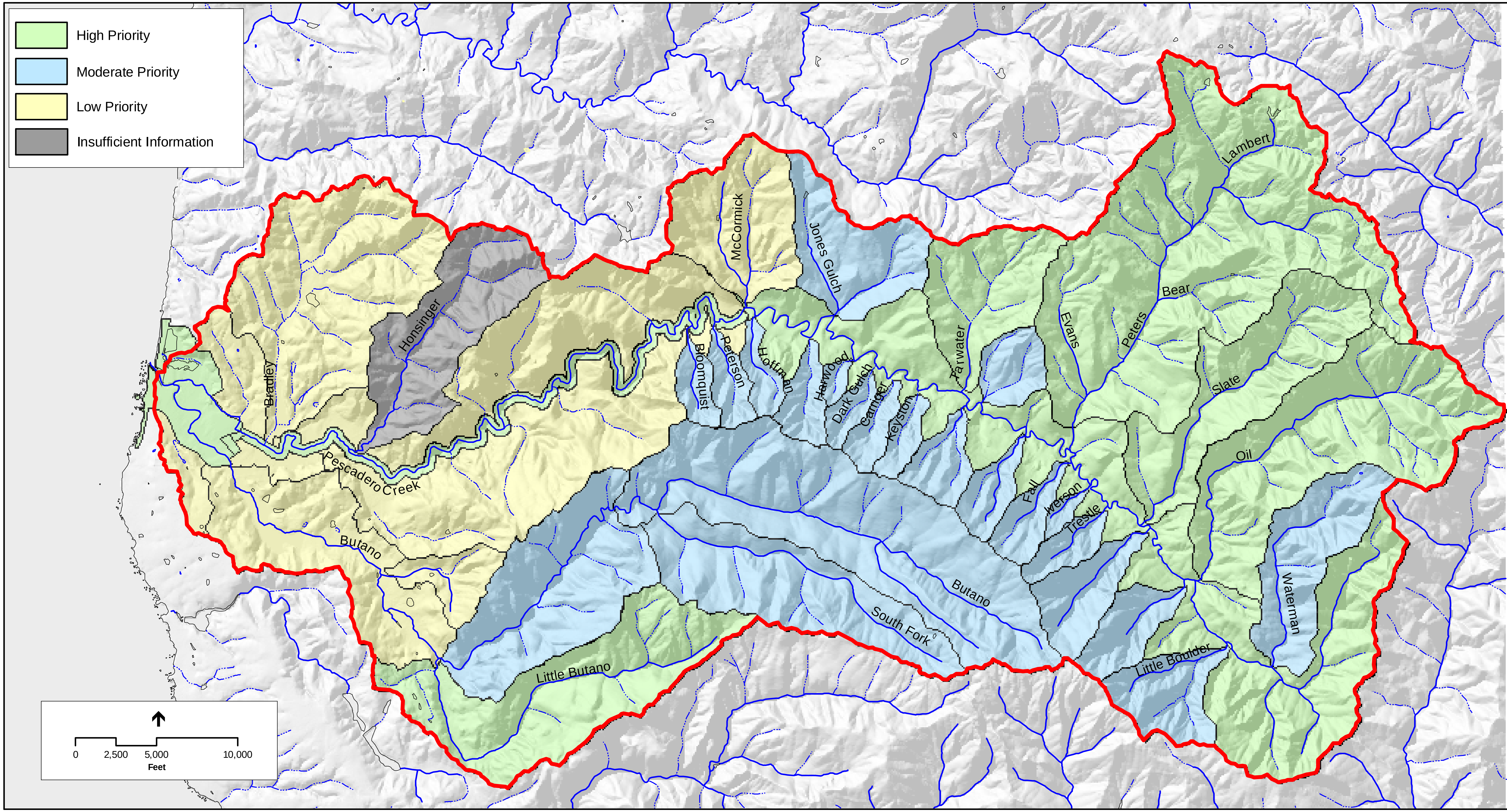
Other streams in the upper Pescadero basin, such as Little Boulder Creek and several other of the tributaries draining the north slope of Butano Ridge, provide only a limited extent of good quality salmonid habitat in their lower reaches, but may be important in contributing cold water to the mainstem channel through the summer, and in providing habitat for other aquatic species. The Old Haul Road crosses nearly all of these streams. Many of the crossings are culverted and pose long-term threats of catastrophic fill failure. Most of the crossings are, however, in steep reaches of these streams, presumably above the natural limit of anadromy. Waterman Creek is still recovering from severe past disturbance, including culverting of its lower reach and filling of its channel. A major stream restoration project, sponsored by the California Department of Fish and Game, has restored this reach, and provided some spawning and rearing habitat, though as yet of limited quality. Further upstream, a log dam presents a barrier to upstream migration. We have assigned these basins a Moderate Priority ranking (Map 2-4) for fisheries conservation and restoration. Protection and enhancement of these areas is of importance to the overall health of the fishery, but is likely to have mostly indirect beneficial effects. Further work on Waterman Creek, particularly to remove the old log dam, may also be warranted.

With the exception of Pescadero Creek itself and Pescadero Marsh, the lower part of the Pescadero Creek Basin, including the Bradley Creek and McCormick Creek basins, is currently of minor importance to the fishery, and consequently we assigned this area a Low Priority ranking. From the perspective of protecting and enhancing the fishery, the most important actions in the Low Priority areas will be controlling sediment, protecting riparian corridors, and minimizing water diversions. Such actions would help reduce sedimentation in the lower Pescadero Creek channel and Pescadero Marsh, enhance biological resources other than salmonid habitat, and might eventually lead to reestablishment of the streams in these basins as spawning and rearing habitat. While landowners should be encouraged to undertake such activities as improvements in their land management practices, they can be expected to have a relatively high cost to benefit ratio, in terms of improvement of the fishery. We only observed conditions at the mouth of Honsinger Creek, which was dry in August, 2003, but one resident subsequently reported that steelhead use this creek for spawning and rearing, and older Department of Fish and Game surveys note use of Honsinger Creek by steelhead. Since we have no further information on Honsinger Creek, we are not assigning this basin a priority ranking, but rather suggest that a survey be conducted to ascertain current habitat conditions, fish utilization, and factors limiting productivity of the fishery.

Pescadero Creek below Loma Mar provides moderate quality spawning and rearing habitat, and is important as a migration corridor. We conclude that protection and enhancement of the stream corridor and its riparian area is of sufficient importance to assign it a Moderate Priority rating for fisheries protection and enhancement.

Much of Butano Creek's fishery is in only fair condition at best, but may be expected to improve gradually over time with the much-improved land management practices now in place in the upper watershed, and as this area continues to recover from the massive disturbance caused by mid-20th Century clearcutting, tractor logging, and the 1955 storm. Our single survey station in the reach of Butano Creek between the Cloverdale Road bridge and Butano Falls received a "good" rating, and one TAC reviewer notes that there are long reaches of Butano Creek upstream of Cloverdale Road where the habitat is very good and densities of steelhead are higher than in sections of Pescadero Creek. It is possible that Little Butano Creek provides limited but good quality spawning for anadromous fish just above its confluence with Butano Creek and below its falls (though we did not survey this reach), and the upper part of this stream, which has excellent habitat and which supports rainbow trout, may serve as an important population and genetic reservoir. We assigned middle and upper Butano Creek above the Cloverdale Road Bridge a moderate rating, indicating that relatively extensive effort, particularly to reduce sediment input to the stream system, is required to effect significant improvements in the fishery. We assigned Little Butano Creek basin a High Priority ranking (Map 2-4).

Pescadero Marsh serves as important habitat for salmonids. The marsh is used extensively by steelhead juveniles and smolts in the period from late spring to early summer, and as a migration corridor for adult fish in the winter and early spring (Smith, 1987). We assigned Pescadero Marsh a High Priority rating, indicating its overall importance for salmonids, and particularly steelhead, in the watershed.



SOURCE: USGS data sets from Bay Area Regional Database; Environmental Science Associates

Map 2-4
Priority Sub-Basins

In regards to the second objective: as stated above, the most broadly observed impediments to a productive fishery include a lack of cover, related to the infrequency of large woody debris; abundant fines, which we observed as deposits in streambeds, but which also are likely to impair water quality during higher flows; and shallow pools.

The anthropogenic causes or contributors to these impediments are for the most part past land management practices, including clearcut and tractor logging, a period of intensive, mechanized agriculture on steep, unstable hillslopes, followed by abandonment of agriculture in these areas, and road construction and other grading activities, all of which have increased erosion and delivery of sediment to stream channels; and disturbances within and along the stream channels themselves, including removal of riparian vegetation, manipulation of stream beds, stream banks, and stream courses, and construction within or adjacent to stream banks. While these practices have for the most part halted or decreased, the legacy of past practices continues to impede the fishery. Investigation of other possible impediments, such as water diversions and water pollution (nutrients and toxics) from runoff, septic system seepage, and other sources, were beyond the scope of this study (see however the forthcoming results of the Regional Water Quality Control Board's Surface Water Ambient Monitoring Program (SWAMP) study in the Pescadero-Butano watershed). We observed several migration barriers in our fieldwork, and noted several more from past California Department of Fish and Game stream surveys. Most of these barriers are close to the natural limit of anadromy, where streams become too steep or too small for salmonids. We did not find that artificial barriers are a major impediment to the fishery in this watershed.

As to the third objective, the fishery can be improved through measures that will increase cover, improve pool depth and frequency, and reduce fine sediment. In the short-term, judicious placement of large woody debris may be used to improve cover and effect pool formation. This should be accomplished first through complete surveys of the anadromous sections of the streams within the high priority basins indicated in Map 2-4, and then by the development and implementation of site-specific work plans based on these surveys. Long-term, the supply of very large, stable woody debris should be achieved through protection of riparian corridors, in order to allow the re-growth of large streamside redwoods. Some of the effective means by which this can be accomplished are fencing to allow recovery of disturbed riparian areas, and in some places active revegetation of streambanks and floodplains; purchase of land for parks, open space, or conservation areas; establishment of conservation easements to limit land uses within riparian areas; and outreach to and education of private landowners to encourage and assist them in their own conservation land management practices. It can be expected to take decades to establish an adequate supply of high-quality, naturally-recruited LWD in parts of the watershed that have been recently disturbed.

In the lower part of the watershed, particularly in the lower channels of Pescadero Creek and Butano Creek, management of large woody debris should take into account protection of private property and public infrastructure: in addition to its general benefit as an element of fish habitat, large woody debris can cause bank erosion, plug culverts, damage bridges, reduce flood conveyance, and pose safety hazards during high flows. Log jams can be particularly destructive and usually provide minimal benefit to fish. The lower reaches of Butano and Pescadero Creeks are used by fish primarily as migration corridors, though some spawning takes place in the lower course of Pescadero Creek. While placement or maintenance of large woody debris in these areas might improve fish habitat by increasing habitat diversity and complexity and by providing cover, these benefits need to be weighed against potential harm to private property and infrastructure. Use of other structures, such as boulders placed in the streambanks, may be more appropriate than log structures if active improvement of fish habitat is deemed desirable. Removal or modification of downed trees and log jams may, in some instances, be a prudent course of action, where there is a clear threat to property or safety.

From the perspective of erosion and stream sedimentation, land use practices have improved in the Pescadero-Butano watershed over the past several decades. The timber harvest practices of the timber companies now active in the watershed are less intensive, and are far more sensitive to issues of erosion and water quality than their predecessors'. Farmers and ranchers in the watershed also are actively improving their soil conservation and other resource protection practices, individually and through work with the Natural Resources Conservation Service and the Farm Bureau. There is also a greater awareness of the need for erosion control during and after construction and road maintenance activities. In addition, the area of protected lands continues to increase with the acquisition of former ranch and timber lands for parks and open space. Such acquisitions generally terminate intensive use of these lands, and the various parks and open space agencies have shown strong interest in addressing on-going and potentially controllable erosion problems. While erosion and sediment delivery resulting from past management will likely continue for some time, we may expect an overall decrease in erosion and sediment delivery to stream channels as land use practices continue to improve and as degraded lands recover both naturally and through proactive treatments.

Nevertheless, relatively high rates of stream sedimentation produced as the legacy of mid-20th century land management practices can be expected to continue, both from features that continue to erode, and from sediment that has already entered the stream system but has yet to be transported through it. The geology of the watershed, the friability and small grain size of much of the supplied sediment, and the vulnerability of the watershed to mass wasting associated with high-intensity storms, mean that fine sediment reduction is a challenging prospect at best.

While eliminating all sources of controllable land management-associated sediment delivery to streams would produce the best results in terms of stream health, certain classes of erosion are both more practical and more cost-effective to address than others. The inventory, assessment and treatment of road-related sediment delivery is perhaps the most cost-effective and immediate strategy for reducing continued anthropogenic sediment loading of stream channels. Timber companies operating on commercial timberlands in the Pescadero-Butano watershed and the San Mateo County Parks and Recreation Division have worked to upgrade their active road networks in recent years. However, there remains an extensive network of secondary, infrequently used, and abandoned logging roads and skid trails on both private timberlands and public parklands that constitute an important source of both chronic and episodic sediment delivery to streams. These roads should be inventoried and treated, with greater emphasis placed on roads in High and Moderate Priority basins.

Similarly, ranch roads, both on actively grazed lands and on recently acquired public lands, appear in many cases to be poorly constructed with regard to drainage, fill stability and slope location. Upgrade of both forest and ranch roads, particularly in those areas or geologies most susceptible to erosion (where most of the commercial timberlands and many park and open space lands are located), would go far in cost-effectively reducing anthropogenic sediment loads.

Many low-order stream channels have been observed to store large quantities of sediment from previous land management practices. While in most cases this sediment cannot be treated cost-effectively, in some instances (particularly in high priority sub-basins) sediment may be removed or stabilized. A comprehensive inventory of lower order stream channels in high priority sub-basins should be undertaken to evaluate both the conditions with regard to stored sediment and the potential for treating degraded stream channels.

Gullies have been shown to be the most important source of controllable sediment delivery in the western part of the Pescadero-Butano watershed. To minimize gully initiation, both cultivation and grazing should be kept at relatively low intensities on the steeper slopes in this area. Additionally, studies should be undertaken to determine the nature, effects and most cost-effective treatment options for re-vegetating former agricultural lands with native plant species to improve their stability. Many existing gullies continue to expand, and should be assessed to determine the nature and rates of this expansion. Many treatments are available to check gully expansion, including the use of heavy equipment to lay back gully walls to a stable angle, slope re-vegetation, arresting head-cutting through installation of knick-point “plugs,” and fencing to prevent livestock trampling and soil compaction. The aim of gully control would be to improve the appearance and the biological productivity of the coastal hills, and to reduce sedimentation of Pescadero Marsh and the lower courses of Pescadero and Butano Creek.

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CHAPTER 3

HISTORY OF THE PESCADERO-BUTANO WATERSHED

EXPLORATION, SETTLEMENT AND LAND USE

Bracketed by almost impassable cliffs on the south and north (Waddell and Devil's Slide), the steep and twisted ridges of the Santa Cruz Mountains on the east, and facing a rugged and rocky coastline, the Pescadero watershed is remarkably isolated, given its proximity to the metropolitan Bay Area. This isolation slowed and dampened the waves of change that came elsewhere in California. From the salt marshes on the west to the dry and rocky "chalks" on the mountain ridgetops, the Pescadero watershed contains a diversity of landforms, soil types and native vegetation.

One element of the Pescadero's topography deserves specific mention – the unusual route taken by Butano Creek as it emerges from the Butano Canyon and then turns sharply north running *parallel* with the coastline for several miles before finally joining the main stem of the Pescadero. Most of California's coastal streams run perpendicular to the coastline as do the valleys through which they flow. The Butano's unusual route caused considerable confusion to the Californios when they laid out the land grants in the 1830s. This confusion eventually came before the Land Commission in the 1850s and then into the California courts, further complicating and delaying the development of the Butano area.

THE NATIVE PEOPLES

The Pescadero area was occupied by several groups of native people that we now term Ohlone. The Quirostes controlled the area from Bean Hollow Creek southward to Año Nuevo Creek and inland to Butano Ridge.[1] The Oljon controlled from the lower San Gregorio drainage southward to Bean Hollow Creek, including the lower Pescadero and Butano drainages. The Cotogen held the land in and around Purisima Creek.[2]

When the first Spanish land expedition traveled on horseback along the immediate coast in October of 1769, they found a grass-covered landscape with only a few trees growing in the deeper arroyos. In many places the grass had been burned by the Ohlone. In the vicinity of

1 Randall Milliken, "The Spanish Contact & Mission Period Ohlone of the Santa Cruz-Monterey Bay Region" in A Gathering of Voices: The Native Peoples of the Central California Coast, edited by Linda Yamane, Santa Cruz County History Journal, Issue Number 5, 2002, pp. 25-33.

2 Randall Milliken, *An Ethnohistory of the Indian People of the San Francisco Bay Area from 1770 to 1810*, PhD dissertation, University of California, Berkeley, 1991, p. 340; 420-1; 445-6.

present-day Pescadero, Padre Juan Crespí wrote, *Only in the watercourses are any trees to be seen; elsewhere we saw nothing but grass, and that was burned.*[3]

The Ohlone kept the landscape open by burning the meadows, a practice that encouraged the native grasses to grow more vigorously providing food for both themselves and the wildlife that they hunted. Because this first Spanish expedition was dependent upon pasturage to feed their horses and mules, they were always on the look-out for meadows that were not burned over. In the vicinity of the present-day San Lorenzo River they found "*a good patch of ground that is not burned, and it is a pleasure to see the grass and the variety of herbs and roses of Castile.*[4] Fire historian Stephen J. Pyne has described this practice as burning in "pulses and patches." Rather than setting one late-season fire that burned the entire coastal terrace, the Ohlone fired the grasses as they dried out, creating what Pyne calls a landscape "dappled with green and black patches."[5]

The landscape that the Spaniards found in 1769 was a managed one, tended by people who knew how to extract the most from it using their most effective tool—fire.

SPANISH CONTACT – 1769 – A BARE AND TREELESS COUNTRY

Traveling north, October 24, 1769 – between Waddell Creek and San Gregorio Creek, Engineer Miguel Costansó of the Portola Expedition wrote,

> *"…arrived at an Indian village, two leagues from the place whence we started. This we found to be without its inhabitants, who were occupied at the time in getting seeds. We saw six or seven of them at this work, and they informed us that a little farther on there was another and more populous village, and that the inhabitants of it would make us presents and aid us in whatever we might need…proceeded for two more leagues over rolling country until we reached the village. The road, while difficult over high hills and canyons, was attractive. To us the land seemed rich and of good quality; the watering-places were frequent; and the natives of the best disposition and temper that we had yet seen.*
>
> *The village stood within a valley surrounded by high hills, and the ocean could be seen through an entrance to the west-northwest. There was in the valley a stream of running water, and the land, though burned in the vicinity of the village, was not without pasture on the hillsides."*
>
> *On October 17, 1769 Costansó wrote: "The country had a gloomy aspect; the hills were bare and treeless, and, consequently, without firewood."*[6] *Father Juan Crespí wrote on the same day:*
>
>> *"…taking a northerly direction, in sight of the sea, over high, broad hills of good land, but all burned over and despoiled of trees. Only through the openings is to be seen the Sierra Blanca which still remains with us, but after half a league's travel there were some groves of redwoods. We crossed two arroyos [Bean Hollow and*

3 Bolton, p. 216.
4 Bolton, p. 215.
5 Pyne, *Fire: A Brief History*, p. 52.
6 From *The Discovery of San Francisco Bay*, edited by Peter Browning – Great West Books, Lafayette, CA, 1992. – pp. 109-111.

> *Pescadero] each one of which carried more than a buey of water. In two leagues we crossed two valleys with very good land and an abundance of running water in each, measuring more than a buey. One of them, besides the water spoken of, has a fair-sized lagoon. This is a fine place, with good lands and an abundance of water, where a good mission could be placed…"*[7]

The expedition returned several weeks later, passing along the coast again but their diaries are much less descriptive.

THE LAST SPANISH EXPEDITION – TRAVELING SOUTH, DECEMBER 1774

In late 1774, Captain Rivera led an expedition from Monterey northward to explore San Francisco Bay. The expedition returned to Monterey via the route taken by the Portolá expedition in 1769, along the coast of present-day San Mateo and Santa Cruz counties. This was the last Spanish expedition along this stretch of coastline as the main route of travel between Monterey and San Francisco was the much easier path through the Santa Clara Valley.

Captain Rivera's Diary, December 8, 1774 *"…march has been very hard because of many high slopes and it being very wet underfoot. We crossed three rivulets* [San Gregorio, Pescadero, Butano] *the second of which might do for a settlement, with plentiful grass, wood, and good timber.*"

Crespí was impressed with the amount of water in the country, particularly after having lived at Carmel for 5 years and experiencing drought there. On December 8, 1774 he wrote *"We went on, and just before twelve entered the valleys of San Pedro Regalado* [Pescadero]*, in which we found two very large arroyos containing a good volume of water and well grown with cottonwoods, alders, willows, live oaks, and some thick groves of redwoods in the side canyons of the valley. Besides the two large arroyos there are other smaller ones with running water and lagoons grown with good patches of tule. These valleys [*note the plural – Pescadero and Butano*] have much good arable land which could be easily irrigated with the water from the arroyos. There are good pastures, much firewood, and timber for building, especially the redwood, which bears a strong resemblance to cedar."*[8]

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[7] From *Fray Juan Crespi: Missionary Explorer on the Pacific Coast, 1769-1774*, edited by Herbert Eugene Bolton. University of California Press, Berkeley, 1927. Pp. 220-221.

[8] *Historical Memoirs of New California by Fray Francisco Palou, O.F.M.* edited by Herbert Eugene Bolton, Russell and Russell, New York, 1966, pp. 290-294.

THE SPANISH PERIOD – 1770 – 1822

The Pescadero-Butano watershed was on the periphery of Spanish California. The Ohlone living there were eventually recruited by the missionaries of Missions San Francisco and Santa Clara. When the Mission Santa Cruz was founded in 1791, the Pescadero fell under its jurisdiction and beginning in 1797, some of the mission's herds were pastured there.

Beginning in the 1780s, the missionaries at both San Francisco and Santa Clara began recruiting Ohlone from the coastal area north of present-day Pescadero. According to Randall Millikin, most of the Indian population north of Año Nuevo had been congregated in those two mission by the time that Santa Cruz was founded in 1791. Though Mission San Francisco was always struggling to find pasturage for the mission livestock, they apparently did not make use of the Pescadero-Butano area.

The coastal area from Pescadero south officially came under the jurisdiction of Mission Santa Cruz following its founding in 1791. The mission padres concentrated their efforts on the coastal terrace immediately east of the San Lorenzo River during the early years. It is doubtful that Santa Cruz pastured very much if any livestock in the Pescadero prior to 1797.

The establishment of the Villa de Branciforte immediately to the east of Mission Santa Cruz in 1797 caused the mission padres to turn their attention northward. Eventually the mission maintained three ranches on the coast north of Santa Cruz, extending a distance of eleven leagues (28.5 miles), including the valley of the Pescadero. As will be shown in the next section, when Mexican citizens requested land grants in the Pescadero and Butano in the 1830s, they had to gain the permission of the priest at Mission Santa Cruz.[9]

We have a rare glimpse of the Pescadero coast from the pen of a French visitor in 1827. Sailing from San Francisco southward to Santa Cruz on February 7, he wrote the following: "*There are eighteen leagues from the entrance to San Francisco Bay to the roadstead at Santa Cruz, and the way is south-southeast, without turns and dangers. All day we had spy-glasses in our hands to examine the coast, whose aspect the swift progress of the ship altered every minute. In general it is very high in the interior, and everywhere covered with forests of fir trees; it then grows lower by a gentle slope toward the shore; but before reaching it, it rises again to form a long ridge of hills, whence it descends finally to the sea, now bathing the foot of vertical rocky cliffs, now gliding in sheets of foam over sandy or pebbly beaches. Beautiful verdure clothed the plains and hills, where we constantly saw immense herds of cows, sheep and horses. Those belonging to Santa Cruz meet those, less numerous of San Francisco; so that this long strip of eighteen leagues is but one continual pasture.*"[10]

[9] Kimbro, et al, Restoration Research:Santa Cruz Mission Adobe, 1985, p. 29.
[10] From California Historical Quarterly, "Duhaut-Cilly's Account of California", p. 149.

MEXICAN ERA – 1822-1848

The Mexican era is dominated by the granting of mission lands to private individuals and the importation of livestock into the Pescadero watershed. There is also evidence of some early logging along Pescadero Creek upstream from the present-day town of Pescadero.

For the first decade of the Mexican Era, the Butano and Pescadero valleys were under the nominal control of Santa Cruz Mission. However, as the Mission's herds grew smaller, its influence retreated southward down the coast. In 1833, when Juan Gonzalez asked to be granted the Pescadero Valley, Father Antonio Real, the priest in charge of Mission Santa Cruz, agreed to the grant:

> *"[the Pescadero] is a place which this Mission does not at present occupy, nor is it deemed necessary for it in consideration of the fact that it has land enough for its few cattle, and that being unoccupied it is considered public land..."*[11]

THE PESCADERO GRANT – 1833

In 1833, Juan Jose Gonzalez, a native of the Mission of Santa Cruz and mayordomo of the Mission, requested that he be given a four square league grant bounded on the north by Pomponio Creek, on the west by the ocean, on the south by Butano Creek, and on the east by the crest of the mountains.

Admitting that he was not that familiar with the land in question but aware that it was mostly pastureland and dependant on the seasons rather than irrigatable farm land, he asked that he be given the land so that he could move his cattle up from the Villa Branciforte. The Mexican government approved the grant, and Gonzalez moved upwards of seven hundred head of cattle onto the property. He built an adobe house on the eastern side of the property near Pescadero Creek and a wood frame house near Butano Creek where his vaqueros lived.

By 1840 Gonzalez's herd had grown to over four thousand head of cattle, roaming across the Pescadero and up into the coastal hills. Periodic rodeos were held to gather the cattle together, slaughter some for the hide and tallow trade, and separate the neighbor's cattle that had wandered onto the grant. Cornelio Perez, a Santa Cruz resident who worked for Gonzalez during these years, later said that the pasture closest to the coast was the least favorable for raising cattle: "[The coastal grasses] are salt and inferior and improve as you go up towards the mountains."[12] Gonzalez also had a herd of horses and a smaller herd of "tame cows" that provided milk for the workers on the rancho.

[11] Land Case Number 104, Pescadero Grant p. 28.
[12] Land Case Number 104, Pescadero Grant, p. 82.

Perez also remembered that Gonzalez cut some timber up the Pescadero during the 1830s:

> *"[Gonzalez] cut some timber, the first he cut was up the Pescadero Creek in the mountains for building his house when he founded the ranch; he also cut some for fences, corrals and everything needed on the ranch."*[13]

Gonzalez hauled the trees down Pescadero Creek with oxen on a trail that crossed and re-crossed the creek numerous times before arriving in the valley.

The impression that one gets when reading the land case testimony given in 1861 is that Gonzalez was an absentee ranchero who lived with his large family of thirteen children near Mission Santa Cruz, while vaqueros and other laborers tended to the ranch. If Gonzalez followed the custom of the time, the majority of his employees were probably Mission Ohlone.[14]

THE BUTANO RANCHO

In September of 1834 Ramona Sanchez, widow of Benancio Galindo, requested that she be granted a "vacant site adapted to keep my cattle on and carry on some husbandry" measuring one league's distance along the coast and a half league from the coast inland. Apparently Doña Sanchez did not actively pursue the grant until 1838 when she was officially given the property. That same year the land along the Arroyo del Butano was occupied by three of her children who built a house on it, corrals and cultivated portions of it.

In 1861 Cornelio Perez testified that the Sanchez children had more than 400 head of cattle and a few horses on the property and that they had "fenced in and planted a portion of the land." It is not clear from the land title documents exactly where the house and corrals were located. Following the death of two of the children, the third left the property and went to live with Doña Sanchez.

ISOLATION

The stories of both the Pescadero and Butano grants reflect a somewhat passive occupation during the Mexican Era. Unlike other grants farther south in present-day Santa Cruz County that were closer to the economic action centered on the landings that ringed Monterey Bay, these two grants and those immediately to their south did not have long-term tenancy.

Bounded by the rugged Santa Cruz Mountains to the east, the rocky defile of Point San Pedro and what became known as Devil's Slide to the north, and a rocky, harborless coastline, the easiest access to and from the Pescadero during the Mexican Era was the road to Santa Cruz on the

13 Land Case Number 104, Pescadero Grant, p. 86.

14 In later litigation following the Land Commission hearings in the 1850s, the 4-league grant was whittled down to less than a league by pressure from neighboring property owners, in particular Loren Coburn and Jeremiah Clarke, who bought the Butano Rancho in the early 1860s.

south. The biggest obstacle to the south was the mudstone cliffs at present-day Waddell Creek that forced horses and wagons to wait for low tide before making a dash along the beach to get around.

EARLY AMERICAN PERIOD – 1848-1868

The period from 1848-1868 was dominated by the quick transfer of the Pescadero and Butano Ranchos into American hands and the efforts by the new owners to extract a living from the isolated valleys. Early logging entered the two watersheds during this period, and most of the agricultural and timber products found their way to the outside world via the chute at Pigeon Point. The obstacle to travel between Pescadero and Santa Cruz became a political issue that resulted in most of the Pescadero watershed being removed from the jurisdiction of Santa Cruz County in 1868 (a small portion of the upper watershed remains in Santa Cruz County).

After residents on the north side of Monterey Bay circulated a petition protesting their being included in the proposed Monterey County, the state legislature decreed that Santa Cruz County's boundaries would include everything on the ocean side of the summit of the Santa Cruz Mountains between the Pajaro River on the south and the headwaters of San Francisquito Creek on the north. There was considerable debate exactly where the northern boundary actually was located, so the boundary used was that of San Gregorio Creek. Therefore, the Pescadero watershed fell within the jurisdiction of Santa Cruz County.

The arrangement was not convenient for the early settlers in Pescadero, however, as it meant that they had to get past the steep cliffs just north of Waddell Creek in order to travel to the County seat in Santa Cruz. As one traveler on horseback described that passage in November of 1849, "*…the road one has to travel is along the beach very close to the water and this can only be done when the tide is low…We experienced two very bad spots because of some rocks, when the very rough sea began to wash over us up to the pommel of our saddles.*"[15] The Waddell Cliffs continued to be a travel hazard throughout the nineteenth century.

When the boundaries of Santa Cruz County were first established by the state legislature in February of 1850, the northernmost boundary of the county was located at the headwaters of San Francisquito Creek on the crest of the Santa Cruz Mountains. Since that creek flowed eastward into San Francisco Bay, the exact location of the headwaters on the opposite side of the ridge was never clear. For administrative purposes, San Gregorio Creek was used as the northern boundary while the legislature attempted to clarify the boundary. Thus all of the Pescadero watershed was within the jurisdiction of Santa Cruz County.

In 1856, San Mateo County was formed out of the southern part of San Francisco County and the northern part of Santa Clara County. This new county, with its county seat at Redwood City, spanned the entire San Francisco peninsula down to San Gregorio Creek on the west or Coast side. Pescadero remained under the jurisdiction of Santa Cruz County, however.

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[15] Justo Veytia. *Journey to Alta California 1849-1850*, published in Guadalajara, Mexico, 1975, p. 49.

There were now two county seats within 40 miles of Pescadero, but they were made much more distant by the ridge of the Santa Cruz Mountains, in the case of Redwood City, and the cliffs at Waddell Creek that blocked the route to the south.

THE COAST ROAD

The trail that evolved into the Coast Road followed the route Portolá first scouted and laid out in 1769. Of importance to the story of the Pescadero is that the road came up from the south on top of the coastal terrace and then swung down into the valley of the Pescadero, avoiding the mouth of Pescadero Creek and the coastal cliffs to the north. After dropping into the valley, the road crossed Butano Creek at a narrow spot and then went eastward before turning to cross Pescadero Creek and go northward along present-day Bradley Creek and over the crest into the valley of San Gregorio. Eventually during this early period a road was laid out going eastward up the Pescadero Canyon as well as southeastward alongside Butano Creek. All four roads came together at an intersection that continues to this day to be the primary intersection in the town of Pescadero. Pescadero Marsh was an obstacle that the roads tried to avoid by crossing the Butano and Pescadero upstream of their entering the marsh.

EARLY FLOODS AND BRIDGES

The first major recorded flood event in the Pescadero watershed came in December of 1852. Though we have no details or eyewitness accounts of this flood, it can be assumed that the lower reaches of the valley were under water, as the *Daily Alta* newspaper published in San Francisco said that there was flooding throughout northern California and that all of the coastal streams between San Francisco and Monterey were running so high that communication between those points was impossible. Farms were flooded and the stage between San Francisco and San Jose on the bay side of the Peninsula was stopped for the time being.[16]

The largest flood event during this period, and perhaps the largest experienced along the Pescadero since 1850, was the flood of December 1861-January 1862. The Santa Cruz newspaper reported: "*At Pescadero the river overflowed its banks and flooded the whole bottom land.*"[17] One measure of the 1861-1862 flood is that, for the remainder of the nineteenth century, subsequent floods were always measured against it.[18]

One direct response to the flood of 1852 was the construction of a more dependable crossing on the Coast Road where it crossed Butano Creek. In September of 1853, with the assistance of local funds and labor, the first bridge was constructed at the location. An 1854 map by the U.S. Coast Survey shows the bridge close to the location of the present-day bridge.[19] There was also a bridge built across the Pescadero between the intersection and San Gregorio, but its construction date is not clear.

[16] *Daily Alta*, San Francisco, December 21-December 25, 1852.
[17] *Santa Cruz Sentinel,* January 30, 1862.
[18] *Redwood City Times and Gazette*, February 12, 1876.
[19] *Redwood City Times and Gazette*, April 17, 1880; U.S. Coast Survey, Register 682, Section X, Map of a Part of the Coast of California, surveyed by W.M. Johnson, scale 1:10,000, 1854.

Both the Mexican ranchos that encompassed the lower Pescadero-Butano watersheds changed hands in the early 1850s. In September of 1852, Juan Gonzalez deeded a small portion of the Pescadero grant to family members and sold approximately eight hundred acres of the valley floor to Eli Moore for six thousand dollars.[20]

RANCHO BUTANO AND LOREN COBURN

That same year, Ramona Sanchez sold the Rancho Butano to Manuel Rodriguez for two thousand dollars.[21] Loren Coburn and Daniel Clark purchased both the Butano and Año Nuevo grants in the early 1860s. They then went into court and successfully argued that the boundaries of their property contained a much more extensive tract of land than the earlier settlers believed.[22] Clark and Coburn were extremely aggressive land owners, contesting boundaries, road placements and wharves wherever they could. It is safe to say that Loren Coburn gained the enmity of both his contemporaries and generations of later historians, but his saga is beyond the scope of this report.[23] In 1880, a writer in a Redwood City newspaper summarized Coburn's acquisition of the two ranchos as a "calamity."[24]

What is important for the land use story of the Pescadero watershed, however, is that Coburn and Clark's legacy of owning (and defending) their large tracts of land effectively slowed subdivision and development of the Butano. While the Rancho Pescadero properties were divided and subdivided in the late nineteenth century, the Butano and Año Nuevo ranchos remained intact. As can be seen by examining the official San Mateo County maps from 1877, 1894 and 1927, (Figures 3-1, 3-2, and 3-3) the land in the Butano was almost entirely one large parcel, effectively blocking any access to the timber in the canyon.

THE TOWN OF PESCADERO

Most towns on California's central coast formed at creek crossings, usually a mile or two upstream to avoid the lagoons and marshes that characterized the creek's mouth. The town of Pescadero grew up where the coast road crossed Pescadero Creek. Most histories of Pescadero have the town being established in the mid-1850s, with the *Pescadero Walking Tour*[25] booklet stating the year 1856.

Many of the early immigrants to the Pescadero Valley were from New England, and by the 1860s, the town had a very New England appearance. Most of the buildings were constructed in the Classical Revival architectural style, a style very popular on the east coast of the United States. None of the original Californio adobe buildings survived.

[20] Land Case Number 104, Pescadero Grant, p. 153.
[21] Land Case Number 271, Butano Grant, p. 29.
[22] *Santa Cruz Sentinel*, November 14, 1861. See also the Land Grant file for Butano, number 271.
[23] See *Pescadero Walking Tour*, p. 5-6.
[24] *Redwood City Times and Gazette*, February 28, 1880.
[25] *Pescadero Walking Tour*, authors various, first published in 1996, p. 4.

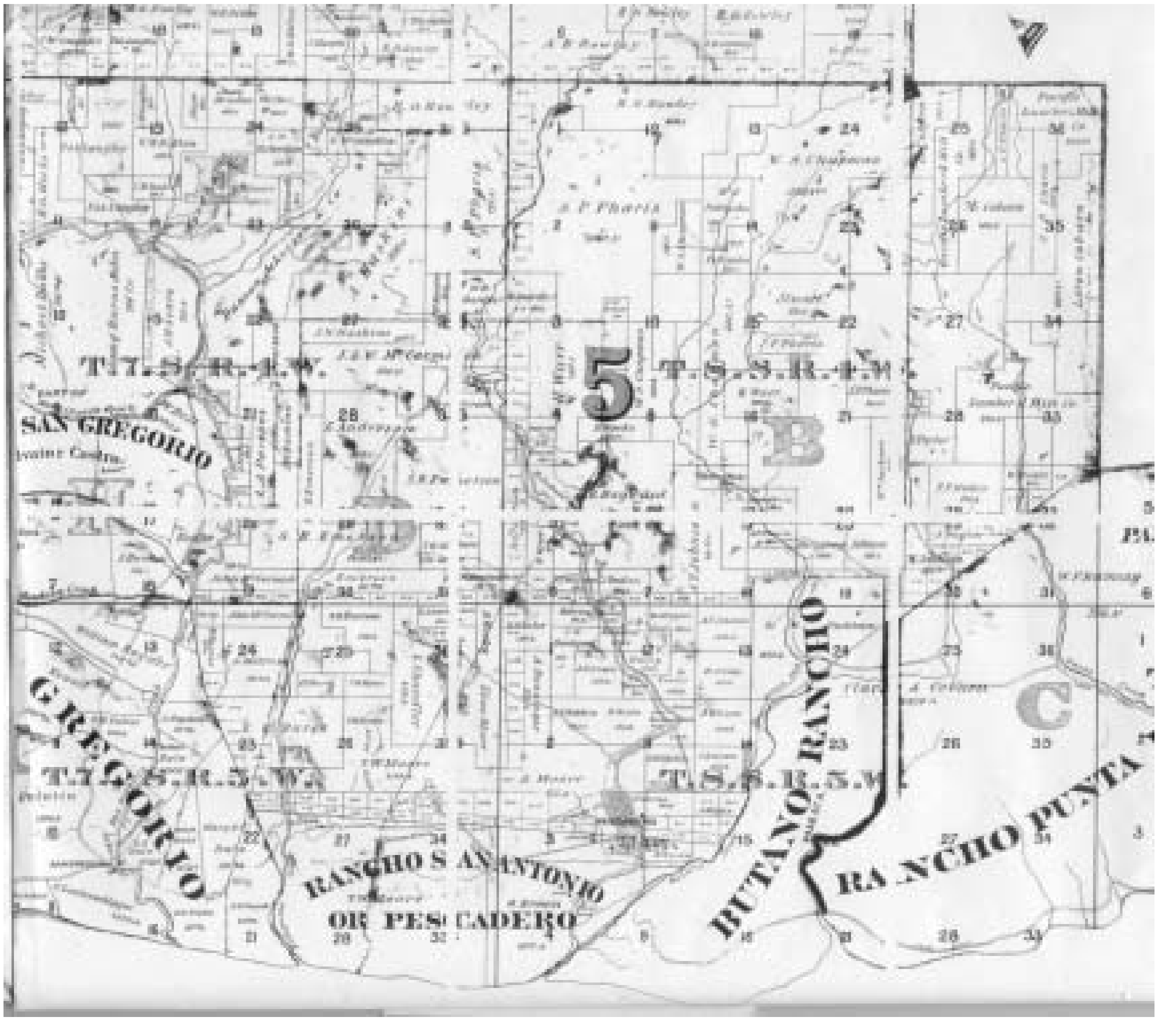

Figure 3-1: Official Map of the County of San Mateo, 1877. This map illustrates the early disparity between the subdivision and development of the Pescadero vs. Butano rancho lands. Pacific Lumber and Mill Co. owns a relatively limited amount of land in the upper watershed, compared to later acquisitions by lumber interests. (Source: San Mateo County Historical Society)

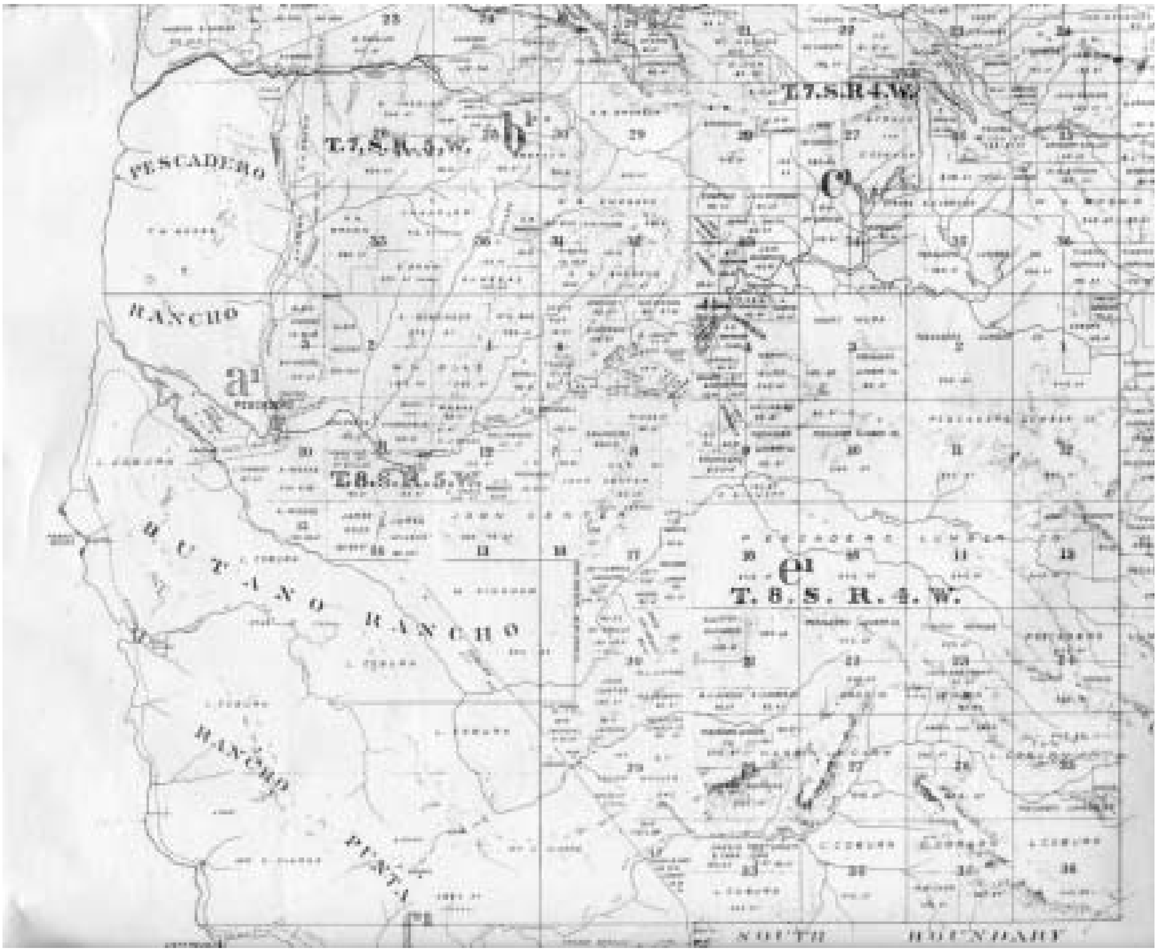

Figure 3-2: Official Map of the County of San Mateo, 1894. This map shows the continuing disparity between subdivision and use between the Pescadero and Butano. By this date the Pescadero Lumber Company has acquired ownership of significantly larger tracts in the upper watershed. The route of the never to be railroad can be seen at the coastline as can the hotel ("Coburns Folley") at Pebble Beach. (Source: San Mateo County Historical Society)

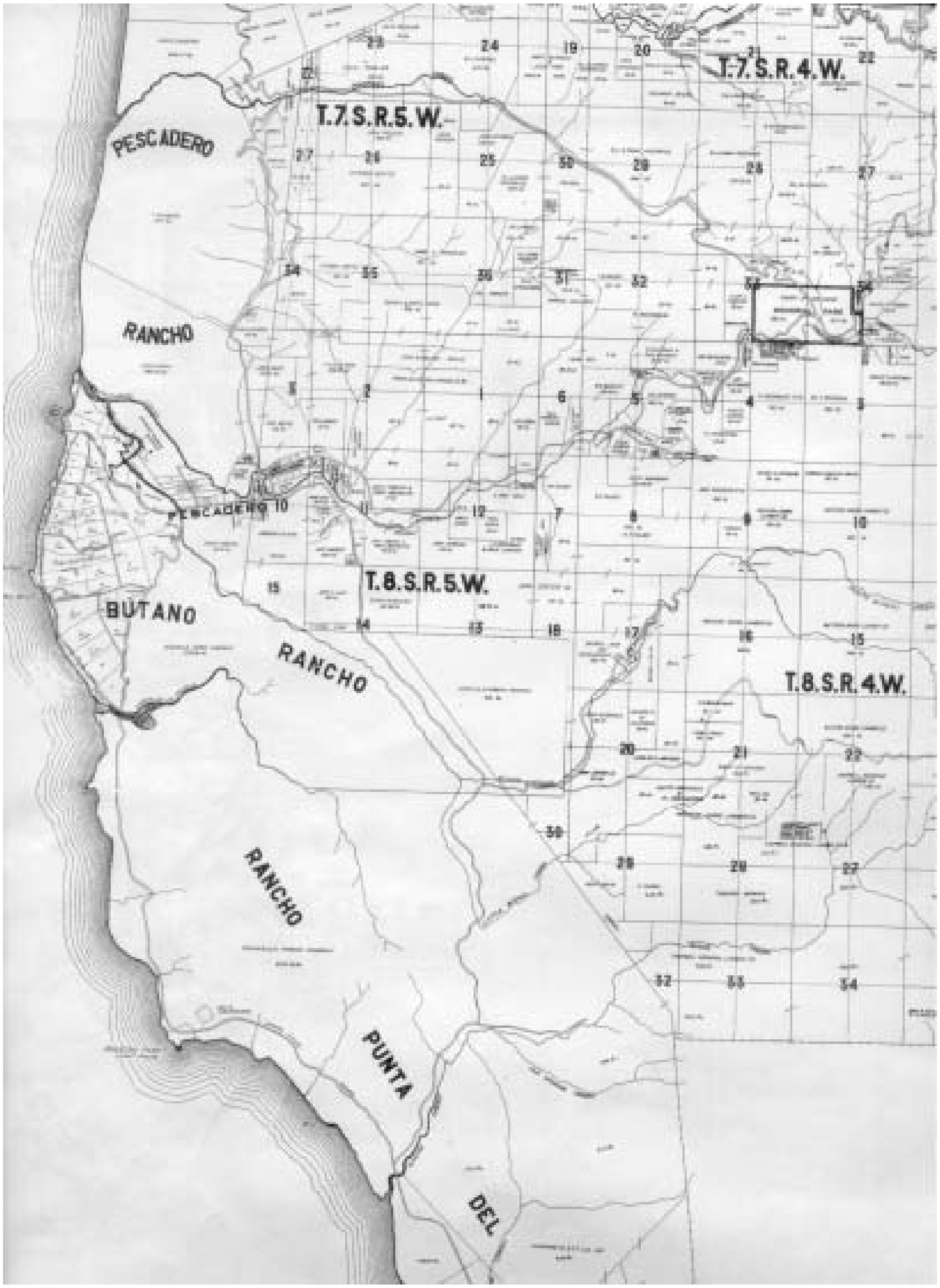

Figure 3-3: Official Map of the County of San Mateo, 1927. The official map of 1927 illustrates the subdivision of lands in the northern coastal portion of the Butano Rancho. Western Shore Lumber has by this time acquired significant holdings in the upper watershed, particularly the Upper Butano. (Source: San Mateo County Historical Society)

Figure 3-4: Pescadero Creek and the Community Church, Built in 1867. View is Downstream and to the Southwest. (Ed Weeks Collection, date unknown).

EARLY AGRICULTURE

Beginning in the 1850s, with the coming of Yankee farmers such as the Moores and Weeks, wheat, oats and barley were the dominant crops grown in lower Pescadero watershed. The crops were dry-farmed, and financial yield was dependent upon sufficient rainfall, the availability and cost of the harvesters, transportation and shipment off the coast. The primary point of shipment during the 1870s and 1880s was Pigeon Point where, at various times, there was either a chute or wharf that allowed small coastal ships to come close enough to take on their cargoes which were bound for San Francisco.

Grain farmers were always dependent on the Pigeon Point Landing, a loading area that was not always dependable. In November of 1880, for example, following a particularly good year for Pescadero grain farmers (rainfall that spring was particularly heavy – see flood account below), early season storms made it difficult for the coastal steamers to land at Pigeon Point. Large quantities of grain waited at the landing well into the rainy season before it was finally shipped. [Redwood City Times and Gazette, November 27, 1880.] Periodic attacks of rust and other pests made wheat farming even more of a gamble.

Figure 3-5: Pescadero, Circa 1900 or earlier, View to the north on what is now Stage Road. Many of these buildings burned in the fire of 1927. (Ed Weeks Collection)

There are few accounts of early agriculture in the Pescadero area. There are references to the cattle and livestock that continued to roam the coastal hills as they did during the 1840s. There is also evidence that both wheat and potatoes were grown in the lower valleys and on some of the coastal hills during the 1850s.

THE PESCADERO VALLEY, 1861

A description of the valley published in 1861 provides a written snapshot of the landscape in the early 1860s:

> *"A view of this valley from an elevated position cannot fail to strike the beholder with admiration. The perfectly level and fertile bottom land, covered with waving grain, interspersed with young orchards, and dotted with white buildings; the green hills which everywhere surround it like sentinels, to guard it from the high winds that prevail on the coast, and the beautiful and clear stream of the Pescadero, that winds through the whole length of the valley, makes a scene more lovely than any we had ever before looked upon."*[26]

[26] *Santa Cruz Sentinel,* May 23, 1861.

The article quoted above also noted that Pescadero farmers were beginning to shift their attention to the raising of livestock:

> *"The farmers in this locality have recently begun to pay more particular attention to the raising of fine stock. We have not space to notice this subject at length, but will state that Messrs. Thos. W. Moore, Braddock Weeks, Alex. Moore, Samuel Besse, B.V. Weeks and others have some of the finest and best stock in the county."*[27]

A description published in 1867 gives an excellent summary of the valley's agriculture:

> *"…The whole valley is extremely fertile and produces excellent crops. Potatoes and barley, however, form the principal articles of produce, potatoes being the preference…An immense number of hogs are fallowed here for the San Francisco market, and every ranch and dairy raises them by hundreds. Barley does well, and the crops yield finely, the soil and climate being in every way adapted; not much is shipped, as it pays better to feed it to the hogs, who are turned out loose in the grain fields in the fall to harvest the crops. A large amount of beef cattle are also fattened here for market, the foothills being covered with excellent pasture year round: the fogs which sweep over the country rendering the grass green and fresh till nearly summer."*[28]

EARLY LOGGING

The focus of the early logging in the central Santa Cruz Mountains was on the east side of the crest as lumber products could be transported much more easily down to ports, such as Redwood City, along the edge of San Francisco Bay. The west side of the crest was much more heavily forested but the difficulty of shipping lumber products off that side of the mountains retarded the development of the lumber industry.

A report published in the *Santa Cruz Sentinel* in 1859 listed twelve sawmills operating in Santa Cruz County of which only two – Tuftley's on the Pescadero (water powered), and Williams' on the Butano (steam powered) – were in the Pescadero watershed.[29] An article published in 1861 describing the landing at Pigeon Point stated, "*No lumber is at present shipped from this point, owing, no doubt, to the difficulty of loading vessels, although extensive forests of redwood abound in the vicinity*.[30]

SHIPPING – PIGEON POINT

The land connections to Pescadero were so tenuous that moving agricultural or lumber products overland was almost impossible. Instead, farmers and lumbermen in this area depended on coastal shipping points or "chutes." It was not possible to build wharves directly into the face of the Pacific Ocean, so systems using cables were adopted all along the coast. Goods were then slid out along the cable and dropped into sail and steamships that moved regularly along the coast.

27 *Santa Cruz Sentinel,* May 23, 1861.
28 *Santa Cruz Sentinel,* July 6, 1867.
29 *Santa Cruz Sentinel,* April 16, 1859.
30 *Santa Cruz Sentinel,* May 23, 1861.

The three closest dependable shipping points during this period were Gordon's Chute at the mouth of Tunitas Creek, Amesport just north of Spanishtown (Half Moon Bay), and Pigeon Point on the coast several miles to the south of Pescadero. Gordon's Chute was nine miles over a relatively steep grade, while the road south to Pigeon Point was only six miles running for the most part atop the level coastal terrace.

Proximity and dependability made Pigeon Point the shipping point of choice during this period, and the daily reports of the San Francisco harbormaster published in the *Daily Alta* make continual references to steamers and schooners arriving after having called at Pigeon Point.[31] The point was originally named Carrier Pigeon Point after the ship *Carrier Pigeon* wrecked there in June of 1853[32], but it was eventually shortened to Pigeon Point.

Pigeon Point was located on the Rancho Año Nuevo, adjacent to Rancho Butano on the south. In the early 1860s, Año Nuevo was also purchased by Clarke and Coburn, and access to the shipping point became a local bone of contention for the remainder of the century.

By 1867 Pigeon Point was bustling:

> *"Long rows of shingles, pickets and other small lumber were piled on the point. The potato season being well nigh over, but few 'spuds' were to be seen, and the supply of butter and cheese is only renewed on the arrival of each schooner. The lumber mills, shipping from this point are Page's, Anderson's Truffler's and Voorhee's, and Steens shingle mills; other shingle mills are in course of erection."*[33]

TOURISM – USING ISOLATION AS AN ASSET

By the mid-1860s, Pescadero's isolation became a selling point to residents of the cities around San Francisco Bay. Regional newspapers began publishing long travel accounts describing the beauty of the valley and the sights that could be found close by. Because of the difficulty of access, once travelers arrived in Pescadero they would either have to camp or stay in a hotel. Thus, most descriptions of Pescadero place great emphasis on the town's two major hotels. The tourist season in Pescadero was the summer, with visitors arriving and spending several weeks while they roamed the surrounding countryside.

In 1867 the primary hotel was the Swanton house:

> *"The Swanton House is a neat and commodious hotel and filled with customers. The proprietor, Mr. J.W. Swanton has more city patrons at this season that he can accommodate; on an average sixty visitors are daily found at this fashionable resort, mostly ladies and children…Every evening some jolly party meet in the parlors of the hotel and enjoy themselves in amusements of some kind, wherein the time is pleasantly and profitably spent. In the daytime, excursions are made to Pebble Beach to gather the beautiful [kelp] thrown on the beach by the waves."*[34]

31 *Daily Alta,* San Francisco – 1854-1858. A re-examination of this span of newspapers will help illuminate exactly what the cargoes were.
32 *Daily Alta,* San Francisco, June 10, 1853.
33 *Santa Cruz Sentinel,* July 6, 1867.
34 *Santa Cruz Sentinel,* July 6, 1867.

In the late 1860s, Albert Evans wrote the following of the Pescadero economy and those who did the work:

> *"The population of Pescadero does not exceed three hundred souls, who depend on the lumbermills in the great redwood forest, the dairies, the grain and potato ranches, and summer visitors from San Francisco for life and trade…The digging [of potatoes] is done by native Californians, or 'greasers.'…A few old California Indians work in the fields quite faithfully after their fashion, but none of the old hands equal the Chinaman 'year out and year in.' Much lumber is hauled from the mountains, and, with potatoes, grain and vegetables, is shipped for San Francisco from the embarcadero at Pigeon Point, six miles south of Pescadero."*[35]

During the early 1860s Pescadero's residents became increasingly impatient with their isolation from the Santa Cruz County seat. The state legislature began to study the issue, and finally, in 1868 to howls of disappointment from Santa Cruz County, an estimated 100,000 acres of the County were shifted to the jurisdiction of Redwood City.

PESCADERO –1870s AND 1880S

Pescadero grew slowly during the 1870s and 1880s. The continued difficulties in shipping lumber and agricultural products restrained the boom in the 1870s that was experienced in nearby areas. Railroads worked their way down the east side of the Peninsula in the early 1870s, and by 1876 there was a railroad line connecting Santa Cruz with outside markets. The isolation continued to be an asset for summer time tourism in Pescadero, however, and the stands of old-growth redwood in the Butano became one of the major destinations for San Franciscans wishing to get away from it all. Agriculture experienced several changes, the most important one being the introduction and success of flax.

When Pescadero became part of San Mateo County, the responsibility for chronicling the weekly news shifted from Santa Cruz newspapers to those in Redwood City. Fortunately, a fairly complete run of the *Redwood City Times and Gazette* still exists, and it is from reviewing the period 1876 to 1880 that we get one of the most detailed pictures of the Pescadero watershed.

The rainfall season of 1875-1876 was punctuated by a February flood. The rainfall drove both San Gregorio Creek and Pescadero Creek to levels not seen since 1861-1862. As one correspondent wrote from Pescadero – "*with the rain driving without, our usually well-behaved Pescadero Creek is running a muddy torrent past my window as I write.*[36]

Then, as often happens in the Santa Cruz Mountains, the rainfall all but stopped, and during the 1876-1877 rainfall year, the California coast suffered a drought.[37] Creek levels dropped to

35 Albert S. Evans. *A La California: Sketches of Life in the Golden State*, San Francisco, Bancroft Company, 1873, p. 43-44.

36 *Redwood City times and Gazette*, February 19, 1876.

37 Rainfall statistics for regional cities are rare, but in Hollister, the annual rainfall total for 1876-1877 was a mere 4.69 inches of a typical annual rainfall of 13.03 inches. At Salinas 4.74 inches of rain fell of a typical rainfall average 14 inches.

unheard of low-levels, and migrating fish schooled up off the creek mouths and were unable to ascend. In February of 1877, the newspapers reported *"large quantities of fish being taken off the mouth of Pescadero Creek."* [38] Cereal grains in the Pescadero Valley were dry-farmed, and without the usually dependable winter rains, the grain crops suffered. Many Pescadero farmers, including Tom Moore, turned cattle into the fields to eat the grain, as the crop was too small to merit harvesting.[39]

By September of 1877, ranchers from Monterey and Santa Cruz County were driving their herds to Pescadero to try to help them survive. Loren Coburn moved large numbers of the cattle he owned on a ranch in Monterey up to his property near the Butano.[40]

Beginning in September of 1877 there were a series of fires in the Santa Cruz Mountains caused in part by the extremely dry forests. By October both the upper Pescadero and upper Butano had experienced large fires and it appeared to the editor of the Redwood City newspaper as if much of California was ablaze. Since most of the fires were caused by either hunters or woodsmen, he urged that "carelessness" in the woods should be made a crime. [41] The period 1876-1878 was further exacerbated by a national depression, and money was extremely tight.

Despite the vagaries of rainfall and economics, Pescadero agriculture continued to diversify during the mid-1870s, and one of the major new crops to emerge during this period was flax. Flax farming came to Central California coast in the 1860s, and there was enough flax being grown in Santa Cruz County to warrant the construction of a linseed oil plant and burlap bag factory near Soquel in 1865.[42]

It is not known when flax was first grown in the Pescadero valley, but a newspaper item in November of 1876 notes that any farmers wishing to purchase flax seed should contact the Brown ranch as "*a large quantity*" was grown there that season. The drought of 1876-1877 probably restricted the further expansion of the area's flax crop, but in February of 1878, the Redwood City newspaper noted that, "*Flax raising on our coast promises to become very extensive."* [43]

During 1878 the amount of flax acreage in and around Pescadero increased. Alexander Moore threshed 180 acres of flax in October 1878 (producing 1,000 pounds of flaxseed per acre), and in a flax status report published in February 1880, it was estimated that flax brought $20,000 into the Pescadero neighborhood. Flax was attractive to local farmers because they could negotiate pre-season contracts with San Francisco linseed oil manufacturers. The primary purchaser of flaxseed was De Witt, Vittler and Company of San Francisco. As with other grain products, the flaxseed was shipped off the landing at Pigeon Point.[44]

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38 *Redwood City Times and Gazette*, February 24, 1877.
39 *Redwood City Times and Gazette*, May 12, 1877.
40 *Redwood City Times and Gazette*, September 1, 1877.
41 *Redwood City Times and Gazette*, October 6, 1877.
42 *Santa Cruz Sentinel*, June 13, 1865.
43 *Redwood City Times and Gazette*, November 25, 1876.
44 *Redwood City Times and Gazette*,

By October 1880 it was estimated that 4,000 acres of Pescadero land was planted in flax and the estimated annual value of the flax crop was $90,000.[45]

As with other areas on the coast between San Francisco and Santa Cruz, much of the impetus for early dairying came from diarymen who had been producing cheese and butter in Marin County. The Steeles, for example, who became synonymous with dairying around Año Nuevo, came first to Point Reyes in 1857 and then after losing their lease in Marin County, leased property from Coburn and Clark on the Año Nuevo Rancho in 1863.[46]

The marsh at the mouth of Pescadero Creek receives very little attention in the historic records of the latter part of the nineteenth century. The San Mateo County maps indicate that the Coast Road continued to enter the valley from the south by dropping off the terrace, crossing Butano Creek, and then swinging around the marsh and exiting the valley along Bradley Creek. The 1894 County map indicates that the road even made a more exaggerated reversal, doubling back along the top of the bluff before dropping down and crossing Butano Creek (Figure 3-2). And that same map has the word “marsh” on the area.

The drought of 1876-1877 might have effected the level of the marsh to the point of emboldening an Italian farming company to lease some of the marshlands from Tom Moore and attempt to remove the vegetation and bring it into production. An article in the *Redwood City Times and Gazette* dated January 20, 1877 notes: “*Divini and Simi who have leased the western part of the Tom Moore Rancho near Pescadero have a strong force of men and teams at work grubbing and improving their land…”* At this time in central California history, the men working in the marsh were no doubt Chinese.

EARLY FLOODS AND CLEARING

Like other regional streamside communities, Pescadero had a volatile relationship with its creek. During the summer months the relatively benign waterway provided recreation such as fishing and swimming while also providing some water for agricultural purposes. But during rainy winters, the creek sometimes tore down into the community, cutting away banks and flooding homes and businesses. Despite the dangers posed by wintertime flooding, the town developed on the streamside terrace between several severe bends in the creek; once structures were built within these elbows, it became necessary to keep the creek within its banks in order to protect private property.

There is evidence that as early as the late 1870s, local residents had been cutting down the willows and other trees in the riparian corridor immediately adjacent to the town to provide a wider and clearer flow for the stream. These efforts were tested in late April of 1880 when a late-season storm pushed Pescadero Creek to its limits. Several lumber mills upstream from Pescadero were destroyed in the flood, along with most of the county’s upstream bridges. James

45 *Redwood City Times and Gazette*, October 2, 1880.
46 *Redwood City Times and Gazette*, July 8, 1876.

McCormick's barn in Pescadero had six feet of floodwater standing in it. One eyewitness account stated:

> *"More water passed down the Pescadero Creek last week than at any one time since the first settlement, but* ***owing to the bed of the creek being so much enlarged****, the waters spread out less than on some former occasions. Had the bed of the creek been as narrow as formerly the whole village would have been under water."* [Emphasis added.][47]

The clearing along the banks of the stream seems to have continued as a matter of routine. Whether the bankside vegetation was cut for firewood or to give potential winter floods unimpeded passage through town, most old-time Pescaderans remember that the stream channel through and below town was wider and the stream itself was much deeper.

PESCADERO AND BUTANO CREEKS AND TROUT FISHING

As Pescadero's reputation as a vacation retreat grew in the 1860s and 1870s, so did the economic importance of trout fishing in Pescadero and Butano Creeks. Fishing was much more than just a periodic diversion for local Pescadero residents; it was one of the major selling points for attracting visitors to the area during the summer months.

The impact of sawmills on trout fishing was always a matter of contention in the communities along the streams flowing out of the redwood covered canyons of the Santa Cruz Mountains. The major issue was the practice of nineteenth century lumber companies of dumping their sawdust directly into adjacent streams. A lengthy article in the *Santa Cruz Sentinel* in 1871 described the practice:

> "*In* [Santa Cruz County] *it has been the practice, heretofore, for years, to remove saw dust from the various mills by sluicing it into the running streams. This system had become universal, and the custom seemed older than any law, until our pure limpid streams were discolored, and the water became, in some instances, as* ***black as tar,--a moving mass of turgid filth****."*[48] [Emphasis added]

The practice of dumping sawdust into the streams made the water unfit for human consumption; even horses and cattle would not drink it. Throughout the 1870s there were numerous lawsuits brought by downstream communities against the upstream sawmills in Santa Cruz County.

An 1867 Santa Cruz Sentinel article describes a similar situation on the main branch of Pescadero Creek: "…the saw mills on the Pescadero have temporarily injured the fishing, from the saw dust running down the creek…." The article went on to mention that an injunction was currently being filed in court against the upstream sawmills.[49]

47 *Redwood City Times and Gazette*, May 1, 1880.
48 *Santa Cruz Sentinel*, May 20, 1871.
49 *Santa Cruz Sentinel*, July 6, 1867.

As the years passed and logging along the Pescadero continued, the attention of anglers and those who supported them shifted to the Butano watershed. Fishing pressure and the sporadic logging operations along Butano Creek must have cut into the fish population there, because in the mid 1870s there were a number of efforts to re-stock the streams.

Local residents were able to get the attention of the California Fish Commission (established in 1870), and in February of 1877 they volunteered to distribute 10,000 young trout in the headwaters of Pescadero, San Gregorio and Pescadero Creeks if the Commission would provide them.[50] The following month the Fish Commission brought 12,000 inch to inch and a half long trout into San Mateo County and 3,000 of them were planted in San Gregorio Creek and 9,000 in Pescadero and Butano creeks. The planting was somewhat unusual, as they were brook trout that had been hatched in California from eggs obtained in New Hampshire by the United States Fish Commission.[51]

THE BUTANO FISH FARM – 1880

One indication of the quality of water in Butano Creek was the construction of an elaborate fish farm in the spring of 1880. In February of that year a man named Mills began building a series of "dams and fish ponds" along the Butano approximately four miles from Pescadero. Described as a man "*who knows as much about pisciculture as any man in the State*" Mr. Mills began raising not only native fish, but also some "*rare and beautiful fish from Germany*."

The operation was damaged by the rare, late April rainstorms that year, but by late May Mr. Mills' operation was up and running:

> "[In one of the ponds] *he has over two thousand trout. He has about a hundred salmon trout weighing from two to six pounds, three or four that weigh ten pounds and one that weighs 20 pounds. In another pond he has some trout which he got out of a small creek near Pescadero that are marked like a leopard and are very gamy.*"[52]

By 1880 Pescadero had a reputation as one of the choicest locations for San Francisco sportsmen. In a lengthy newspaper article extolling the virtues of Pescadero and Butano trout fishing, the writer declared:

> "*During the months of May and June one person may catch as many as a hundred* [trout] *a day. Their flavor is as fine as that of real mountain trout. May, June and July are gay months at Pescadero, and large numbers of San Francisco people resort there to fish. There have been days when the boarders of the Swanton House have brought home a thousand trout.*"[53]

50 *Redwood City Times and Gazette*, February 10, 1877.
51 *Redwood City Times and Gazette*, March 3, 1877.
52 *Redwood City Times and Gazette*, February 28, 1880; May 1, 1880; May 22, 1880. A distance of four miles from Pescadero would place the fish farm somewhere near where Butano Creek comes out of the canyon and meets Cloverdale Road. Unfortunately we have not had the resources to pursue this story beyond 1880.
53 *Redwood City Times and Gazette,* May 22, 1880.

LOGGING IN THE BUTANO

The history of logging in the Santa Cruz Mountains is episodic and diverse. Sawmills and shingle mills came and went depending primarily on economic forces and the availability of dependable shipping. There are only a few clues about the early logging history in the Butano canyon. In a list of the twelve sawmills in Santa Cruz County in 1859, one of the few steam-powered sawmills listed was operated by Mr. Williams on Butano Creek, cutting 10,000 feet of lumber per day.[54] It is not clear exactly where on the creek the mill was located.

The story of Butano logging becomes more sharply focused in the mid-1870s, when there are several mentions of a "Butano Mill" that began operation in 1876. It is not clear whether the Butano Mill made just shingles, or lumber, or both, but when Ralph Sidney Smith did his famous walk up to the Butano Falls in 1877, he used the location of the "Butano Mill" as a reference point. The mill was located at the end of a road up the canyon, and from there to the Falls, Smith had to walk.[55]

Later that year, during the 1876-1877 drought, a fire began upstream from the mill:

> *"A fire was started by someone in the Redwoods, on the Butano Creek above Clelland's Mill, which has caused a great deal of damage to timber, and at last accounts (on Wednesday last) was still spreading, having then been burning six days and has crossed to the north side of the creek and almost to Pescadero Creek at Hayward's.*"[56]

The reference to "Clelland's" is confirmed as being about a mile up in the canyon on the county map of 1877 (Figure 3-1).

One of our best sources of information about logging in the Butano is Martin McCormick. McCormick's great-grandfather, James McCormick, and his grandfather, James McCormick Jr., built a sawmill in the Butano in the late 1880s. The 1894 County map (Figure 3-2) shows that the land previously owned by Clelland was then owned by McCormick, Hamilton and Levy.

> *"My grandfather and great grandfather both were involved in the operation of the mill and there was a partner whose name was Hamilton. Unfortunately, in the earlier years of the mill operation, [Hamilton] got killed when a big stone flywheel disintegrated. This was Hamilton, my great grandfather's partner. It was called the Hamilton McCormick Mill. After that, I presume, it was just the McCormick Mill...I think the mill started operating in 1889, as best I can figure out. It operated at various production rates over those years. It probably ceased operations in, I would guess, 1908 or 1909. My dad was born in 1909 and he didn't remember the mill actually in operation."*

54 *Santa Cruz Sentinel*, April 16, 1859.
55 *Redwood City Times and Gazette*, May 19, 1877; June 9, 1877.
56 *Redwood City Times and Gazette*, September 22, 1877.

The McCormicks focused their operation on the bottom of the canyon:

> *"When my great-grandfather logged it, he didn't go up very high* [on the canyon walls]. *There is no way they could get those trees all the way down easily, so they logged mostly the flat of the canyon. They pretty much took everything out except for a few selected trees. I have photographs that show the canyon very cleared. Of course, the growth today is all back."*[57]

The McCormick Mill provided the basis of the development known as the Butano Tract. The logging of the Butano Canyon upstream from the Falls occurred in the early 1950s.

SAVE THE BUTANO – MAY, 1877

Historians chronicling the history of the preservation of coast redwoods credit Redwood City newspaperman Ralph Sidney Smith with writing the earliest editorials calling for the preservation for the upper Butano Creek and Big Basin when he edited the *Redwood City Times and Gazette* in 1886. Smith is given credit for beginning the movement that resulted in creating Big Basin as a state park in 1886.[58]

Our recent review of the Redwood City newspaper files suggests that Ralph Sidney Smith made the first suggestion to create a state redwood park in the spring of 1877, and the particular redwoods he wanted to save were those in the Butano Creek watershed. In May of 1877 Smith described a walk that he took up Butano Creek. After reaching the Butano shingle mill a little over a mile from present-day Cloverdale Road, Smith described the old growth redwood forest:

> *"Following a path scarcely distinguishable to the eye, the pedestrian soon finds himself in the midst of a real forest of redwood timber. Around him on all sides tower immense trees, veritable monarchs, whose grand bodies reach two, three and four hundred* [?] *feet in the air, and through whose branches he had glimpses of a sky as blue as an Italian ever saw.*
>
> *"To the keen observer, almost every step discloses some new and interesting object. Here is a circle of young redwood trees which have risen from the roots of a giant, dead long ago, leaving no other traces of centuries of growth than a bed of reddish colored vegetable mold around which the young and healthy scions have grown as if to protect the grave of their mighty chief. Here is another immense fellow whose trunk is beginning to show the effect of time's merciless grasp, and in whose decayed sides the ferns, mosses and lichens grow. So the journey is continued, over decayed logs crossing the stream on some fallen tree trunk down into the bed of the creek under overhanging ledges of rock where the ferns, mosses, maiden's hair, lichens and many other beautiful plants grow in delicate profusion, when suddenly a sound of rushing water is heard and on turning a corner we come in full view of the falls of the Butano."*
>
> *"The basin, at this point is probably seventy-five feet in diameter, almost circular and very deep in some places. They can scarcely be called falls properly as there is a series of shelving rocks over which the water dashes in numerous cascades, the first one*

57 Interview, Martin McCormick, December 2, 2002, p. 3, 6.
58 Barbour, Lydon, Borchert, et al. *Coast Redwood: A Natural and Cultural History*, Cachuma Press, Los Olivos, 2001, p. 128.

> *immediately at the basin being about twenty feet high and more nearly perpendicular than any of the others. Above the falls there are numerous basins and pools where the trout stay in abundant quantities. The path lies along the bed of the stream, for almost the whole distance now. From the lower falls to the upper, perhaps a mile distant, trout are numerous and the scenery is beautiful, although the view is necessarily more confined than further down the creek as the banks are high and close to the stream. The water is clear as crystal and said to be the best in the state. At any rate water was never taken with greater relish than that obtained from the basin at the lower falls."*[59]

This may be the oldest extant description of Butano Falls. Notice that there is no road into the canyon beyond the shingle mill on the Clelland property.

Smith concludes the article with a suggestion that the entire area be turned into an "immense park." Smith later revisited this suggestion to make Butano into a park, and eventually the movement he spearheaded did create California's first redwood state park at Big Basin. The genesis of California's redwood preservation movement, however, seems to have come out of Smith's love and admiration for the redwoods and water falls of the Butano.

STATUS REPORT – 1886

On August 7, 1886, the *Redwood City Times and Gazette* published a summary of the status of San Mateo County including a lengthy analysis of Pescadero and vicinity. Excerpts from this summary:

> "*The leading industries of Pescadero and vicinity are farming, dairying, cattle-raising, lumbering and shingle manufacture. There is less grain raised than formerly, though oats, barley, flax and potatoes grow well and yield abundant crops. Potatoes are especially noticeable…Of late years farmers and land-owners are giving more attention to stock-raising and dairying, as the rich natural pasture and the uniformly genial climate makes that business more profitable than grain-raising.*
>
> *"…Many millions of redwood shingles are shipped every year, besides lumber, fence material and tan-bark. Chestnut oak, or 'tanbark oak' as it is called is plenty in many localities and furnish one of the best tanning barks known.*
>
> *"…The butter and cheese products are very large, amounting each year to not less than 2,000 boxes of butter and 300 to 500 tons of cheese, ranging in price from 9 cents to 20 cents per pound for cheese; and from 15 cents to 40 cents per pound for butter, the prices being governed by the San Francisco market…Butter and cheese carried by wagon to San Mateo, thence by rail to San Francisco costs shippers $10 to $13 per ton. The same articles shipped by steamer or schooner from Pigeon Point cost for freight less than one-half those prices."*

[59] *Redwood City Times and Gazette*, May 19, 1877.

THE SCENT OF A RAILROAD

Beginning in 1870, Pescadero and the surrounding country were teased by the idea of a railroad connection with the outside world. The mid-1870s saw a frenzy of narrow gauge railroad building just over the ridge from the south San Mateo County coast. The completion of the Santa Cruz & Felton Railroad in 1875 connecting Felton with wharves in Santa Cruz, and the connection of Santa Cruz to the outside world by rail in 1876 spurred the imaginations of many of those doing business along the coast between San Francisco and Santa Cruz. With so many non-Southern Pacific Railroad narrow gauges being built, shouldn't there be one in Pescadero's future?

A coastal route was proposed in 1878 and local property owners were exhorted to contribute from five to ten percent of the value of their property with the assurance that each property owner "*would make money even though his subscription were an outright donation.*" It was suggested that coastal property would at least double in value should a railroad be built.[60]

Nothing came of the 1878 proposal and by 1886, a Pescadero correspondent was blasé about yet another railroad survey coming down the coast:

> "*It is reported that a force of engineers are about to make a final survey of some proposed railroad down the coast from SF, taking in Pescadero en route. Rumors of this kind have prevailed for the past 15 years -- three surveys made and no railroad yet.*"[61]

Several proposals were made to connect Pescadero via a "backdoor route" with Boulder Creek over the Butano Ridge. In 1883 a company with the hopeful name of Felton and Pescadero Railroad Company was incorporated with a stated intention of running a line from Felton to Boulder Creek and eventually to Pescadero. But once the line was completed to Boulder Creek it became clear that the railroad had no intention of extending the line across the steep and daunting ridge to Pescadero.[62] For a time in 1886 there was even a tri-weekly stage running from Boulder Creek eleven miles to the summit of the ridge which then connected with a trail good enough for horseback riders to complete the remaining thirteen miles to Pescadero. This arrangement did not survive the year.[63]

By the 1890s it was clear that the only feasible route for a railroad connecting Pescadero with the outside world was across the terrace adjacent to the coast. Despite the formidable geographical barriers at San Pedro Point (present-day Devil's Slide) and the cliffs at Waddell Creek, a serious proposal emerged in the early twentieth.

Meanwhile, the twisting and looping Coast Road continued to be the primary lifeline for Pescaderans wishing to reach the outside world.

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60 *Redwood City Times and Gazette*, April 20, 1878.
61 *Redwood City Times and Gazette*, May 15, 1886.
62 Rick Hamman. *California Central Coast Railways*, 1980, Pruett Publishing, p. 100.
63 *Redwood City Times and Gazette*, May 29, 1886.

THE OCEAN SHORE ELECTRIC RAILWAY – 1905

In 1905 a group of West Coast financiers, including J. Downey Harvey and J. A. Folger (of the coffee company of the same name), came together and formed a railroad company to build a coastal line between San Francisco and Santa Cruz. Construction began at both ends in the fall of 1905. This was to be a double track standard gauge electric railroad, and by early April of 1906 there were 4,000 men working on the line. The April 18, 1906 earthquake brought construction to a halt, but remarkably, construction resumed and by the fall of 1907 the train was completed from San Francisco south to Tobin (near present-day Rockaway Beach in Pacifica.) New communities sprang up ahead of the railroad with names such as Montara, Moss Beach, Princeton and Miramar. Meanwhile, the line extending northward from Santa Cruz had reached the cement plant at Davenport and was soon extended to a new town named Swanton.

The Ocean Shore company was most interested in extending its line southward to Pescadero to open up the estimated 1.5 billion board feet of redwood just waiting to be cut. Half of that redwood was estimated to be in the Butano and Gazos creek watersheds. By 1908 the line had reached southward from San Francisco to Tunitas Creek. Passengers wishing to continue on to Santa Cruz boarded a Stanley Steamer automobile bus that shuttled them across the "gap" to Swanton where they boarded a second train to Santa Cruz. By 1910 the Ocean Shore was in heavy financial difficulty, and though the railroad continued to operate at both ends for the next decade to 1917, the "gap" was never closed, and a rail connection with Pescadero was never completed.[64]

IMPACT OF THE OCEAN SHORE

Though the Ocean Shore never made it to Pescadero, its very promise had several impacts on the area's land. The railroad's right of way followed the immediate coastline rather than looping inland at San Gregorio and Pescadero as the Coast Road did. Thus there were several real estate frenzies on the flat (called by locals The Mesa) south of Pescadero Creek. The subdivision of smaller parcels out of the Coburn properties (and now called "Shoreland Properties" or "Ocean Shore Properties" by locals) occurred in anticipation of the railroad's arrival in the early twentieth century (Figure 3-3). Loren Coburn himself attempted to revive his Pebble Beach hotel (sarcastically called "Coburn's Folly") by Pescaderans to service railroad passenger visitors.

Agriculture felt the impact of the railroad much more directly. By 1907 it was possible for Pescadero farmers to load fresh vegetables onto wagons bound for Tunitas or Half Moon Bay where they could be placed on the Ocean Shore and shipped to San Francisco markets.

64 The primary work on the Ocean Shore Railroad continues to be Jack Wagner, *The Last Whistle: Ocean Shore Railroad*, Howell-North, Berkeley, 1974. See also Hamman, *California Central Coast Railways*, pp. 169-192.

THE SOUTHWARD MARCH OF THE ARTICHOKE

One industry that was directly affected by the less-than-complete Ocean Shore Railroad was the growing of artichokes. It is not clear when the first artichokes were planted on the coastside of the San Francisco Peninsula, but there were enough artichoke farmers along the coast to cause the formation of the San Francisco Artichoke Growers Association in 1912. By 1920 two more artichoke associations were formed – the Half Moon Bay Coastside Artichoke Growers Association, and the San Pedro Artichoke Growers Association.

Artichoke farming was dominated by immigrant Italian farmers. Though there are a few references to other ethnic groups, such as Japanese, dabbling in artichokes, the industry was a niche controlled by the Italians. Tom Kuwahara noted, "[Japanese] *did not do too much artichoke because the Italian people were raising it.*" Italian immigrant Bruna Odello of the noted Odello artichoke family of the Carmel Valley explained that artichokes needed to be grown on a large scale to be profitable, while the Japanese tended to have smaller farms and work on more specialized crops.[65]

The primary market for the artichokes was the Eastern United States, so it was necessary for the farmers to organize to get enough artichokes to fill entire refrigerator cars on the cross-country railroad. Originally the artichokes were shipped in barrels, but early on the farmers began using full and half-sized apple boxes.

It was estimated that in 1920 the artichoke district stretched along the coast from San Francisco County southward to the city of Santa Cruz, a distance of 70 miles. Within that distance there were an estimated 5,500 acres of artichokes under cultivation with most of the crop finding its way by rail to San Francisco and then to the East Coast.

The farmers found it necessary to enrich the coastal soil with "trainloads" of manure hauled in from San Francisco. The farmers also grew peas, horse beans, Brussels sprouts and potatoes between the rows of first-year artichoke plants, and then plowed much of that vegetation back into the soil.[66]

In the early years, most of the labor used in the growing, sorting, and packing of artichokes was done by the Italians themselves. By the middle of the 1920s, however, as the industry matured and moved ever southward into Santa Cruz and Northern Monterey counties, Japanese, Filipinos and Mexican laborers worked in the industry.

65 Interview, Tom Kuwahara, December 12, 2002, p. 7; Bruna Odello, June 15, 2002.
66 *Half Moon Bay Review*, April 3, 1920.

DIVERSIFIED AGRICULTURE

Inspired by the arrival of the artichokes and the better shipping possibilities offered by the Northern Section of the Ocean Shore Railroad, Pescadero farmers were growing many different crops in the 1920s. An Anonymous Respondent recited a remarkable list of crops grown by his father around Pescadero before World War II:

> *"…lettuce; broccoli; sprouts; sugar beets; flax. Different grains; hay, oats, barley. Tomatoes and artichokes. Strawflowers, statice, sypsophila, peas and beans (small whites; favas, red beans, every kind). Pumpkins."*[67]

In 1939 Ed Weeks' family was also growing a variety of crops:

> *"We raised beans, broccoli, beets, carrots, cauliflower and cabbage. We raised beets and carrots for Gerber Baby Food. You would call it truck farming."*[68]

Since shipping was still problematic, several vegetable canneries were built in Half Moon Bay during World War I to can not only artichokes, but also other vegetables. A similar vegetable cannery was built in 1916 in the Seabright area of Santa Cruz.

PESCADERO MARSH-MANAGEMENT AND RECLAMATION

There were a number of efforts undertaken in the late nineteenth and early twentieth centuries to alter stream flows and clear willow lands to bring more land into agricultural production around Pescadero.

The mouths of most of the coastal streams along the Central California coast became blocked by sand during the summer months causing formation of coastal lagoons. Early winter stream flows were often insufficient to breach the lagoon, and until the force of the water was strong enough to do so, upstream flooding usually occurred. Farmers sometimes resorted to picks, shovels, plows, and even dynamite to break open these sandbars.

During the drought of 1897-1898, Pescadero Creek did not have sufficient rainfall to breach the sandbar, though there was enough rain to cause flooding of the adjacent farmlands following a healthy rain during December 1898. Pescadero farmers raised an estimated $200 to drill a tunnel through the point on the south side of the beach, hoping that the hole would offer an outlet to the creek and prevent further flooding. The tunnel provided limited success and eventually plugged up with sand.[69] As Ron Duarte noted, most people who see the tunnel believe that it is natural, but not so:

> *"A bunch of old timers made that tunnel. It is not natural. Everybody thinks it is natural but it is not. They thought* [the tunnel] *was going to keep the mouth of the creek open.*

67 Interview, An Anonamous Respondent, September 19, 2003, p. 3.
68 Interview, Ed Weeks, November 7, 2002, p. 3.
69 *Santa Cruz Sentinel*, December 16, 1898.

Maybe it did and maybe it didn't. But, most of the time I don't think it did much good. That was man-made, that tunnel."[70]

In January of 1904 a Santa Cruz newspaper reported that the Pescadero Creek sandbar was closed:

"…the tide water at the mouth of Pescadero Creek is closed and… a big lagoon has formed and the water is backing up very rapidly, and if the bar formed is not soon opened the water will flood the town of Pescadero."[71]

Martin McCormick remembered local residents using bulldozers to breach the sandbar after World War II:

"…it was a big deal every [fishing] *season for someone to go out* [to the mouth of Pescadero Creek] *with a Caterpillar and rearrange the beach –to 'open the mouth' as they called it. My dad always told us when they were 'opening the mouth' and we would go over and go fishing. We would be elbow to elbow. There would be hundreds on each side of* [the creek] *for a couple hundred yards up from the mouth and the fish were just pouring in. It was pretty incredible."*[72]

RECLAMATION OF WILLOW LAND ALONG BUTANO CREEK

Chinese laborers were the main force involved with reclamation and the clearing and draining of marginal farmlands in Central California in the nineteenth century. Chinese usually entered into leases with landowners to exchange the use of the land for five years in return for all of the crops grown there during the lease.[73] There are scattered references both in the published record and in the interviews about Chinese laborers clearing and grubbing willow land in the Pescadero watershed during the nineteenth century. For Ron Duarte, the presence of the Chinese was prevalent enough in the nineteenth century to characterize the entire period:

"My grandfather Cardoza—we don't know when he came, but he wound up here on the coast side where the Chinese were clearing all the land, 'grubbing all the brush' as they would say."[74]

Japanese laborers took the place of the Chinese in reclamation after the turn of the century, and they continued similar work in the Pescadero area. According to Tom Kuwahara, the land alongside Butano Creek where it flows beside present-day Cloverdale road was grubbed and cleared by Japanese farmers before World War II:

"It wasn't that wet but, you know. nobody farmed it and it just grew wild. So, when they started checking around they found nice, soft ground for the farming. They pulled all the willows out and made flat ground all the way down Cloverdale."[75]

[70] Interview, Ron Duarte, November 14, 2002, p. 6.
[71] *Santa Cruz Surf*, January 28, 1904.
[72] Interview, Martin McCormick, December 2, 2002, p. 15.
[73] See Lydon, *Chinese Gold*, pp. 76-77; 219; 286-90.
[74] Interview, Ron Duarte, November 14, 2002, p. 2.
[75] Interview, Tom Kuwahara, December 12, 2002, p. 8.

FISH PLANTING-TWENTIETH CENTURY

The fish planting begun by the state of California in the 1870s continued into the twentieth century. The contemporary newspapers are peppered with accounts of such plantings. For example, in July of 1919, the local game warden supervised the planting of 70,000 trout in the streams near Half Moon Bay, with a total of 380,000 fish being planted throughout San Mateo County.[76]

Besides the usual plantings of rainbow trout, the introduction of exotic trout continued. With the development of the Butano Falls Tract, numerous attempts were made to establish non-native fish stocks in the area above Butano Falls. Both the author and Gaston Periat remember a particular stretch of the Cascades just above the Falls where a large number of Dolly Varden trout had taken up residence. The author's grandmother, Mrs. E.C. Lydon, explained that the Canyon homeowners had planted many different kinds of trout above the Falls prior to World War II.[77]

LOGGING IN THE PESCADERO WATERSHED

The idea of saving some of the remaining stands of uncut coast redwood in the Santa Cruz mountains first bore fruit with the establishment of the California Redwood Park in Big Basin in 1901. Most of the 3,000+ acre park was in the San Lorenzo River watershed, but a part of it draped across the ridge into the upper Pescadero.

In July of 1902, several sawmills were built in the upper Pescadero Creek watershed and an incline was built to hoist the cut lumber up and over the ridge and then down into Boulder Creek. The 4,200-foot incline had a rise of 1,100 feet, and with it the lumber companies were able to thwart, for a time, the absence of dependable transportation down into Pescadero and out to lumber markets.[78]

Meanwhile, Ralph Smith's call to place the Butano canyon under some kind of government protection went unheeded. Small logging operations continued to nibble away at the edges of the Butano Creek watershed, but the rugged and isolated landscape provided protection for the time being.

THE BUTANO LAND AND DEVELOPMENT COMPANY

As the automobile began to give middle class Californians the mobility to go to places not served by railroads, there was an increasing number of summer visitors car camping in the Butano and other places in the Pescadero watershed.

In 1912, James McCormick subdivided a parcel of his land that he had logged just downstream from Butano Falls. Known as the Butano Falls Tract, the official name was the Butano Land and

76 *Half Moon Bay Review*, July 26, 1919.
77 Telephone interview, Gaston Perait, January 28, 2002; the author caught a foot-long trout that was positively identified by a resident as being a Dolly Varden in the Cascades in the summer of 1950.
78 *Santa Cruz Surf*, July 10, 1902.

Development Company. He put the 120 lots on the market and advertised the area at the Panama-Pacific Exposition in 1915 as California's "Second Yosemite." By the early 1920s there were several dozen summer homes in the tract, with many of the owners living in the San Francisco Bay Area. Those with young families would move over to the Butano at summer's beginning while the husband would continue to work in the Bay Area, commuting by automobile or on horseback to join their families on week-ends.[79]

The old growth redwoods growing above Butano Falls remained in the hands of Pacific Lumber Company. As more and more people began hiking into those old growth stands, a campaign began to save them.

THE SECOND CAMPAIGN TO SAVE THE BUTANO – 1923-1955

The campaign to save the Butano was lengthy and complicated, but it is punctuated by a number of efforts to either give or sell at a small cost the land above the Falls. Both the State of California and the County of San Mateo declined offers to purchase the area at one time or another prior to World War II. In 1946 the land was still uncut, but the postwar California building boom created an enormous appetite for redwood, and lumbermen came into the redwoods all over California with the same determination with which they had vanquished the forces of Japan and Germany.

As the logging frenzy heated up, so did the campaign to save the Butano. However, once again, a series of missed opportunities plagued the campaign. Following the 1955 veto of legislation that would have saved 3,120 acres centered on the forks of North and South Butano creeks, Santa Cruz Lumber Company began logging the huge trees that Ralph Smith had campaigned so hard to preserve.

Finally, after almost eighty-five years of efforts to save the Butano redwoods, a 2,177-acre Butano State Park was dedicated in 1961. The park contained only 315 acres of uncut old growth redwoods out of the estimated 11,000 acres that Ralph Smith had called to save in 1876.[80]

Several informants believed that the logging above the falls was the cause of the first damaging flood in the watershed, and that much of the damage was due to logging undertaken by the Santa Cruz Lumber Company (Pacific Lumber Company still owned the land) in the upper Butano beginning in early 1955. Martin McCormick remembered that his father was amazed by the amount of debris that came over the Butano Falls in December 1955:

> *"My dad was not awed by the creek in 1955. I remember him saying that it had been like that before, but he had never seen the trees and things wash down. That was the difference."*[81]

[79] Interview, Martin McCormick, December 2, 2002; Interview, Rocky Lydon, January 2003. Mr. Lydon remembered regularly riding on horseback from San Mateo to the Butano in the late 1920s.
[80] See Barbour, Lydon, Borchert, et al. *Coast Redwood: A Natural and Cultural History*, Cachuma Press, Los Olivos, 2001, p. 144 for a detailed account of the Butano campaigns.
[81] Interview, Martin McCormick, December 2, 2002, p. 7.

Gaston Periat, another long time resident of the Butano, remembered going up into the logged-over land above the Falls and being so emotionally affected by what he saw that he actually vomited. He also noted that the excellent trout fishing that he had enjoyed above the Falls declined quickly after the 1955 flood:

> *"The creek silted up so bad after the 1955 flood that the pool at the bottom of the Falls was completed silted in."*[82]

THE UPPER BUTANO-LOGGING AND RESTORATION

The Upper Butano watershed, that is the two deeply cut stream valleys above Butano Falls, has experienced logging of various types over the past 50 years or so. Santa Cruz Lumber began logging in the lower portion of the Upper Butano in 1952, when the property was owned by Pacific Lumber Company. Big Creek Lumber purchased the land and began its operation in 1979. The two companies took very different approaches to their operations, that have had vastly different effects on the landscape and the condition of the stream corridor from the Falls up to the top of the watershed. Homer "Bud" McCrary and Frank "Lud" McCrary, two of the founders of Big Creek Lumber, sat for a lengthy interview about their memories of past logging operations in the Upper Butano and their own forest practices there over the past 34 years.

THE SANTA CRUZ LUMBER OPERATION 1952 TO 1969

Santa Cruz Lumber approached the problem of reaching the redwood timber in this rugged terrain in an unusual fashion. Rather than building roads up along the stream, Santa Cruz contracted with Granite Construction to build a substantial haul road from their mill in the headwaters of Pescadero Creek over the ridge to the upper reaches of the Butano watershed, and down along the stream. Presumably the haul road was built in 1950 or 1951. The haul road (part of which is still in use) ran down to a point near the Falls and close to what is now Butano State Park. Bud McCrary recalls that a deal had been struck between the company and Parks and Recreation whereby a parcel would be set aside for the Park and another was opened to logging. Santa Cruz Lumber moved quickly to log this parcel, in part, according to Bud McCrary, because they were worried the politicians might change their minds about the deal. As noted above, the condition of the forest above the Falls after it was logged was a shock to some observers. Santa Cruz Lumber continued logging in the two drainages until 1969, eventually taking timber out of all sections of the 4,000 plus acre parcel.

The operation was heavily dependent on roads to skid logs to the main haul road. Bud McCrary remarked, half jokingly, that "They built a road to every tree they cut down." The State required the operation to leave at least six "seed trees" per acre, practices that Bud McCrary defines as very close to a "clear cut," Seed trees were to be 24 inches DBH (double breast height). Bud recalls that Santa Cruz Lumber exceeded this requirement, partially due to the nature of their purchase agreement with Pacific Lumber (the land owner). Rather than paying Pacific Lumber for stumpage, that is, an agreed upon number of trees, or all trees in a parcel, Santa Cruz Lumber

[82] Telephone Interview, Gaston Periat, January 28, 2002.

was paying for only usable lumber, which could be accurately quantified at the mill (called "recovery basis"). This reduced the pressure to cut as much timber as possible, but it also meant that some trees that were cut and found to be inferior were left behind.

Seed trees were simply that. They were left to grow, which according to Bud and Lud, they did quickly with increased sunlight and access to nutrients. They also cast seeds that fell on bare, disturbed ground, where they stood a better chance of germination and survival. (Bud noted that pathogens in normal forest duff hinder germination.) The McCrarys noted that these seed trees are now 30 to 40 inches DBH.

As was the case downstream, the Upper Butano suffered heavy damage in the Christmastime Flood of 1955. Bud McCrary, who kept an eye on the region from his private plane, noted "hundreds, and possibly thousands of landslides" in the Upper Butano. At this time Santa Cruz Lumber had finished operations just above the falls, and was concentrating on logging the perimeters of the parcel, that is the ridges above the drainages, and the roads may have contributed to the number of landslides. Bud noted that the older roads did not have any erosion control, such as water bars or dips.

The McCrarys took control of the parcel in 1979, and describe it is as heavily logged, with an abundance of slash and other forest debris, and a haven for Scotch broom and pampas grass, the latter attributable to the lack of shade from a forest canopy. The parcel became very attractive to off-road motorcycle riders after Santa Cruz Lumber ceased operations in 1969. Hundreds of miles of remote logging roads were the draw, and access was difficult to control. Bud remembers that the damage attributable to the motorcyclists was extreme in some areas, including gullying on bare hillsides and erosion in the roadbeds. More control was exerted as neighbors took measures to limit access and Big Creek Lumber began active management of the parcel. Big Creek's goal was to restore the land to productivity and include it in its own operation, which emphasizes minimal disturbance and selective harvest.

BIG CREEK LUMBER AND RESTORATION

Big Creek Lumber was able to take out 10,000 board feet of lumber per acre when they began in 1979, mostly by harvesting the now much larger seed trees left behind by Santa Cruz Lumber. Big Creek took a different approach to access, building a principal haul road into the Upper Butano from lower down Pescadero Creek, at Dearborn Park. Logging has continued to the present. Big Creek builds as few roads as possible, preferring to skid logs over longer distances. The harvest is selective so that no one site is cleared of trees. Big Creek has also used high lead and helicopter techniques to minimize damage and harvest trees from remote areas that would otherwise require construction of new roads.

Big Creek undertook active restoration quickly. The extensive road system left by Santa Cruz Lumber was badly eroded and a source of sedimentation. Stream crossings were impeding stream flow and creating sediment ponds. Just three years after taking over the parcel, the flood of 1982 raised havoc in the upper Butano. Bud McCrary remarked that there may have been thousands of slides in the parcel, again because of the extensive road system and bare hillsides.

Big Creek's approach to the road system has been to stop using some roads, and installing erosion control measures on roads that are in use. The most common technique to control water is a "rolling dip" in the roadbed. Rolling dips are diagonal depressions in the road that guide water off the road on the down slope side. On a tour of the Upper Butano, Bud compared a State fire road constructed without erosion control measures. The road was rutted in several places up to two feet, due to the momentum gained by the water as it flows down the flat road bed. Bud offered ample evidence that erosion can be controlled on even steeply sloped roads.

Santa Cruz Lumber had installed log crossings, sometimes called "Humboldt crossings" at streams. These were essentially stacked logs very low in the streambed, that in time became log dams. These were removed and where necessary, replaced with true bridges elevated much higher above the streambed. In some locations, Butano Creek had been diverted out of its bed and had begun to flow down logging roads. Big Creek diverted the creeks back to their natural courses. Finally, the return of the forest canopy is shading out the once ubiquitous pampas grass. Bud McCrary notes with some pride the change in the parcel. "When we were first in there the area between the creeks was nothing but brush. Later there were a few conifers sticking up through the brush. Now all you see are conifers."

THE INTRODUCTION OF EXOTIC SPECIES – BEAVERS

One of the major impacts on land use, particularly in the Pescadero Marsh, was the introduction of a half-dozen beavers by the California Department of Fish and Game in 1937 or 1938. An Anonymous Respondent actually witnessed their release. The intent was that the beavers would build dams that would create ponds and help area farmers, but most believe that the beaver dams actually exacerbated the flood along the lower Butano.[83]

THE ETHNIC DIVERSITY OF THE 1930S

The diversity of agricultural crops noted above was driven, in part, by several immigrant groups living in the Pescadero Valley that carved out specialized farming niches. Though there was often some cross-over in crops grown, there was a general understanding that the Japanese would grow truck crops (peas and beans), the Swiss would focus on the dairies, and artichokes would be an Italian crop. The Portuguese seemed to be the most diverse in their occupations, growing many different vegetable crops or owning small dairies.

An analysis of the United States manuscript census of 1920 and 1930 demonstrates the ethnic diversity of Pescadero. The following numbers reflect only the foreign-born people counted, so the numbers would be considerably higher if their America-born children were included:

[83] Interview, An Anonymous Respondent, December 2, 2002. See also, William H. Cook, *The Restoration of Butano Creek, Its Lower Channel and Floodplains, & The Flooding of Pescadero Road*, 2001, p. 6 ff.

TABLE 3-1
TOP SIX SOURCES OF FOREIGN-BORN PEOPLE IN THE FIFTH SUPERVISORIAL DISTRICT OF SAN MATEO COUNTY[84]

1920		1930	
Portugal (Azores)	155	Portugal (Azores)	105
Italy	60	Japan	79
Japan	51	Italy	74
Switzerland	18	Philippines	59
Sweden	16	Mexico	19
Ireland	14	Switzerland	10

According to our informants, the groups all seemed to coexist without rancor or acrimony (Figure 3-6). When describing the 1930s, Tom Kuwahara noted:

> *"Before* [World War II]*, everybody was friends. There were a lot of Portuguese, Italian and Japanese. Very few Mexican families. That was it, but everybody got along."*[85]

STRAIGHTENING THE COAST ROAD

Beginning in the late 1930s, the California Department of Highways began building a new highway along the immediate coast, removing the inland loop that took travelers through Pescadero and over the hill to San Gregorio before returning to the coast for the trip to Half Moon Bay. The section to be realigned began at Bean Hollow Beach and followed the coast northward to the top of the hill beyond San Gregorio.

Ed Weeks remembered that his mother took in four highway engineers as borders during the construction of the highway.[86] The route of this new highway, eventually named Highway 1, was the final legacy of the Ocean Shore Railroad as, in many places, it followed the route of the railroad right-of-way.[87] The construction of this by-pass assured Pescadero's continued isolation.

According to Ron Duarte, the construction of the new highway and the bridge across Pescadero Creek also altered the flow of Pescadero Creek into the sea. He remembered the construction of a haul road that allowed trucks to bring riprap down the hill from San Gregorio. According to Duarte, the haul road was not properly removed when the highway was completed in October of 1941. Prior to that time, there was considerable tidal action between the lagoon and upstream. The tide sometimes generated a wave all the way up to the intersection of Butano and Pescadero Creeks. Following the highway construction there was, *"…no tidal action now."*[88]

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84 United States Census, Manuscript, San Mateo County, 1920 and 1930
85 Interview, Tom Kuwahara, December 12, 2002, p. 9.
86 Interview, Ed Weeks, November 7, 2002, p. 8.
87 Jack Wagner, *The Last Whistle*, pp. 119 ff.
88 Interview, Ron Duarte, November 14, 2002, p. 7.

Figure 3-6: Pescadero Grammer School, 1937. Pescadero's ethnically-diverse population is evident in this Pescadero Grammar School photograph. In less than five years, the Japanese students will have been removed to Relocation Centers throughout the West. (Ed Weeks Collection)

WORLD WAR II

World War II brought several major changes to Pescadero. The ethnic conviviality that marked the town and surrounding countryside disappeared with the Japanese attack on Pearl Harbor. As Tom Kuwahara put it, *"When the war started, everything changed."*[89]

By the spring of 1942, Pescadero's Japanese community was gone, its members either having relocated into the interior of the United States, or reporting to the War Relocation Authority center in San Bruno. Tanforan racetrack was converted into a temporary detention center while concentration camps were being prepared elsewhere in the United States.

89 Interview, Tom Kuwahara, December 12, 2002, p. 9.

The military presence on the Pescadero coast began before World War II began. Ed Weeks remembered:

> *"There were two army camps. The first one was up just adjacent to our farm. On the road past Pigeon Point, go by the buildings, at Muzzi's and there is a rood. Before the Second World War started, they built a radio station up there for overseas aircraft. During the war they brought in the Signal Corps. I was a teenager then. But they had foxholes dug out in the field where grain was planted. That was in operation from then until the war ended."*

> *"At Bolsa Point, just this side of the lighthouse, where there are a bunch of buildings, I farmed right up the hill from that. That was an anti-aircraft gun. This came after the war had started. They were flying planes at night and would shoot with anti-aircraft guns. We had the blackout in those days...The soldiers would come to* [Pescadero] *and drink beer. We played basketball. Some Sundays, we would play basketball."*[90]

THE END OF FLAX AND RECENT EROSION

Like logging, Pescadero-area agriculture was episodic and diverse. Beginning with the potato boom in the 1850s, farmers quickly shifted crops as economic, weather, shipping and crop pests dictated. The Pescadero Valley's proximity to the markets of San Francisco always encouraged farmers to grow for that fresh vegetable market. And, when shipping became more dependable in the twentieth, the number of different crops increased.

Some crops flourished in the nineteenth century, disappeared, and then returned in the twentieth. Flax is an excellent example of this renewal. As we have already seen, flax was an important crop in the late 1870s. Fields of flax covered the hill lands around Pescadero in 1880.

Flax returned to the Pescadero hillsides immediately following World War II. Ed Weeks remembers farming flax during those years:

> *"The terraces were plowed at the beginning of the winter rains. The ground was then disked in late February or early March, to kill weeds and then packed down. Flax was planted in drill rows six inches apart....Flax was never irrigated but did take up some moisture from the prevailing summer fogs. Harvesting began September 1 and continued for one to one and half months."*[91]

Ron Duarte remembers the flax growing around Pescadero in the 1940s was used for linseed oil only.

> *"The hills were never so pretty. It was like looking at the ocean. It was a purplish bloom that would get about so high. This high was a good crop. The wind would come and it was just like looking at the ocean."*

[90] Interview, Ed Weeks, November 7, 2002, p. 12.
[91] Interview, Ed Weeks, November 21, 2003, p. 2. The author also remembers flax on the hillsides above Butano Creek along Cloverdale Road and south almost to the Gazos.

He also remembers that the flax attracted all of the deer out of the nearby mountains:

> *"When they raised flax here, that sucked all the deer out of the timber. They went nuts over the stuff...The deer would stick their heads down in it. It wasn't so much the tops. I think they might have eaten tops when it was a malty stage or something."*[92]

Ed Weeks puts the end of the flax production in the Pescadero Valley in 1958 or 1959. The use of synthetics in paint put an end to the need for flax. During a recent driving tour around the valley, Ed Weeks noted that cultivation on the hillsides ended when flax was no longer grown there. He had driven a harvester along the contours of the hillsides during one of the last flax harvests. When pointing at a particular hillside he noted that he could drive a harvester there in 1959, but would not be able to do so now because of the huge gullies that have been eroded into the hills. He was not sure what had caused the erosion, but was very clear that it was not there when flax was being grown in the late 1950s.

Figure 3-7: Pescadero Marsh and Town to the Northeast (Circa late 1950). This view was taken from Cloverdale Road at the site of the old town dumpsite, above Butano Creek. This illustrates the condition of the hillsides at about the time flax growing ended. The area discussed by Ed Weeks, above, can be seen in the central background, to the left of the town flagpole.

92 Interview, Ron Duarte, November 14, 2002, p. 13.

Ron Duarte believes that the erosion was caused in part by farming practices and land ownership patterns in the 1920s and 1930s:

> *"You see all the erosion? Ninety percent of that* [eroded land is owned by] *absentee landowners....North of the Salt Pond on top of the hill, you see lots of big erosion. They claim that was an absentee owner and they claim that when Half Moon Bay and Pescadero used to control the pea market during the twenties and thirties, you planted your peas up and down and then they just left* [the rows]. *The erosion, the water, came right down those rows. That is where most of the erosion came from. If you went in there right away and contoured it, it would have held it. Or, put a cover crop. Like barley."*[93]

PEST CONTROL

Perhaps the first target of eradication by local settlers was the grizzly bear. Accounts of encounters with grizzly bears in the Pescadero, Gazos and Waddell were frequent in the 1860s and 1870s. The bears usually remained in the mountains, but when drought or wildfire forced them out, they often clashed with local residents. In 1866, for example, at the end of the 1865-1866 drought, the bears came down into populated areas:

> *"Mr. A.P. Thompson, who has a ranch east of Pescadero informs us that grizzlies are very plentiful in that section. Five miles east of Pescadero, two large bears were poisoned this past week and another attacked the house in the night, while occupied by the families. These marauders are mostly she bears, with their cubs, and have come down out of the mountains laid bare by recent fires, to luxuriate in the young clover near the seacoast...Our informant has lived eight years in this country and he has never known grizzlies to be so plentiful and daring as this year."*[94]

Grizzly bear encounters continued into the 1870s, with perhaps one of the most famous being the attack and eventual death of William Waddell in 1875 in the canyon that bears his name.

Poisoning and hunting eventually narrowed the range of the huge bears, but as late as the 1880s, there were still reports of bears being seen in the remote reaches of the Santa Cruz Mountains.

GROUND SQUIRRELS

Another indigenous creature that tormented local farmers, though not as dangerous and noteworthy as the bears, was the ground squirrel. Ground squirrels had always posed a problem for local farmers, from the amount of grain they could consume to the danger their burrows posed for horseback riders.

The concern about ground squirrels reached a peak in 1876 when the California Legislature enacted a squirrel eradication law. Enacted to include the counties of San Mateo, Santa Cruz, and Monterey, among others, the law put the responsibility of eradication on the individual landowners. If the landowner did not take care of the squirrels on his or her property, then the county could do so and pass all costs back onto the landowner. Each county covered by the law

93 Interview, Ron Duarte, November 14, 2002, pp. 14-15.
94 *Santa Cruz Sentinel,* May 12, 1866.

was to hire a Squirrel Inspector, whose duties included surveying the county and notifying landowners if their ground squirrel populations were notable. The law took effect on October 1, 1876.[95]

Apparently neither the Squirrel Inspectors nor local newspaper editors successfully eradicated the squirrels, because another major campaign against ground squirrels began in 1917. An editorial in the *Half Moon Bay Review* on July 21, 1917 tried to put into monetary terms the damage ground squirrels could do:

> *"It is an expensive luxury for a farmer to keep ground squirrels. Every squirrel costs the farmer at least $1.50 a year, causing damage to grain and pasture grass. They also spread Plague. Poison grain is the most effective method to get rid of them. The plan is to poison the grain, and then sow it broadcast over ranges and pasturelands inhabited by the squirrels at a rate of 10 or 15 pounds per acre. The squirrels find the individual kernels, but livestock cannot eat enough to be endangered."*[96]

The war against the ground squirrels continued. In 1920, a ground squirrel expert showed farmers in Half Moon Bay just how much produce one ground squirrel could put away. *"He took a pick and shovel and dug out a hole of this little animal and in its storeroom found over a half of a grain sack of horse beans, besides a great deal of different kinds of grain."*[97]

Apparently over the decades, the campaigns to eradicate ground squirrels had some success in the Pescadero area. When asked about ground squirrels, Ron Duarte noted that the County Trapper's efforts seem to have been the most successful:

> *"Gus Cinoni, one of the finest bird shots around, he spent his whole life as a depredation hunter. The last ground squirrels—he had them literally exterminated from San Mateo County, except, he told me himself, over by Stanford where San Mateo County and Santa Clara County met. Santa Clara County didn't have a depredation hunter for ground squirrels. They kept coming over* [into San Mateo County]. *He said 'I couldn't get them all.' The last ones that I saw was just in front of the high school where that ridge road goes up."*[98]

RECENT TRENDS IN AGRICULTURE

According to San Mateo County Agriculture Commissioner Gail Raabe, the number of harvested acres in the County devoted to vegetable farming has dropped from 3,020 acres in 1996 to 2,504 in 2001. Artichoke acreage has dropped 68 per cent over the same period. Meanwhile, the indoor floral and nursery industry has become the top agricultural dollar producer in the County.

95 *Redwood City Times and Gazette*, September 16, 1876.
96 *Half Moon Bay Review*, July 21, 1917.
97 *Half Moon Bay Review*, January 3, 1920.
98 Interview, Ron Duarte, November 14, 2002, p. 16.

County farmers attribute the decline in acreage devoted to farming to a number of causes, including new residents unwilling to tolerate the noise and disruption of nearby farming, government regulations, an increasing number of acres being put into open space preserve, and depredation by wildlife (wild pigs and deer) coming out of those preserves to damage their crops.

B.J. Burns, a farmer living and working east of Pescadero, is devoted to overcoming the above obstacles and allow farming to continue in the County. *"If we don't do something soon, agriculture will have a short life in this County."*[99]

POSTWAR PESCADERO

One of the most important long-range effects of World War II on Pescadero was that many members of the Japanese-American community did not return. Ron Duarte noted, *"There were a lot of Japanese here before the war and only a few came back.*"[100] Tom Kuwahara's family was one of the few to return, and he remembered it being very difficult for persons of Japanese ancestry in postwar Pescadero.

An anonymous respondent noted that the postwar straw flower industry was actually begun in the late 1930s by members of the Morimoto family. Following the war there was a boom in straw flowers that lasted into the 1970s. The respondent's family grew straw flowers for 45 years.[101]

Several of the interviewees spent their boyhood years in Pescadero roaming the creeks and marshes, fishing, hunting and boating. Though none of them was a trained scientist, their anecdotes and observations offer an invaluable window to the day to day and season to season life of the creek, the marsh and its human and wildlife inhabitants. Using local terms and names for things, they helped us reconstruct a rich and diverse landscape.

FISHING IN RECENT YEARS

Sport fishing was one of the primary sources of income for Pescadero. As noted earlier, the town filled with summer visitors from the San Francisco Bay Area who fanned out in all directions in pursuit of trout. Locals such as Ron Duarte and Ed Weeks had the further benefit of being able to fish the local streams all year long.

Many of the place names used by locals—Round Hill, Spring Bridge, The Blue Gums—became part of a code to protect their favorite fishing spots from being found by outsiders. Ron Duarte said that they did that so *"others wouldn't know what the hell you were talking about.... They didn't know where you were fishing."*

99 "Withering Away," in the *San Francisco Chronicle,* April 18, 2003.
100 Interview, Ron Duarte, November 14, 2002, p. 15.
101 Interview, An Anonymous Respondent, September 19, 2003, p. 3.

They fished pretty much all year long, with steelhead fishing in the lower reaches of the creek giving way to trout fishing in the upper Pescadero, Butano and Gazos, and then moving back down to the lagoon as they (and the fish) awaited the winter flows that would breach the sandbar and allow the steelhead and salmon to enter the Pescadero to start the cycle over again.

> *"There used to be damn good fishing. Pescadero Creek had a nice run of steelhead. The biggest one I ever caught locally is thirteen and a half pounds, in the San Gregorio. But, I caught many from ten to eleven pounds and some twelve* [in the Pescadero.] *In a year like this, and the mouth of the creek was open and the lagoon was the way it used to be, there would be the tidal action and you would always want to fish for steelhead on an incoming tide. You could get an early shot at it because the creek was a little murky—a little muddy."*

> *"As soon as the new fish would come in they were just all over the place. Then they would get acclimated and come upstream. You would wait for another little storm to come up or if the creek didn't come up a little bit, they would go up. That is when they would usually spawn in the lower reaches. If you got a creek half full of water, or three-quarters full, they would go clear to Portola State Park or Memorial Park, clear upstream."*

Ron Duarte remembers watching the steelhead spawn at Camp Spalding:

> *"There were deep holes and a nice riffle. That is what it takes—a log jam, a nice hold for them to lay in and then when they weren't disturbed or anything like that, they would go down and spawn. The males would try to keep the grilt away. They would come and rob a few eggs and [the male steelhead] would chase them and come back. It was fun to watch. The eel bothered them, too. Fresh water eel, the ones with holes—slimy. In fact when we would go to school in the morning, if there was an eel down there, he would rattle rocks off 'the works' [the spawning beds] so he could get the eggs. We would drop a rock on him. They would come back when we were gone."*[102]

Several local fishermen remembered the grilt. Martin McCormick:

> *"A grilt follows the spawning fish just to chow down on the eggs. That has always been my perception. My dad always called them grilt and it is just a juvenile salmon...They can be good-sized. They can be a couple of pounds—18 to 20 inches long. They come up and they go back down again."*[103]

Ron Duarte also remembered the grilt:

> *"As far as I am concerned, all winter long, your trout are hatched. When the water warms up, approximately in April, and all the streams recede, the fish work back down and go to the marsh. They will stay in there in July, August, June—really not sure. They would go out into the ocean and they would come back into the stream where they were hatched from. They were what you would call half-pounders. They are beautiful trout to eat because the meat was going from white to pink. I always think it is the best eating trout in the world. After they come in awhile, they turn red, just like the steelhead. [Once they turned red] they weren't desirable at all. They weren't worth a damn."*

[102] Interview, Ron Duarte, November 14, 2002, pp. 3-4.
[103] Interview, Marty McCormick, December 2, 2002, pp. 10-11.

> *"These [grilt] were steelheads. In the Butano Creek, they always said because of the canyon and the roots, they would turn darker, redder faster. The Waddell the same thing."*[104]

Another local fish that all the kids used to fish for were crayfish, or, called locally "crawdads."

An old-timer told Ron Duarte that the French planted the crayfish in the local creeks:

> *"They were good to eat, but [his informant] didn't think they did the trout population any good. He said they would get the trout. I have seen [the crayfish] wave [their claws] at them. They would hibernate in the banks of the creeks in the winter.... The first bridge past Cloverdale Road, where that riprap is just up from the bridge, that used to be a big hole there. It was a good spot for them to hibernate."*[105]

Ed Weeks remembered the crayfish:

> *"We used to get the ones with claws, like crawfish. You could get them with bait on a string. You could catch them by the bucket full.*[106]

Dave Pederson fished for crayfish in the 1930s upstream in Pescadero Creek, near Wurr Road:

> *"In the 30s we kids could catch 50-60 crayfish a head over a few hours in Pescadero Creek. We cut up bacon for bait and caught them with nets."*[107]

Martin McCormick remembers the crayfish feeds:

> *"We used to have great crawfish feeds. They were plentiful. You could go out and bag forty to sixty crawfish in an hour or so. Boil them up and have a great feed, maybe a couple times during the summer and it never seem to put a dent* [in their population]*."*

McCormick believes that the storm of January 1982 marked the decline in the crayfish population in Butano Creek.

> *"I think when I noticed the crawfish start to fall off was after the '82 storms. I think the creek bed got really flushed out. A lot of the little protected areas—and this may also affect the trout population as well—were really flushed out. The gravel areas were silted in which makes less of a habitat [for the crayfish] I think."*[108]

A lot of local memories of fish in the creek include lamprey eels (Martin McCormick sent one home with a friend who kept it in his bathtub), and bullheads (sculpin). Martin McCormick remembers that bullheads were prevalent all the way to the Butano falls.

All informants agree that there were many more fish in the local streams than at present. Martin McCormick summed it up. When he and his friends would walk in Butano Creek, "*there would*

[104] Ron Duarte, Interview, November 14, 2002, p. 4.
[105] Ron Duarte, Interview, November 14, 2002, p. 5.
[106] Interview, Ed Weeks, November 7, 2002, p. 5.
[107] Interview, Dave Pederson, conducted by Meg Delano, February 8, 1999.
[108] Interview, Martin McCormick, December 2, 2002, p. 10.

be these little pools of minnows that would be zipping all over the place. You just stepped in and they would zip around. Crawfish all over the place. It is not like that anymore."[109]

An anonymous interviewee agreed:

> *"Years ago the creeks were full of fish. You could swim in deep water. Now the holes are filled with silt."*[110]

THE FLOODS OF 1937, 1938, 1940 AND 1941

All of the manipulation resulting from the construction of Highway One was tested in an unusual series of rainfall events between 1937 and 1941. Over this five-year period there were four major flood events in the Pescadero watershed. All of them occurred in February: February 15, 1937; February 14-16, 1938; February 27, 1940; February 11, 1941.

The 1940 flood seems to be the most prominent pre-war flood in local memory. Over a 24-hour period from February 27 into February 28, 1940, Ben Lomond received an astonishing 11.57 inches of rain while Boulder Creek received 11.42 inches. A Santa Cruz newspaper briefly reported on the status of Pescadero:

> "*Pescadero Under Water: The 500 persons of Pescadero 50 miles south of San Francisco found half their town under water at the dawn of the wet gray day."*[111]

Despite the high floodwaters experienced throughout Central California, no one was killed in this event.

Ed Weeks singled out the 1940 event as one of the most serious in his memory. He said that the 1940 flood in Pescadero was deep enough to float a rowboat at the town flagpole that was located in the center of the town's main intersection. He remembers that the 1940 flood washed out at least three homes alongside the creek.[112]

THREE BIG FLOODS: 1955, 1982, AND 1998

Everyone living in the area during the last half of the 20th century has vivid memories of the three major flood events: December 1955; January 1982; February 1998.

THE CHRISTMASTIME FLOOD, 1955

As noted above, Martin McCormick's father, Graham McCormick, believed that the December 1955 flood was the first damaging flood in the twentieth century, and the damage was caused by the logging that had begun in the Butano Canyon above the Falls.

[109] Interview, Martin McCormick, December 2, 2002, p. 9.
[110] Interview, anonymous.
[111] *Santa Cruz Sentinel*, February 28, 1940.
[112] Interview, Ed Weeks, November 21, 2003, p. 1.

Ed Weeks awoke in the early morning of December 24th:

> *"Something woke me up around one. I looked out and saw my neighbor's wood floating down from across the street. So, we knew something was happening. Actually I went down town to help Earl Williamson remove some beer. I went in the building that is now the Made In Pescadero Shop. He was the beer distributor and several us helped him put it up on the dock so it would stay out of the water. I left my wife home here, alone. She was a little concerned when the water started gurgling in the bathroom, the toilet and the septic tank and all of that. The water didn't stay too high, maybe just for three hours. I imagine it was only, maybe, eight inches* [deep] *around the house."*[113]

Martin McCormick remembered the damage done in the Butano Canyon:

> *"All four bridges in our canyon—the one main one that splits the road on this side of the creek we call the Madrone Bridge today was out and all the other three bridges that serve a minor number of home sites were also out…There were trees down. I had never seen the water so high…Pescadero was all flooded. The street, all the land behind Duarte's, way out to the Pescadero Creek bridge—that was all under water. All the Level Lea was flooded."*[114]

The water reached as high as the floor of St. Anthony's church on North Street, on the north side of Pescadero Creek, as the author spent several days assisting in replacing the linoleum floor following the flood.

In response to the 1955 flood event, the Pescadero Road Bridge over Butano Creek was rebuilt, and the western end of Pescadero Road was built on fill around 1960.

THE FLOOD OF JANUARY 1982

All of those who had memories of the January 1982 event remembered the floodwater being somewhat higher than that of December 1955. An anonymous respondent said that it was a "*pretty good flood*" but that it didn't go into his house.

Martin McCormick noted that his family lost considerable land in Butano Canyon to the January 1982 flood. "*We lost major land. We lost probably about eight good sized redwood trees. They all fell right across the creek, narrowly missing a house across the creek….We lost probably fifteen to twenty-five feet of bank from the creek back along a hundred foot stretch of the bank."* All the Butano bridges went out again, though they weren't washed out completely: instead their ends slipped off of their abutments.[115]

Ed Weeks remembered the flood of January 1982 as being *"a little bit higher than* [1955] *and the one in 1998 was higher yet…I was working for the propane company* [in 1982] *and I had to use my wet suit that I had saved. I had a half dozen floor furnaces in town that were affected and had to all be cleaned out."*[116]

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[113] Interview, Ed Weeks, November 7, 2002, p. 6.
[114] Interview, Martin McCormick, December 2, 2002, p. 5.
[115] Interview, Martin McCormick, December 2, 2002, p. 5.
[116] Interview, Ed Weeks, November 7, 2002, p. 7.

THE FLOOD OF FEBRUARY 1998

Again our informants agreed that the water associated with the flood event of February 1998 was higher than 1982.

Ed Weeks:

> *"Then in 1998, it got higher yet, so more houses up North Street, and I guess down Pescadero Road coming into town by the Butano Bridge, had problems."*[117]

An anonymous respondent believed that the 1998 flood waters were about six inches higher than 1982. Following the 1998 event, one resident reporting having to raise his house eighteen inches.

The Butano Canyon again received a heavy blow from the 1998 event. Martin McCormick:

> "We lost the Madrone Bridge again in 1998. It is still not replaced."[118]

RECENT CHANGES IN THE PESCADERO-BUTANO AREA: YEAR-ROUND RESIDENCY

Perhaps the most important change in Pescadero and the surrounding countryside in recent years has been the increase in the number of year-round residents. For example, in the 1950s there were only two full-time residents in Butano Canyon, Mr. Hall, and Mrs. E.C. Lydon. As San Mateo County's population and housing costs increased, the seasonal housing in the Butano became increasingly attractive. Presently, Martin McCormick estimates that over fifty percent of the previously seasonal houses in the Butano are occupied full time.

Similarly, the housing all along Pescadero Creek has shifted from predominantly seasonal to full-time houses residents. The town of Pescadero itself, where in the 1960s there were numerous empty houses, is now feeling the pressure of new, year-round population.

The pressure that this new population places on infrastructure such as water systems, roads and sewers is considerable.

OPPORTUNITIES FOR FUTURE RESEARCH

This chapter has been intended to provide a broad chronology of the major events that have shaped the Pescadero-Butano watershed. The authors have done this through a combination of research in secondary sources, oral history covering the recent period, and research in primary sources for the earlier period. Fortunately, a parallel oral history program sponsored by the San Mateo County Resource Conservation District provided critical information, which would only be otherwise available through intensive primary research in modern records and archives. Given adequate time these records may provide data to address specific research questions.

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[117] Interview, Ed Weeks, November 7, 2002, p. 7.
[118] Interview, Martin McCormick, December 2, 2002, p. 5.

LOGGING IN THE WATERSHED

- field interviews with Bud and Lud McCrary, Big Creek Lumber founders, Information sources include **f**urther interviews, along with a review of the company's maps and files;
- Review of the San Mateo County lumber literature in their extensive files;
- Review of CDF files for Timber Harvest Plans in San Mateo County;
- Further Interviews with Martin McCormick;
- For the 1950s Butano logging, review Santa Cruz Lumber Company records in the Museum of Art and History archives, Santa Cruz, along with interviews with Ley Family members;
- Field interviews with employees of Red Tree Lumber;
- Review Butano State Park unit logs and histories;
- Review San Mateo County Memorial Park and Portola State Park unit histories and literature.

AGRICULTURE IN THE PESCADERO WATERSHED

- Review shipping records in the California Alta newspaper, 1850s, 1860s;
- Review literature and files in the University of California Ag Extension Office, San Mateo County'
- Review literature and files in the office of the Ag Commissioner;
- Review literature and files in the Agriculture Library, Shields Library, UC Davis;
- Review literature in San Mateo County Farm Bureau Office;
- Review files and loose materials at the San Mateo County Resource Conservation District, Half Moon Bay.

FLOODING EVENTS, PESCADERO CREEK WATERSHED

- Review contemporary newspapers, (San Mateo Times, etc.) for accounts of the events of 1937 - 1941. Newspapers on file in the San Mateo County Library, Redwood City.

- Air photo and map research, and oral history interviews to determine dates and extent of stream channel modifications, including channel straightening, levee construction, and channel relocation.

EARTHQUAKE EVENTS AND THE PESCADERO CREEK WATERSHED

Another area of possible study is the impact of the April 18, 1906 earthquake and the Loma Prieta Earthquake of October 17, 1989 on the watershed. There are lengthy reports following the 1906 event (including the Carnegie Commission Report) that might be reviewed to see what impact the earthquake had on the steep slopes in the canyons.

Some observers noted that following the 1989 earthquake there were numerous fresh landslides in the Santa Cruz Mountains. Dr. Gerald Weber conducted an extensive survey of the landslides in the upper Aptos Creek watershed in the Forest of Nisene Marks State Park following the Loma

Prieta earthquake. The earthquake revived numerous old landslide areas, dumping considerable debris into Aptos Creek. There may have been similar studies done in San Mateo County.

CHAPTER 4
ANALYSIS OF GAUGING RECORD

INTRODUCTION

This chapter presents an analysis of data gathered by the US Geological Survey (USGS) at their gauging station on Pescadero Creek. The gauging record, which is continuous for the past 50 years, represents the most complete and the lengthiest physical scientific data set for the watershed. In addition to measurements of stage height (water level) and discharge (water flow) taken at 15-minute intervals, the gauging record also includes periodic information on the configuration of the stream channel at the gauging station. Much of this information is summarized and made available to the public in electronic format at the USGS website.

This chapter includes two major elements: an analysis of the flood record on Pescadero Creek, from 1951 through 2001, and an analysis of changes in streambed elevation at the gauging station during this same time period. The flood record analysis, which includes flood magnitude and flood frequency, provides a basic view of the hydrology of the Pescadero Watershed, and by inference the Butano Creek Watershed as well.[1] Considerable space in this chapter is dedicated to the analysis of changes in streambed elevation at the gauging station. This analysis provides important clues to an understanding of how the Pescadero Creek channel responds to major rainfall and flood events, an understanding that is further developed in the following chapters.

The USGS gauging station, Pescadero Creek near Pescadero, is located at a bridge on Pescadero Road, 3.0 miles east of the town of Pescadero and 5.3 miles upstream of the mouth of Pescadero Creek. The station was established April 14, 1951. The gauge datum is 62.3 feet NGVD29. There are 45.9 square-miles (119 square kilometers) of watershed above the gauge. The low-water control for the gauge is a gravel riffle which varies in distance from the gauge and is subject to shifting. The high-water control is the channel. The gauge height of high flows shifts due to variations in the willows and other vegetation lining the channel (USGS, 1999). Figure 4-1 shows the channel cross section at the bridge in 1975. The cross section was taken from a San Mateo County Public Works Department drawing showing a proposed widening project (San Mateo County, various dates).

The reach upstream of the gauge is one of the sites (PES 100) discussed in the Stream Channel Assessment (Chapter 7) and in the Fisheries Habitat Assessment (Chapter 8). The sampled reach was 320 meters (1,050 feet) long and has a slope of 0.3%. The bankfull channel width is about 15 meters (50 feet). The channel above and below the gauge consists of alternating long sandy

1 The USGS Butano Creek gauging record is much shorter than the Pescadero Creek record, from 1962 until 1974.

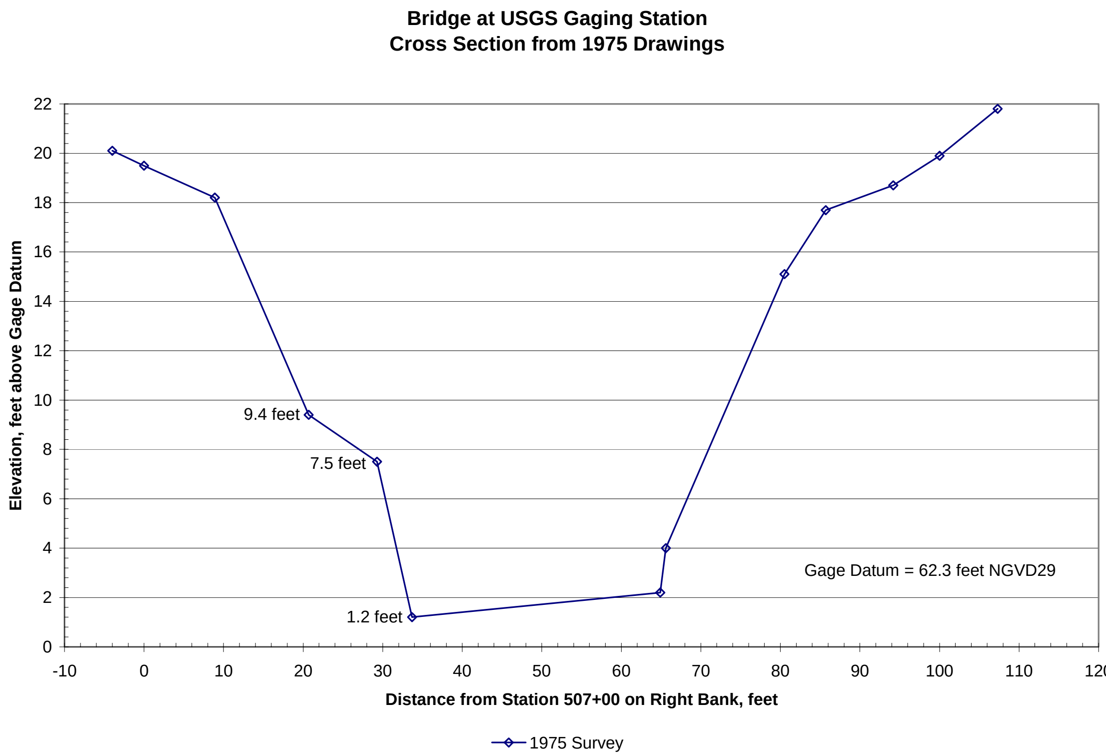

Figure 4-1: The above graph shows the channel cross section at the USGS gauge in 1975. The elevations shown on the graph have been converted into gauge heights. The elevation of the gauge datum is 62.3 feet.

reaches with coarse riffles. No bedrock is visible in the streambed. However, the 1975 drawing shows that the footings for the existing bridge abutments are anchored about 10 feet above the elevation of the streambed, indicating that the lower portions of the streambanks may be composed of bedrock. It is possible, therefore, that bedrock may be relatively close to the surface below the streambed. An additional search of the San Mateo Public Works files may yield boring logs made in the vicinity of the USGS gauge.

Figure 4-2 shows the channel looking downstream from the bridge. The low-water control riffle can be seen near the top of the photograph and is approximately 300 feet downstream of the bridge. The gauging pool is long and shallow and would probably be classified as a run by a fisheries biologist.

Figure 4-2: Photograph of Pescadero Creek just downstream of the USGS gauging station, taken from the Pescadero Road bridge.

FLOOD RECORD

The series of annual maximum instantaneous flood peaks (annual flood series) for the 1952 through the 2001 water-years is used in the following analysis[2]. Summary statistics for the annual flood series are shown in Table 4-1. The summary statistics for the annual flood series divided by its average (mean annual flood) flood and the statistics for the common log transformation of the peak discharges are also shown in Table 4-1. Table 4-2 gives the discharges estimated for various recurrence interval floods, based on the Log Pearson Type III probability distribution. Table 4-2 also shows the discharges for each return period as a ratio with the mean annual flood.

The annual flood series for the Pescadero Creek stream gauge was found to be random at the 1% level by both a runs test and a test for serial correlation using computer software developed for this purpose (McKuen, 1993). These tests are designed to detect a steady increase or decrease in the flood record. They show that there is no statistically significant change in the annual flood record for the Pescadero gauge.

2 For an earlier analysis of the Pescadero and Butano flood records, see Curry et al, 1985, pp. 56-62.

TABLE 4-1
SUMMARY STATISTICS FOR THE PESCADERO CREEK NEAR PESCADERO GAUGE MAXIMUM ANNUAL FLOOD SERIES

	Peaks	Peak/Mean	Log(Q)
Years	50	50	50
Max	10,600	3.59	4.025
Min	67	0.02	1.826
Mean	2,950	1.00	3.248
Median	2,225	0.75	3.347
Std Dev	2,660	0.90	0.514
Skew	1.207	1.21	-0.827
Coefficient of Variation	0.90	0.90	0.550

TABLE 4-2
THE RECURRENCE INTERVALS OF VARIOUS PROBABILITY FLOOD EVENTS ESTIMATED FROM THE LOG PEARSON TYPE III DISTRIBUTION

Probability	Recurrence Interval	Discharge cfs	Ratio of Discharge to Mean Annual Flood
66.7%	1.5	1,230	0.42
50.0%	2.0	2,080	0.70
37.3%	2.7	2,950	1.00
25.0%	4.0	4,170	1.41
20.0%	5.0	4,860	1.65
10.0%	10.0	6,980	2.37
4.0%	25.0	9,710	3.29
2.0%	50.0	11,700	3.96
1.0%	100.0	13,600	4.60

These tests do not, however, determine if the rainfall-runoff relationship has changed over time. Detecting a change in rainfall-runoff relationship for the Pescadero gauge is beyond the scope of this analysis. Such an analysis could be the subject of future research. The lack of a long-term (50 years) precipitation record for a location in the watershed would seem to be a significant problem in developing a test to determine if the rainfall-runoff relationship has changed significantly since the early 1950s.[3]

[3] For a brief analysis of nearby rain gauging records, see Curry et al, 1985, pp. 55-56. See also Ellen and Wieczorek, 1988.

The annual series for the San Lorenzo River at Big Trees was used to extend the Pescadero Creek flood record back to the 1937 water-year. The correlation between the Big Trees annual flood series and the Pescadero annual flood series is 0.92, indicating a high degree of relationship. Figure 4-3 shows the extended flood record for the Pescadero Creek gauge. The annual flood series is expressed as the ratio of the annual flood to the mean annual flood. Scaling the annual flood series by its mean allows the gauging record to represent any location in the watershed, and allows comparisons with the flood record of neighboring USGS stations.

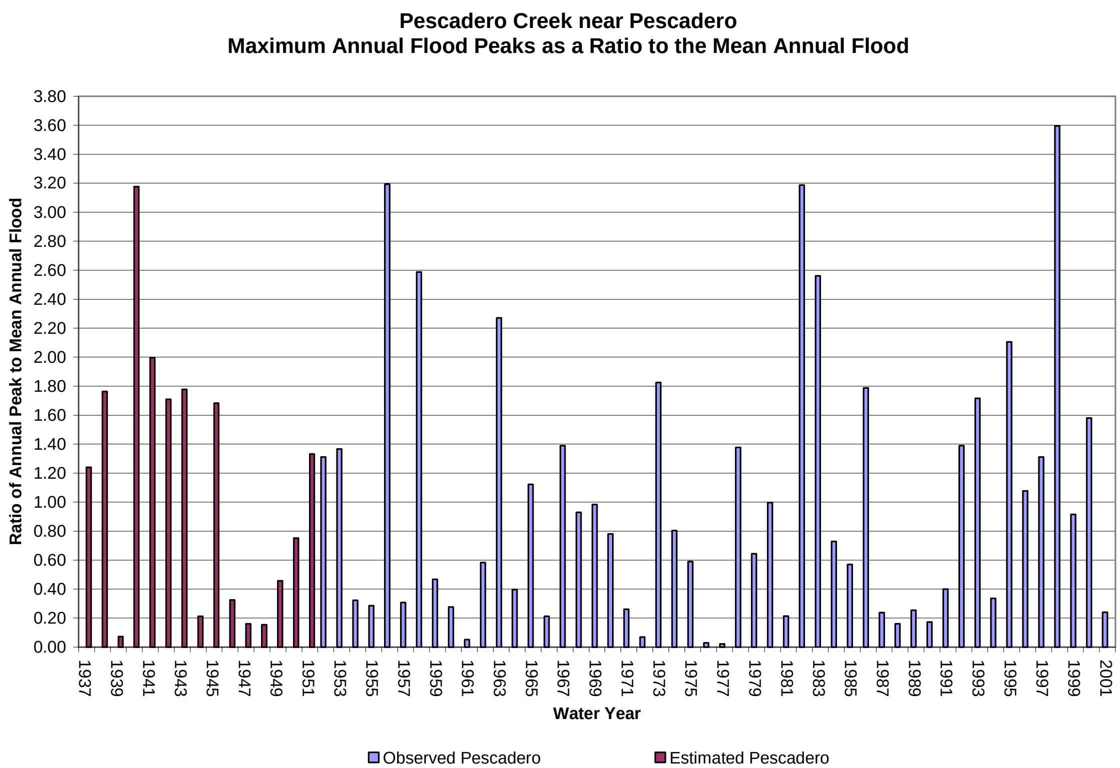

Figure 4-3: The annual maximum peak discharges for the USGS station, Pescadero Creek near Pescadero, are expressed as a ratio to the mean annual flood. Earlier peaks were estimated using the San Lorenzo River at Big Trees record.

The bench on the right bank of the cross section shown in Figure 4-1 might correspond to the bankfull event at the gauge. The bench lies between 7.5 and 9.4 feet gauge height. The bankfull discharge is usually considered to occur in the range between the 1.5-year return period discharge and the mean annual flood. The bankfull discharge is considered to be the discharge that shapes the channel, over the long run.

The 1.5-year discharge is estimated to be about 1,230 cfs, which has a gauge height of about 7.4 feet. The mean annual flood is 2,950 cfs, which has a return period of about 2.68 years on the Log Pearson Type III distribution. The gauge height of the mean annual flood is about 10.4 feet. The bench shown in Figure 4-1 therefore lies within the expected range. A discharge of about

2,300 cfs, with a 2.16-year return period, has a gauge height of about 9.8 feet, which is close to the elevation of the upper edge of the bench. We can surmise that the bankfull discharge is about 2,300 cfs, which is about 80% of the mean annual flood. Figure 4-4 shows the extended flood series with only the annual peak floods greater than the estimated bankfull discharge that is greater than 80% of the mean annual flood shown.

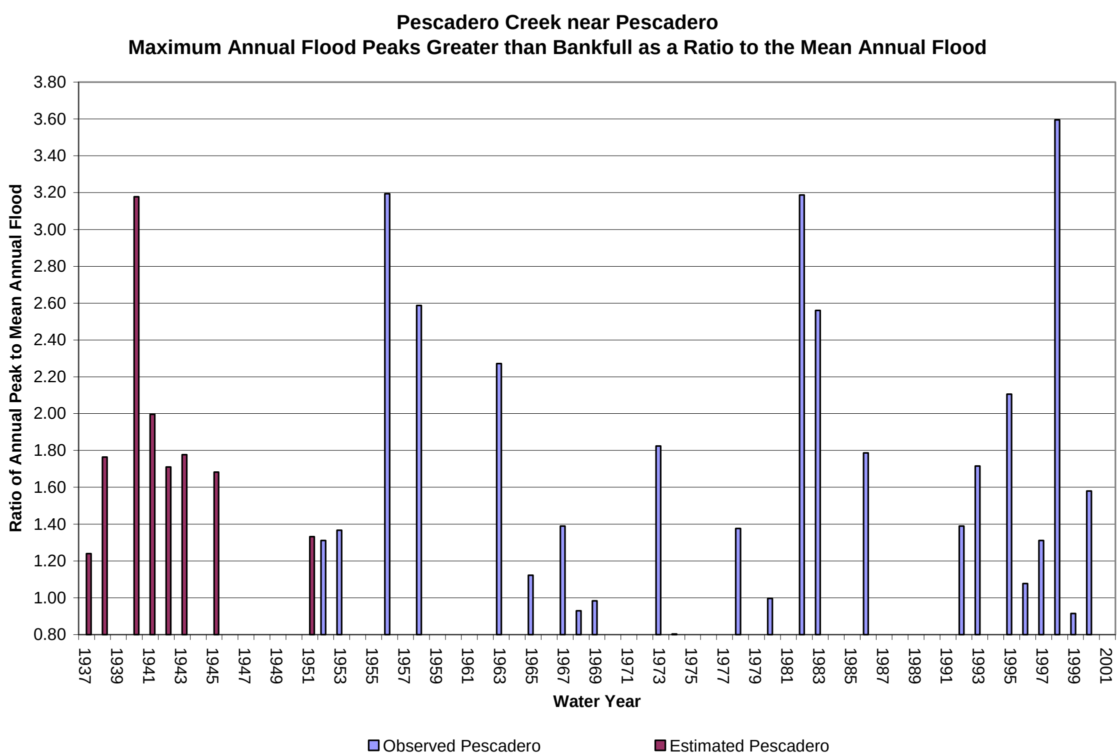

Figure 4-4: The annual flood series is shown with only the annual peaks larger than the estimated bankfull discharge of 0.8 times the mean annual flood.

CHANGES IN STREAMBED ELEVATION AT THE USGS GAUGE

Stream gauging data for 50 years of record will be used to develop a picture of how the elevation of the stream channel at the USGS gauge has changed over time. No other point in the stream channel network has a comparable record of changes in the stream channel.

Rating tables 23 through 30, which cover the period from 1986 to the present, were obtained from the USGS. Rating tables prior to 1986 have been sent to the federal archives and would take months to retrieve. The flow cessation point (zero discharge) for each rating table is shown in Figure 4-5. Changes in the elevation of the point of flow cessation reflect changes in the elevation of the control riffle for the gauge. The control riffle is the pool tail-crest of the gauging pool; it acts like a weir. Figure 4-5 reflects the changes in the elevation of the crest of the control

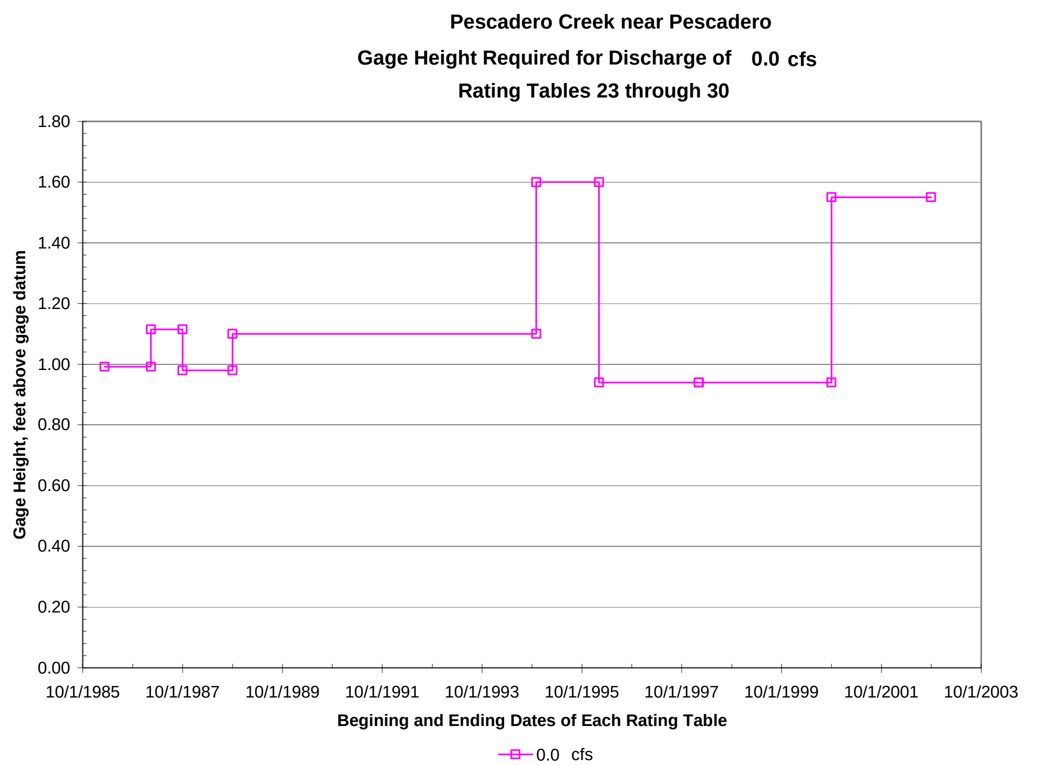

Figure 4-5: The above graph shows the gauge height for the flow cessation point for 1986 – 2002.

riffle over time. The elevation of the crest of the control riffle is taken as a surrogate of the streambed elevation. The USGS rating tables show that the point of flow cessation ranges from a gauge height of 0.94 feet to 1.60 feet between 1986 and 2002: there has been a total fluctuation of only 0.66 feet in the elevation of the control over this period.

A table of all the measurements made by the USGS at the Pescadero Creek gauge was downloaded from the Internet. This table was found to be missing the measurements taken between September 14, 1972 and August 18, 1987, a total of 175 missing measurements out of a total of 698. Figure 4-6 shows all 338 of the available discharge measurements less than 25 cfs in each decade from the 1950s through the 2000s.

Figure 4-7 shows only the discharge measurements made in the 1950s that were less than 25 cfs. Figure 4-7 shows that the flow cessation point in the 1950s varied from about 1.5 feet to about 3.5 feet. The gauging station was established in 1951. From first measurement up until October 25, 1955 the gauge height of the flow cessation point was less than 2.1 feet. The gauge height of the next measurement on November 23, 1955 increased enough to move it away from the original rating curve. The next five measurements made during the 1956 water-year are the measurements that are the furthest to the right on Figures 4-6 and 4-7. It appears that the elevation of the flow cessation point reached its maximum in the 1956 water-year. The maximum elevation of the flow cessation point appears to be between 3.0 and 3.5 feet.

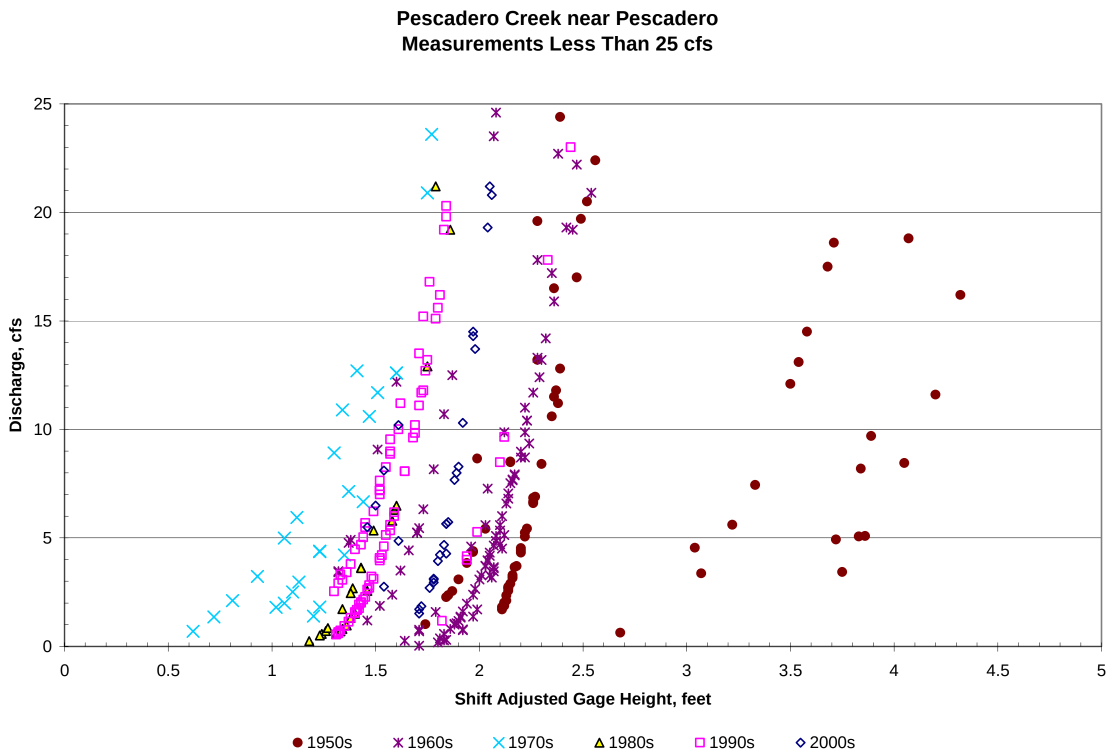

Figure 4-6: The discharge measurements less than 25 cfs for Pescadero Creek near Pescadero are shown above.

The range in the gauge height of the flow cessation point for each decade was visually estimated from individual graphs of the discharge measurements similar to Figure 4-7. This method is less accurate than reading the zero discharge gauge height from a rating table, but the rating tables prior to 1986 are not available. Figure 4-8 shows the resulting range of the gauge height of the point of zero flow by decade. The error of estimating the flow cessation point is probably not great enough to alter the general trend visible in Figure 4-8. Looking at the discharges by decade provides a convenient way to look for significant changes in the stage-discharge relationship. The large number of measurements missing from the summary posted on the Internet precludes a thorough analysis by storm event or other criteria. The measurements that are missing from the summary table on the Internet may be available in the federal archives, so an analysis of all the measurements could be the subject for future research.

The flow cessation point for the 1960s through 2000 range from about 0.5 to about 1.7 feet. Figure 4-7 indicates that the maximum elevation of the flow cessation point was between 3.0 and 3.5 feet during the 1956 water year which is about 1.5 feet higher than it was in later years.

The flow cessation point apparently dropped to its minimum value in the 1970s and then rose to its present range. However, measurements were available for only up to September 14, 1972, so it is possible that the flow cessation point had a greater range during the 1970s than indicated on

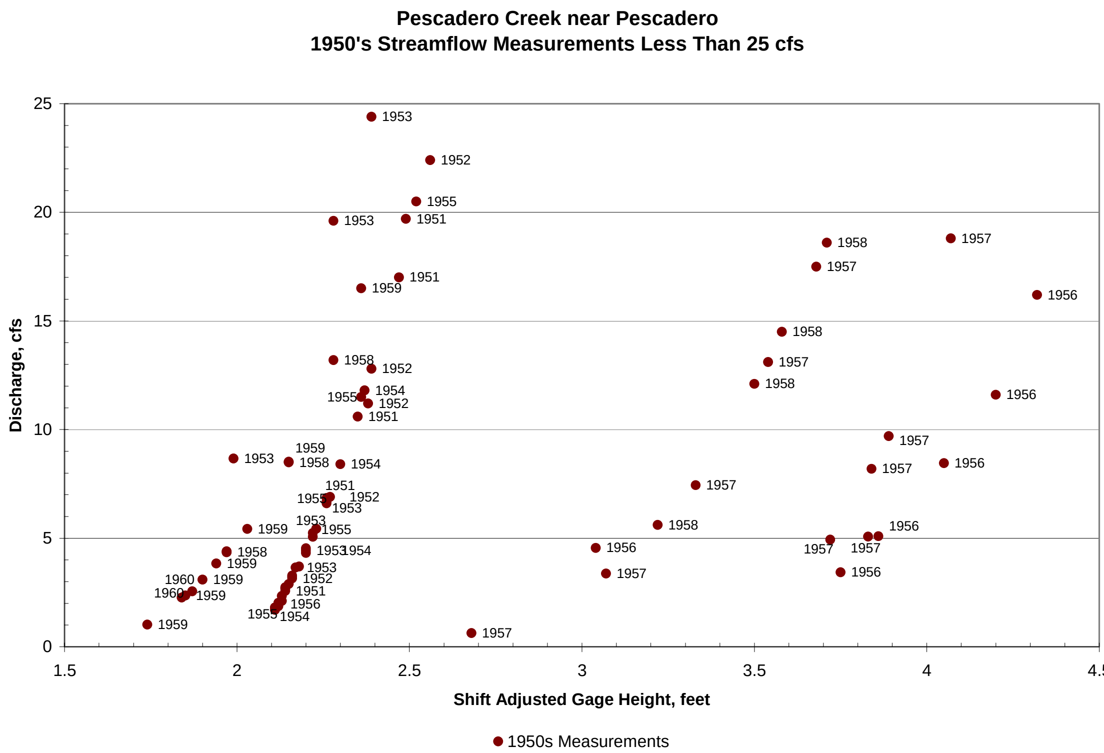

Figure 4-7: The discharge measurements less than 25 cfs for only the 1950s are shown above. The labels, adjacent to the data points, indicate the water-year of the measurement. Note that the gauge height scale begins at 1.5 and ends at 4.5 when comparing Figure 4-7 with Figure 4-6.

Figure 4-8. All four of the years during the 1970s with maximum annual floods greater than bankfull occurred after the last available measurement taken on September 14, 1972.

Figure 4-8 shows a small range in the elevation for the flow cessation point for the 1980s, but the first available discharge measurement for the 1980s was on August 18, 1987. The four years with discharges greater than bankfull that occurred in the 1980s were before August 18, 1987 measurement. Again, the actual range in the elevation of the flow cessation point was probably higher in the 1980s than is shown in Figure 4-8.

All of the streamflow measurements are available for the 1960s, 1990s, and for the beginning of the current decade. Despite the missing measurements in the 1970s and 1980s, Figure 4-8 clearly shows a lowering of the flow cessation point from the 1950s followed by a period that is relatively stable with minor fluctuations in the elevation of the flow cessation point.

Figure 4-8 suggests that a significant slug of sediment passed the location of the USGS gauge in the 1950s. The peak of this sediment slug was at the gauge in the 1956 water-year, immediately following the December 1955 flood with a discharge equal to 3.19 times the mean annual flood (see Figures 4-3 and 4-4).

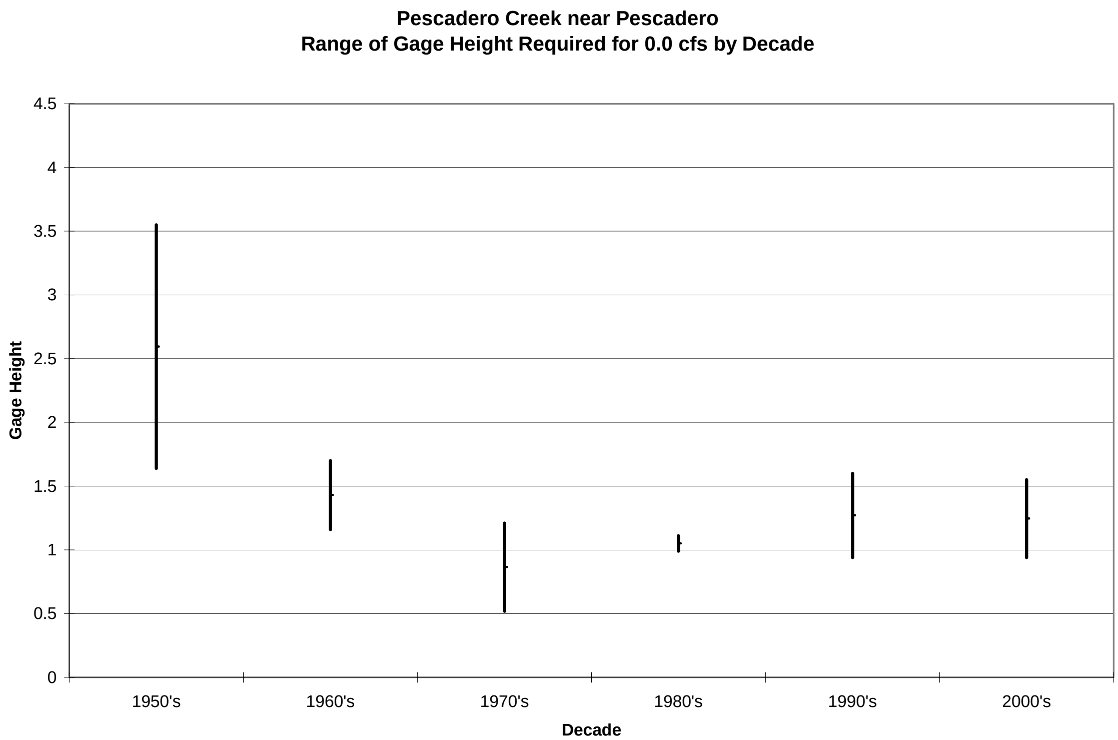

Figure 4-8: The range of the gauge height for the point of zero flow, by decade, is shown in the above graph.

INTERPRETATION

Heavy equipment such as bulldozers became widely available after the end of World War II in 1945. The availability of this heavy equipment and the post-war economic boom fostered a dramatic increase in logging in the Pescadero-Butano watershed. In addition, the heavy equipment was typically used without regard to the connection between disturbance of the forest and water quality.

The start of the post-war logging boom was accompanied by a relatively dry period. There were no bankfull discharge events during the 1946 through 1950 water-years (Figure 4-4). This drought was followed by three years with maximum annual peak discharges of about 1.34 times the mean annual flood, which has a return period of about 3.7 years. These three events probably introduced the first significant amount of sediment into the stream channel network after the beginning of the post-war economic boom. No bankfull discharges occurred during the 1954 and 1955 water-years. Then the December 1955 event occurred. It was measured as 3.19 times the mean annual flood, with a return period of 31.4 years.

The elevation of the flow cessation point jumped by about 1.5 feet within months of the December 1955 event. Chapter 6 of this report shows that the December 1955 event produced significant landslides in the watershed. During the 1957 water-year the elevation of the flow cessation point decreased by about one foot. It stayed at that level for a few months until the April 2, 1958 event of 7,630 cfs (2.59 times the mean annual flood with a return period of 13.9 years) lowered the flow cessation point below its 1951 elevation, when the station was established. The sediment wave therefore appears to have moved past the USGS gauge in about 2.25 years, and to have had an amplitude of about 1.5 feet. The April, 1958 event demonstrates that large events can erode the channel bed as well as aggrade the bed. A flood can also cause no change in the elevation of the bed, at a particular location along the channel network.

Only the floods of January 1982 and February 1998 were of similar magnitude to the December 1955 event. The missing streamflow measurements between September 14, 1972 and August 18, 1987, roughly a 15 year period, make it impossible to tell if there was an increase in the elevation of the flow cessation point associated with the 1982 flood event. The complete response cycle of the flow cessation point to the 1955 flood took only 2.25 years, so the period of missing data appears to be long enough to completely hide any response to the floods of 1982 and 1983.

Figures 4-5 and 4-8 show that the 1998 flood is not associated with a significant increase in the elevation of the point of cessation of flow.

Additional fine sediment probably is introduced into the channel network during years with less than bankfull discharge, though it is unlikely that significant amounts of coarse sediments are added to the channel network during these years. During the periods with no bankfull discharge, the coarser bed material is not moved on most streams. However, the geology of the Pescadero watershed is dominated by relatively low-density mudstone and sandstones. These relatively light rocks might be moved at discharges somewhat lower than the normal bankfull event, and there may be a limited re-working of the coarser bed material during the periods with discharges less than bankfull. Figure 4-4 shows that it is relatively common to have periods of up to five consecutive years without a bankfull discharge event.

Why was there no significant change in the elevation of the flow cessation point after the flood of 1998, the largest flood on record? There are several different factors whose interaction would determine the type of response. The following is a partial list of the factors that would determine the response of the flow cessation point to the flood. A list of likely factors includes the following:

- Amount, caliber, density and distribution of bed material upstream of the control riffle;
- Presence of a near surface bedrock layer at the control riffle;
- Presence of large woody debris to trap sediment;
- Overall channel slope and slope of the control riffle;
- Channel roughness;
- Duration of the flood event.

To understand how a flood may change the elevation of the flow cessation point it is important to keep in mind how flow past the gauging station occurs and how the USGS records discharge. A recording device tracks the elevation of the water surface above the gauge datum. The USGS determines discharge by periodically measuring the discharge and noting the height of the water surface above the arbitrarily chosen datum for the station. A statistical relationship between the discharge and gauge height (elevation of the water surface) is developed from the discharge measurements. The statistical relationship is used to develop a rating table which gives the discharge for any gauge height. The gauge datum is set so that the a zero gauge height is at or below the bottom of the gauging pool, which minimizes the chance for changes in the streambed to result in negative gauge heights.

At low flows, the gravel riffle at the tail of the gauging pool controls the relationship between gauge height and discharge. The flow cessation point is the crest of the low-flow control riffle. At some discharge, near or above the bankfull discharge, the control for the station probably shifts from the low-water gravel riffle to the general channel roughness downstream of the gauge. In large flood events, the overall character of the channel reach downstream of the station controls the relationship between gauge height and discharge.

Flood events may cause bedforms to migrate, which in turn can result in a change in the location of the gauging pool control. A shift of the control up or down the channel may have very little effect on the elevation of the water surface in the gauging pool for a given discharge. The elevation of the gauging pool control (flow cessation point) is what determines the water surface elevation in the gauging pool.

If a large amount of coarse material were located just upstream of the gauge at the start of a flood, it is reasonable to expect that the flood would move at least a portion of the material down to the low-flow control riffle, where it might be deposited. However, if the flood were of long duration, the deposited material could also be eroded.

If there were a deficit of coarse bed material upstream of the station, the low-flow control riffle might be eroded. Or, if there was a large deposit of fine bed material upstream, the flood might move the material quickly past the low-flow control riffle, which might result in no change to the control or even erosion of the control. Similarly, if the bed material upstream were of low density, such as the sandstone and mudstone rocks found in the Pescadero watershed, the material might also be quickly moved past the gauge.

A large woody debris dam downstream of the low-flow control riffle might cause deposition on the control if it were in the backwater area of the jam, or a thick growth of riparian vegetation on the sides of the channel banks might slow the flow sufficiently to encourage deposition on the low-flow control. A large woody debris jam and the growth of riparian vegetation are both examples of increased channel roughness. A debris jam can also decrease the channel slope upstream of the jam.

Previous floods may have eroded the channel downstream of the low-water channel. The associated increase in channel slope could induce erosion of the low-flow control riffle.

A bedrock layer just below the streambed could place a lower limit on the elevation of the low-flow control riffle. This is a possible explanation of why the elevation of the flow cessation point has not lowered any further than it has.

Channel morphology is controlled by water discharge, sediment discharge, woody debris load, bank composition, and other factors. Changes in land use have the potential to alter the water, sediment and woody debris loads, but would not change the geology underlying the channel bed or the composition of the banks, at least in a time span of decades. Statistical tests of the annual flood series for the Pescadero gauge show no systematic change in the magnitude of annual flood events. Therefore, changes in land use do not appear to have affected the flood record, but may have changed the sediment load or the woody debris load.

There has been a decrease in the amount of logging in recent years, compared to the post-World War II period. The passage of the Forest Practice Act in 1972 imposed regulations that were designed to decrease timber harvesting's impact on water quality. The decrease in sediment load to the stream channel network from timber harvesting would reduce the probability of an increase in elevation of the flow cessation point at the USGS gauge. The widespread practice of clearing large woody debris from channels in the 1960s, may also reduce the probability of an increase in elevation of the flow cessation point at the USGS gauge: removal of large woody debris would reduce channel roughness and possibly increase local channel slope.

The low density and fragile nature of the mudstone and sandstone rock units found in the Pescadero-Butano watershed appear to have a significant bearing on the amount of sediment stored in the channel network. The low density of the rock indicates that bedload movement would be expected to be initiated by smaller discharges than in watersheds with denser rock. In addition, the low density of the rock implies that a given discharge can transport larger sizes of material than the same discharge in a watershed with denser rock; the low density rocks may result in a higher bedload transport rate than in other watersheds with denser material. The fragile nature of the sandstone rocks leads to a rapid breakdown to smaller particle sizes which may result in a portion of the bedload being converted into suspended load. The expected higher bedload transport rate in the Pescadero watershed may result in less storage of sediment in the channel network.

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CHAPTER 5

RE-SURVEY OF BRIDGE CROSS SECTIONS

INTRODUCTION

Many of the San Mateo County road bridges over Pescadero and Butano Creek were replaced in the late 1950s or early 1960s when local, state, and federal governments were focused on improving the nation's highway system. Construction drawings made during the bridge replacement projects often include a detailed survey of the stream channel. Re-surveying the stream channel at the bridges provides a unique way of directly observing the net changes in the streambed that have occurred over the last 40 years, which provides insight into how the streams have responded to major floods (see Chapter 4) and changes in sediment input (see Chapter 6). This chapter presents the results of six cross section re-surveys conducted for this study at County road bridges on Pescadero and Butano Creeks.

BRIDGE SURVEY PROCEDURE

Cross sections were surveyed in the fall of 2003 at five bridges in the Pescadero watershed and one bridge in the Butano watershed. The surveyed cross sections were located so that they could be compared to cross sections taken from "as built" bridge construction drawings. Comparison of the two sets of cross sections gives some insight into the channel changes that have occurred since the bridges were built.

Figure 5-1 shows the locations of the bridges surveyed in the fall of 2003. Table 5-1 lists the bridges surveyed and summarizes the comparison of the bridge surveys.

Cross section surveys were taken by using a weighted tape to measure the distance from the bridge deck to the streambed. An automatic level and stadia rod were used to determine the elevation of the bridge deck. The distance from the bridge deck to the streambed was subtracted from the elevation of the bridge deck to obtain the elevation of the streambed.

The elevations at each end of the bridge deck along the centerline of the road, were obtained from the construction plans for each bridge. The elevations of these points were assumed to be essentially the same as when the bridge was constructed. However, the elevations of these points may have changed slightly since the bridge was built due to maintenance activities such as road re-surfacing or centerline painting. The assumed centerline elevations at each end of the bridge deck were used to establish the elevation for the bridge survey.

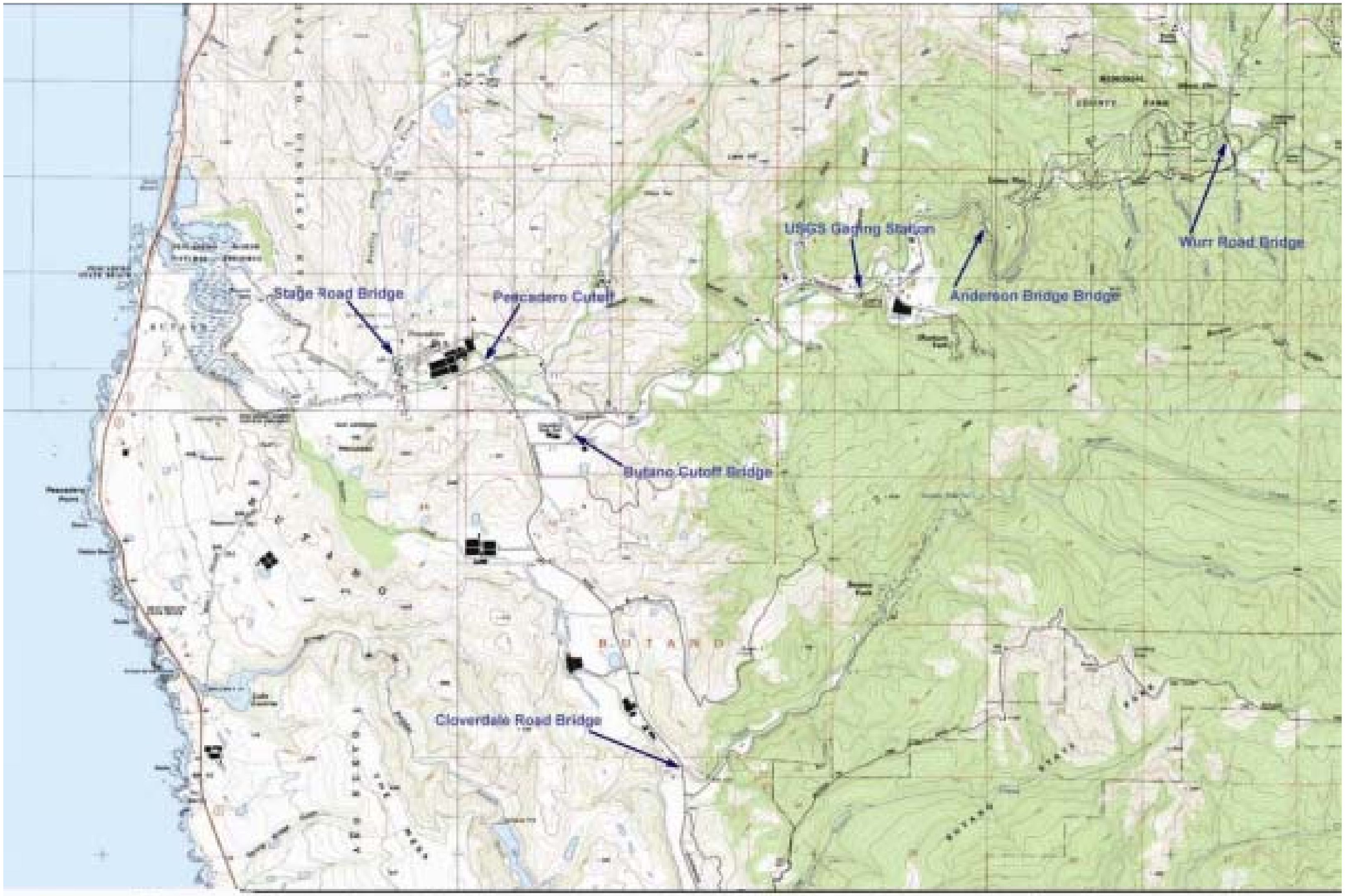

Figure 1. Location of bridges surveyed for the Pescadero watershed assessment.

Scale: 1 inch equals 4000 feet

TABLE 5-1
SUMMARY OF THE BRIDGE SURVEY COMPARISON

Pescadero Creek Bridges	River Mile	Mean Stream bed Elevation[1] feet	Watershed Area Above Bridge sq-mi	Slope Class at Bridge	Year Built	Channel Modified during Construction	Change in Thalweg Elevation	Change in Profile Elevation	Net Scour or Deposition
Stage Road Bridge	2.41	10	53.9	0-0.5	1961	Cut Both Banks	-0.2	1.5	Mixed
Pescadero Cutoff Bridge	3.32	20	53.4	0-0.5	1957	Cut Right Bank	-0.9	-0.2	Mixed
Butano Cutoff Bridge	4.1	30	50.4	0-0.5	1963	Cut Right Bank	-1.6	N/A	Slight Scour
USGS Gaging Station	6.83	63.5	45.9	0-0.5	1937	N/A	N/A	N/A	N/A
Anderson Bridge	8.51	97	44.4	0.5-1.5	1937	No	-1.1	N/A	Slight Scour
Wurr Road Bridge	12.06	173	41.2	0-0.5	1961	No	-0.9	N/A	Mixed
Butano Creek									
Cloverdale Road Bridge	6.11	90	12.5	0-0.5	1962	Channel Moved	-4.7	N/A	Significant Scour

The Change in thalweg elevation for Stage Road and Pescadero Cutoff is the average over their respective profiles, excluding the upstream portion of the profiles that may be a response to the channel modification during bridge construction. Note that in the column labeled *Net Scour or Deposition*, "Mixed" indicates that both scour and deposition occurred on the cross section, "Slight Scour" indicates that scour was apparent across the entire bottom of the cross section, but the net change in elevation less than -2 feet; "Significant Scour" indicates that scour occurred across the entire bottom of the cross section, and that the net change in elevation was greater than 4 feet.

[1] Mean streambed elevation from construction drawings.

At the Stage Road bridge over Pescadero Creek, a national Geodetic Survey benchmark, H-1240, dated 1972, was found on the southwest end of the bridge. The bridge deck was surveyed as described above by using the centerline elevation at the south end of the bridge as the reference elevation. The benchmark H-1240 was then surveyed. This procedure assigned an elevation of 33.59 feet NGVD to the benchmark. The published elevation for benchmark H-1240 is 33.43 feet NGVD, a difference of 0.16 feet. This check indicates that the error in elevation in the survey is on the order of 0.2 feet, which is acceptable for the determination of whether there has been a significant trend of aggradation or degradation of the streambed at the bridges.

Profile surveys were also performed at the Stage Road and Pescadero Cutoff bridges. The elevations along the profiles and cross sections were taken using an automatic level and stadia rod. The construction surveys are laid out using a centerline with cross sections at right-angles to the centerline. The thalweg profile was not surveyed during the bridge replacement projects and so was not surveyed in 2003. The cross sections for these two bridges were some distance away from the bridges. No unusual conditions, such as grade control structures or significant debris jams on the bridge piers, were observed during the 2003 survey.

The construction drawings for four of the six bridges show the high water surface elevation from either the 1955 flood or the 1937 flood. All four of the drawings show that the high water surface of the noted large event was below the level of the bridge deck. Drawings for the Cloverdale Road bridge over Butano Creek and for the Butano Cutoff bridge over Pescadero Creek did not show the high water mark from previous storms. Presumably this is because these two bridges were built at locations away from the original bridge site.

The location of the profile line used in the survey to plan the bridge construction was determined from the construction plans. The points where the profile line intersected the upstream and downstream side of each bridge were estimated. A weighted tape was lowered at each of these points and was used to locate the position of a stake driven into the streambed. The tape was then used to measure the distance from the bridge deck to the top of the stake. The automatic level was used to determine the elevation of the bridge deck above each stake in the streambed. The elevation of each stake was determined by subtracting the distance from the bridge deck to the top of the stake.

The stakes driven into the streambed were assumed to be on or close to the profile line indicated on the construction plan for the bridge. A tape measure was strung between the two stakes and carried downstream (or upstream) so that the end of the tape was in a straight line with the two stakes. The location of the center of the bridge on the stream profile line was noted on the construction drawings. This distance was used to adjust the 2003 survey profile tape readings.

The construction drawings show the pre-construction streambed and lines indicating the cuts to be made to the streambed. Typically, the post-construction streambed has a trapezoidal cross section. In some cases, only one bank was shaped and the other left alone. In other cases both banks and streambed were shaped.

DISCUSSION OF THE BRIDGE SURVEYS

STAGE ROAD BRIDGE

The present bridge over Pescadero Creek on Stage Road was built in 1961. The new bridge replaced a narrower bridge. The new bridge was placed at a slight angle to the original bridge alignment. Two piers were placed in the streambed. The piers were placed at a 63 degree angle to the centerline of the bridge. Pescadero Creek is shown as flowing sub-parallel to the piers and making a jog towards the right bank near the center of the bridge.

A profile centerline is shown running from upstream of the bridge at Station 0+10 to a Station 1+95 downstream of the bridge. The centerline is exactly parallel to the bridge piers. The center of the bridge was at Station 1+00 on the profile centerline. The profile centerline crossed the upstream face of the bridge at approximately Station 0+76 and the downstream face at approximately Station 1+20

The construction diagram shows that channel widening was to begin at Station 0+10 and extend down to Station 1+95. A 30 degree turn towards the west was to be initiated at Station 1+55. Upstream of Station 0+10 the distance between the 10-foot contour lines is about 10 feet. The construction diagrams show that the channel bottom reached a maximum width of 40 feet between the 10-foot contour lines, at Station 0+89.

The construction drawings show that the left bank was cut to a trapezoidal shape at Station 0+25. Both banks were cut to a trapezoidal cross section from Station 0+51 to Station 0+64. From Station 0+89 to 1+35, fill was placed on the right bank to obtain the trapezoidal cross section. Minor cuts were made at Station 1+55 to obtain the trapezoidal shape. All of the cross sections show a dead-flat bottom with an elevation of 10 feet NGVD. The pre-construction Pescadero Creek is shown flowing between the 10-foot contour lines, implying that the bottom of the stream was lower than the 10 feet NGVD as shown on the 1961 cross sections.

The 2003 survey found that there had been significant lateral migration of the low-flow channel upstream of Station 0+51. The low-flow channel has moved towards the right bank and there has been significant deposition on the left bank, the inside bank of a turn. The cross section at Station 0+25 was re-surveyed in 2003. The graph of the cross section (Figure 5-2) shows that the channel has apparently migrated about 40 feet towards the right bank.

The lateral migration of the channel upstream of Station 0+51 may be the result of the channel modifications associated with the 1961 bridge replacement. It is also possible that the channel migration is the result of other processes. Determination of the cause of the apparent channel migration was not within the scope of work for this project. However, no matter what the cause of the apparent channel migration, it is likely that loss of material from the right bank is probably approximately equal to the deposition along the left bank. Therefore, the lateral movement of the channel may not represent a significant change in the amount of alluvial material stored in the channel banks.

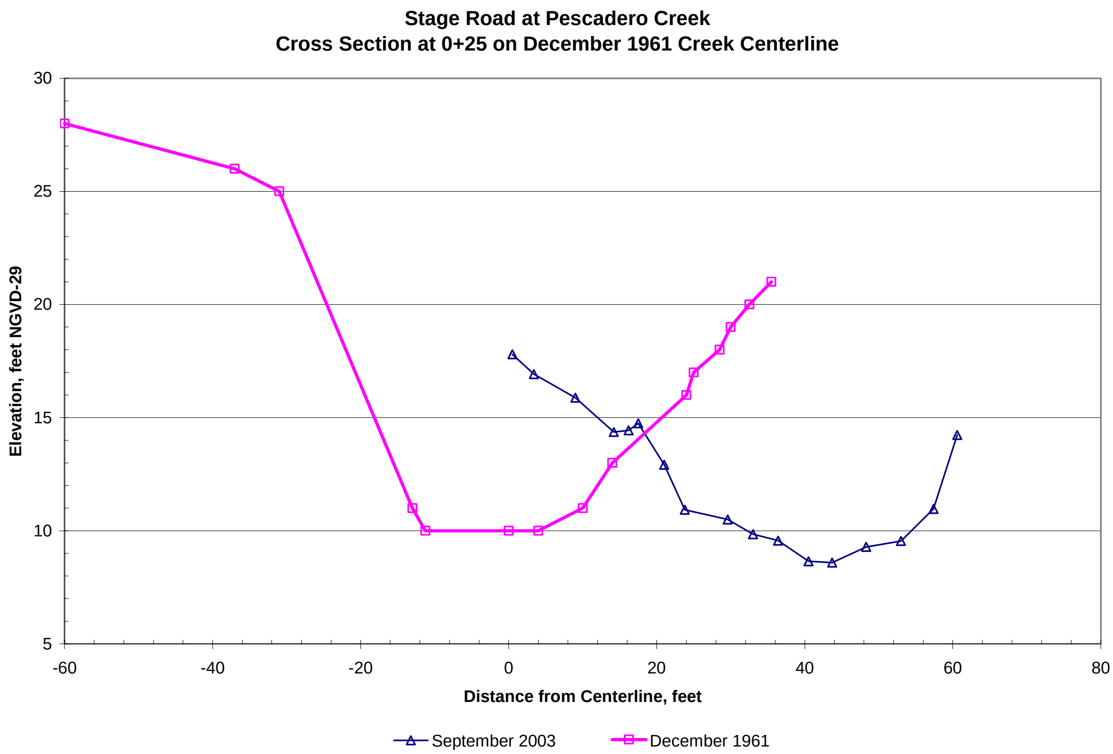

Figure 5-2: The graph of the cross section at Station 0+25 shows the apparent channel migration upstream of the Stage Road Bridge over Pescadero Creek.

The thalweg at Station 0+25 dropped -1.4 feet over the 42 years since 1961. A drop of -1.4 feet is within the range of change that might be observed between any two consecutive years, based on our experience with repeated surveys of streams in Mendocino and Sonoma counties. The drop in thalweg at Station 0+25 does not therefore indicate a trend of streambed scour upstream of the Stage Road Bridge. Of course, knowing the thalweg elevation at the beginning and ending point of a 42-year period does not reveal what happened during the intervening years.

The centerline rose about 7.8 feet between the surveys. The increase in the centerline elevation was the result of the apparent channel migration and is not considered indicative of significant deposition at Station 0+25 since an equal amount of material appears to have been eroded from the right bank.

Figure 5-3 shows the thalweg and centerline profiles along Pescadero Creek under the Stage Road Bridge. The average change in thalweg elevation from Station 0+51 to 1+55 was -0.2 feet. The maximum change in thalweg elevation downstream of Station 0+51 was about -1.0 feet. The centerline elevation downstream of Station 0+51 increased about +1.5 feet, on average. The maximum increase in centerline elevation was about +2.5 feet. The average drop in the thalweg and the average rise in the centerline are within the normal range of expected year-to-year change. In addition, the majority of the observed change may be the result of the stream

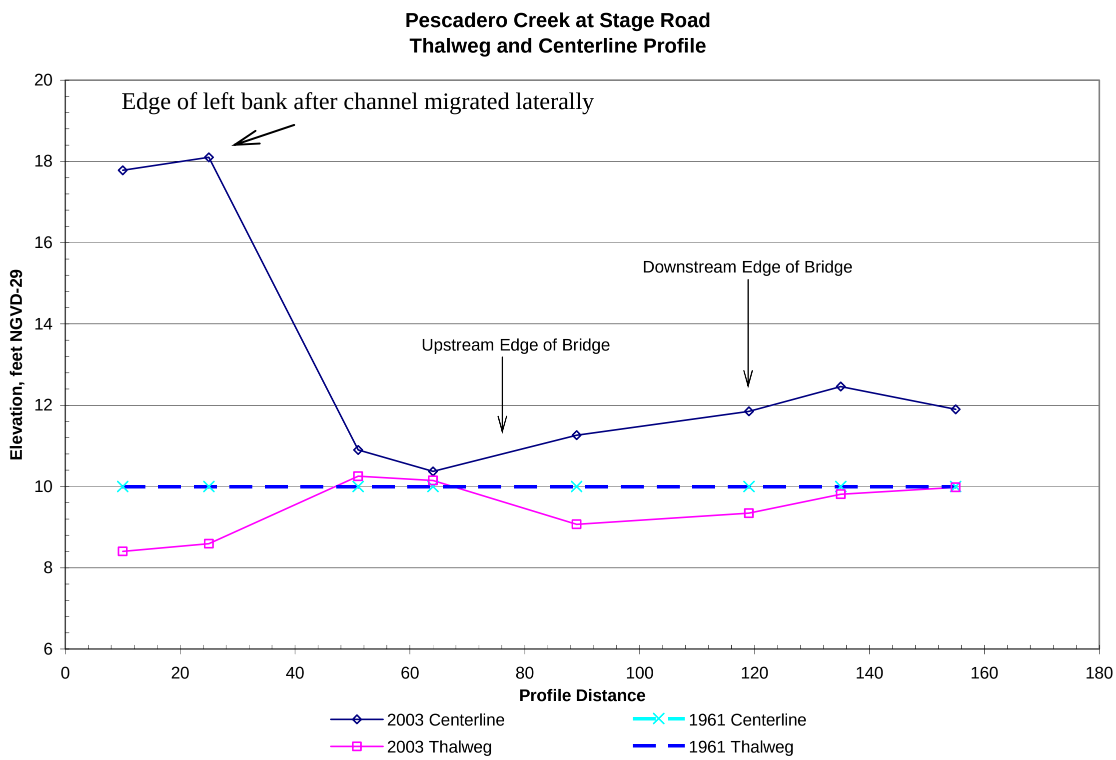

Figure 5-3: The graph shows the change in the centerline and thalweg profiles of Pescadero Creek under the Stage Road Bridge.

responding to creation of a trapezoidal channel with a dead-flat bottom at the time the bridge was constructed. A low gravel bar next to the thalweg is the typical configuration seen in the low-flow portion of Central Coastal California stream channels.

Boring logs from prior to the bridge construction are also available for the Stage Road Bridge. A total of 13 boring logs were made. Nine of the boring logs were made in holes in the lower portion of the channel. The elevation of the streambed at the boring locations ranged from 9.5 to 11.4 feet NGVD. The bottom of the post-construction channel was specified to be 10 feet NGVD. All nine of these boring logs show a layer of sand and gravel at the surface. The thickness of the sand and gravel layer ranges from 4.4 feet to 13.5 feet with an average thickness of 9.0 feet. The borings upstream of the bridge centerline tend to have a thicker surface layer of sand and gravel. The presence of a surface layer of sand and gravel that is between 4.4 feet and 13.5 feet thick shows that scour at the Stage Road Bridge was not limited by the presence of a surface bedrock layer.

Most of the channel changes revealed by the comparison of the 1961 and 2003 surveys appear to be in response to the creation of a wider channel with a dead-flat bottom. The evidence from the 2003 survey indicates that no significant net change in the elevation of the Pescadero Creek streambed at Stage Road has occurred, excluding the changes related to the apparent channel migration upstream of the bridge.

PESCADERO CUTOFF BRIDGE

The Pescadero Cutoff Bridge over Pescadero Creek is located near the intersection of Cloverdale Road and Pescadero Road. The bridge was built in 1958. Figure 5-4 shows the bridge in relationship to the stream channel, and shows that a significant channel modification was made when the bridge was constructed.

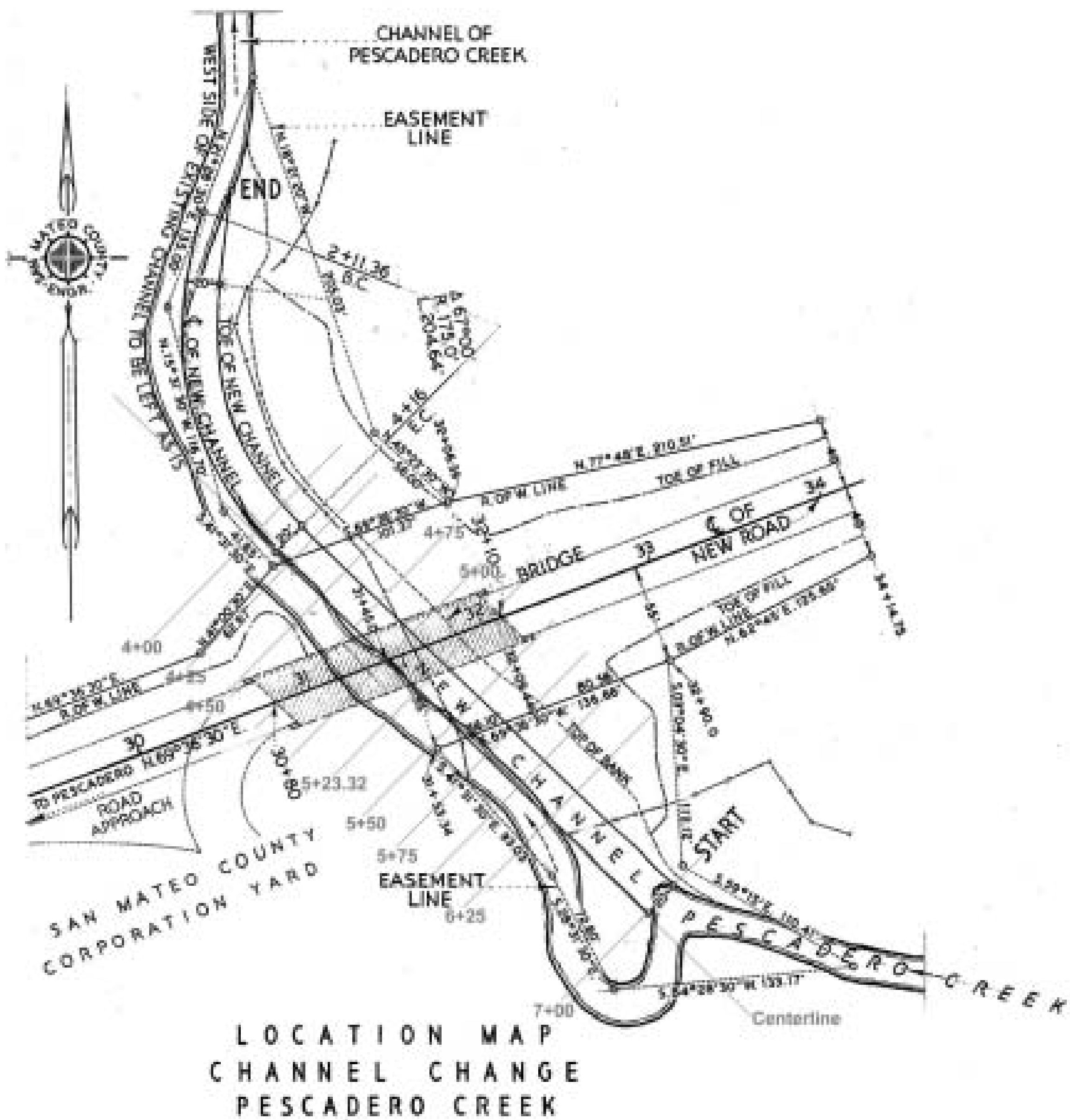

Figure 5-4: The channel change map for the Pescadero Cutoff Bridge is shown above. The flow is from the bottom of the page towards the top. The creek stationing and centerline were added by the author based on the stationing shown for the 175 foot radius turn north (downstream) of the bridge.

The 1957 survey shown on the construction drawings shows the centerline of the new channel. The channel centerline intersected the bridge centerline at Station 5+00. The channel modification started about 200 feet upstream of the bridge centerline at Station 7+00 and extended about 300 feet downstream of the bridge centerline to about Station 2+00. The main purpose of the channel modification was to double the bottom width of the channel, from about 20 feet to about 40 feet. Most of the additional bottom width was created by excavating the right bank (Figure 5-4).

Upstream of station 6+25, the original channel wrapped around a bend on the right bank. The construction drawings show what might have been a flood overflow channel. A portion of the higher discharges would have left the main channel at Station 7+00 and rejoined the main channel just upstream of Station 6+25.

The material above the May 1957 waterline was removed from the inside of the bend between stations 6+25 and 7+25. The excavation resulted in a 100 foot long reach with a bottom width from 55 feet to 83 feet. The point of maximum width of the modified channel was four times as wide as the original channel. Significant deposition would be expected to occur in this region.

The 1957 profile centerline was resurveyed from Station 6+00 downstream to Station 4+00 in September 2003. The 2003 profile (Figure 5-5) shows that a vegetated gravel bar upstream of the bridge extends down to about Station 5+75. The low-flow portion of the 2003 channel is in the new channel excavated from the right bank in 1957.

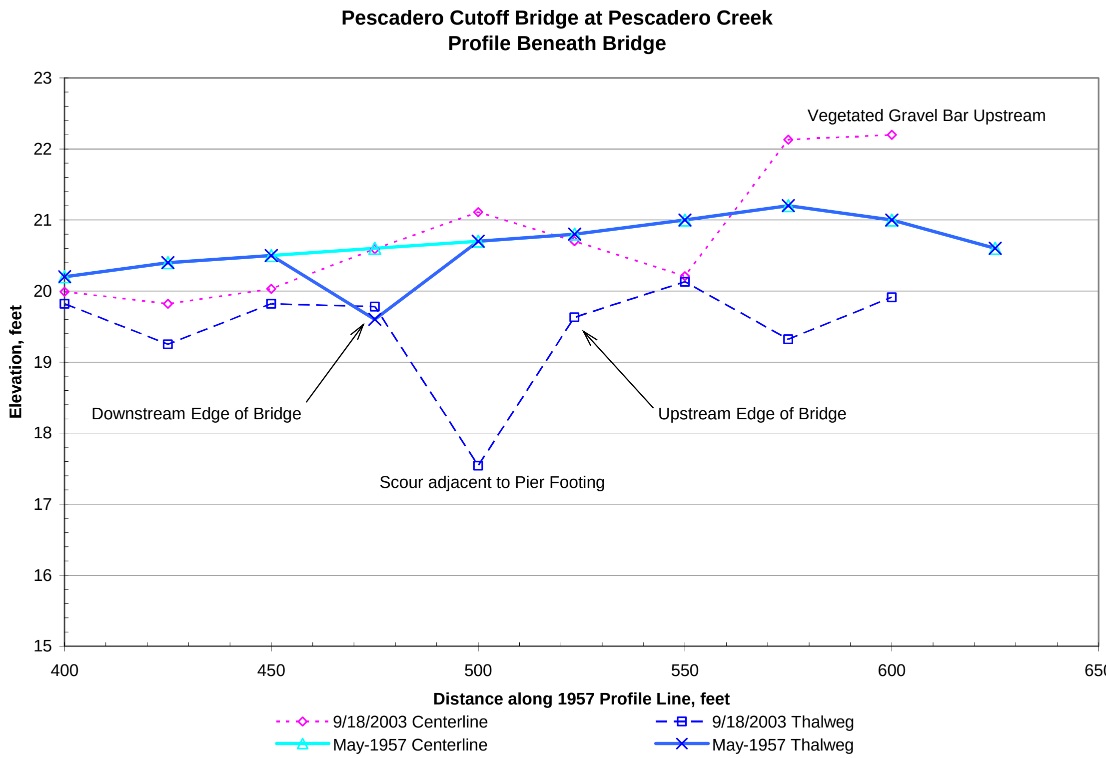

Figure 5-5: The comparison between the 1957 profile and the 2003 profile is shown.

The 2003 low-flow channel is against the right bank upstream of Station 5+50 where it crosses to the left bank. The low-flow channel is against the western bridge pier. The scour at Station 5+00 adjacent to the bridge pier has lowered the thalweg from 2.0 to 2.2 feet lower than the thalweg upstream or downstream of the pier (Figure 5-5). Excluding the bridge scour, the average change in thalweg elevation was -0.9 feet from 1957 to 2003.

Upstream of the bridge, the centerline runs along the vegetated gravel bar. Since this portion of the channel was graded flat and made very wide, it is not surprising to see an increase in the elevation of the centerline, indicating that deposition occurred (Figure 5-5). The changes along the centerline upstream of the bridge are probably the result of the 1957 channel modifications and are not the result of system-wide trends in sediment transport.

Figure 5-5 shows that the elevation of the centerline increased slightly (a maximum of +0.4 feet) under the bridge between 1957 and 2003. Downstream of the bridge the centerline elevation decreased since 1957. Excluding the vegetated bar upstream of the bridge, the centerline elevation declined an average of -0.25 feet since 1957.

The channel cross section at Station 4+00 downstream of the bridge was also re-surveyed in 2003 (Figure 5-6). After the channel was modified in 1957, it was trapezoidal in shape and had a dead-flat bottom that was 40 feet wide, which is twice as wide as the pre-modification channel. The 2003 survey shows a small gravel bar attached to the left bank. The gravel bar, at the cross section, was about 15 feet wide and about 1.6 feet high. The low-flow channel is now about 21 feet wide. The bottom of the right bank appears to be about 2 feet closer to the channel centerline than shown on the 1957 drawings. The deposition at the sides of the channel may be in response to the over-widening of the channel bottom in 1957. The cross section thalweg elevation has lowered -0.4 feet and the elevation at the centerline elevation lowered about -0.2 feet compared to the 1957 elevation.

The changes in the thalweg and centerline elevations, at cross section 4+00, are well within the expected annual change seen in repeated surveys of channel cross sections in other coastal California streams. The average decline in the profile thalweg elevation of -0.9 feet and the average decline in the centerline elevation of -0.25 are both well within the range of annual change. The deposition on the side of cross section 4+00, and upstream of the bridge appears to be in response to the 1957 channel widening. Therefore, it is reasonable to conclude that there has been no net difference in the 1957 streambed elevation and the 2003 streambed elevation at the Pescadero Cutoff Bridge.

BUTANO CUTOFF BRIDGE

The Butano Cutoff Bridge was moved about 250 feet downstream in 1963. The channel modification with the construction of the new bridge appears to have been limited to a 180 foot reach, starting about 100 feet upstream of the bridge, at Station 1+00, and extending about 80 feet downstream, to Station 2+80. The channel modification appears to be limited to cutting a 2:1 slope on the right bank. The construction drawings show that the bottom of the channel was widened between a total of about 6 to 10 feet starting from the centerline of the bridge at Station 2+00 and extending downstream to Station 2+60.

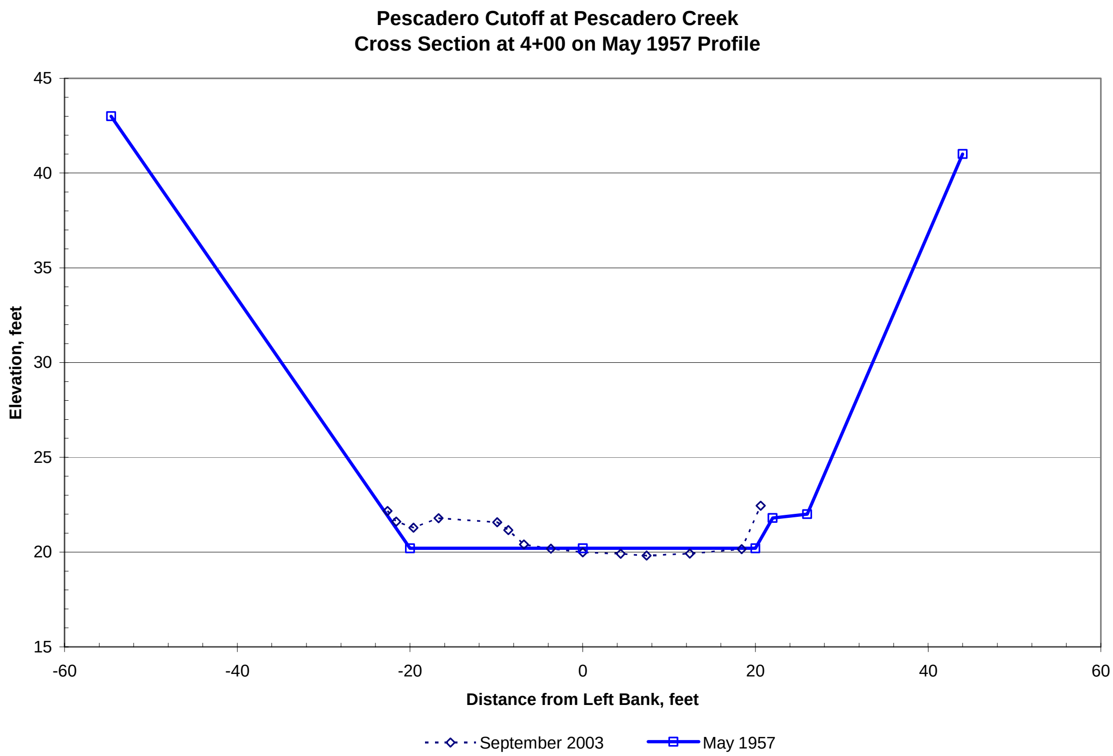

Figure 5-6: The comparison between the 1957 and 2003 surveys at station 4+00 is shown above.

In September 2003, a cross section was surveyed along the downstream face of the bridge. The 2003 survey is at approximately Station 2+17 on the 1963 stream survey centerline. A cross section was surveyed at Station 2+20 in 1963, or 3 feet downstream of the 2003 cross section. An offset of 3 feet from the 1963 cross section was deemed to be acceptable for the purpose of the 2003 survey.

Figure 5-7 compares the 2003 survey at the downstream face of the bridge to the 1963 cross section at Station 2+20. Figure 5-7 shows that there is a bench on the right bank, the top of which is similar to the original 1963 ground surface. Therefore, it appears that the right bank was not modified to the extent as shown on the 1963 construction drawings. The 2003 survey found a concrete lined drainage ditch running across the top of the bench. The presence of the concrete drainage ditch supports the idea that the right bank was not modified as much as the construction drawings suggest. Therefore, it appears reasonable to conclude that the modified right bank in 1963 closely matched the right bank shown in the 2003 survey.

The 2003 thalweg is -1.6 feet lower than the 1963 thalweg. The 2003 centerline is -1.8 feet lower than the 1963 centerline. The observed changes are large but still within the annual range of elevation change for a coastal California stream. However, since the entire bottom of the channel appears to be lower in 2003 than it was in 1963, this suggests that there may be a slight tendency towards scour at the Butano Cutoff Bridge.

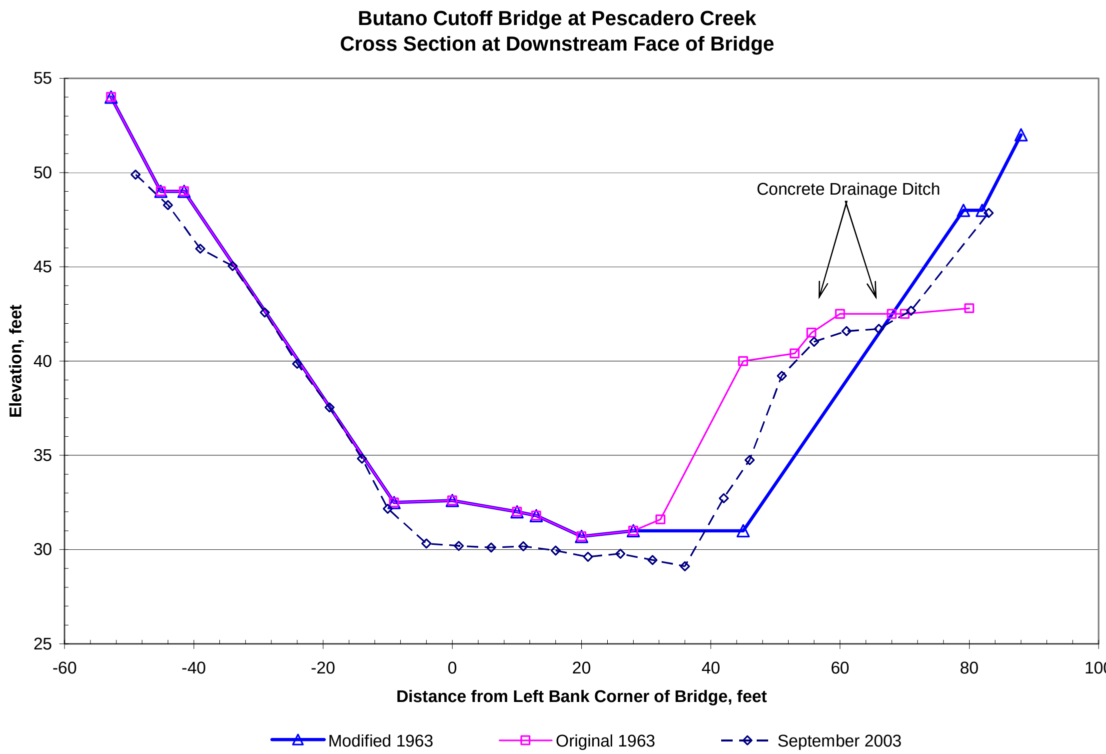

Figure 5-7: The comparison between the 1963 survey of the cross section at Station 2+20 and the 2003 survey alongside of the downstream bridge face at about Station 2+17 is shown. The 2003 cross section is about 3 feet upstream of the 1963 cross section. The original 1963 ground surface appears to be close to matching the top of the bench on the right bank suggesting that the right bank was not modified as much as suggested by the construction drawings.

BRIDGE AT USGS STREAM GAGE

See the Analysis of Streambed Elevation at the USGS Stream Gage report.

ANDERSON BRIDGE

The Anderson Bridge is in the canyon between the USGS stream gage and the community of Loma Mar. The channel bed is dominated by boulders and sand and there appears to be only a small amount of gravel on the bed visible from the bridge.

The bridge was built in 1937. Construction drawings and a survey were prepared in 1986 for a replacement project that was never carried out. There are also two *as-built* construction drawings from original bridge construction. These two drawings were revised on January 20, 1938. One of the revised drawings shows drawings of cross sections at the upstream face, downstream face and centerline of the bridge. Points on the channel cross sections at the upstream and downstream bridge face were scaled from the 1938 drawings. The 1938 drawing used to scale the channel cross sections does not show the riprap shown on the as-built drawings from 1938. Therefore, it seems likely that the 1937 cross sections may represent the channel before the bridge construction.

The 1986 survey also includes cross sections at the upstream and downstream face of the bridge. The survey notes for the 1986 channel cross sections at the bridge were available, so there is no error from scaling points on the drawing.

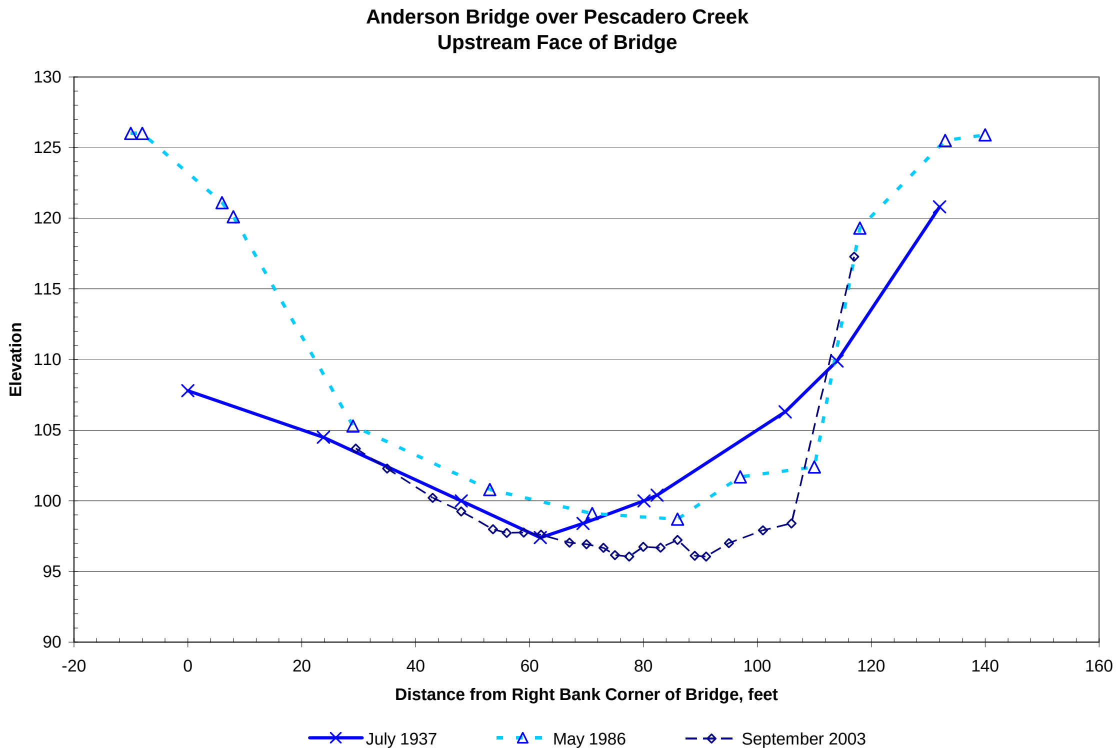

Figure 5-8: The comparison of the 1937, 1986 and 2003 cross section surveys for the upstream bridge face are shown above.

Cross sections along the upstream and downstream bridge face were taken in October 2003 by lowering a weighted tape from the bridge deck and using an automatic level to determine the elevation of the bridge deck.

An *as-built* drawing from 1938 indicates that both banks were armored with rip-rap when the bridge was built. The rip-rap is protecting the slope below the bridge abutment and is behind the bridge piers on both banks. The left bank of the channel at the bridge is on the outside of a bend, which causes more of the force of flood flows to be directed at the left bank. The pier in front of the riprap adds to the turbulence of the water, which increases its erosive force as it makes the turn. Therefore, some scour is expected to be found on the left bank.

Figures 5-8 and 5-9 show the cross sections from 1937, 1986 and 2003 for the upstream and downstream bridge face, respectively. In these figures, the horizontal distance is measured from the right bank of the channel.

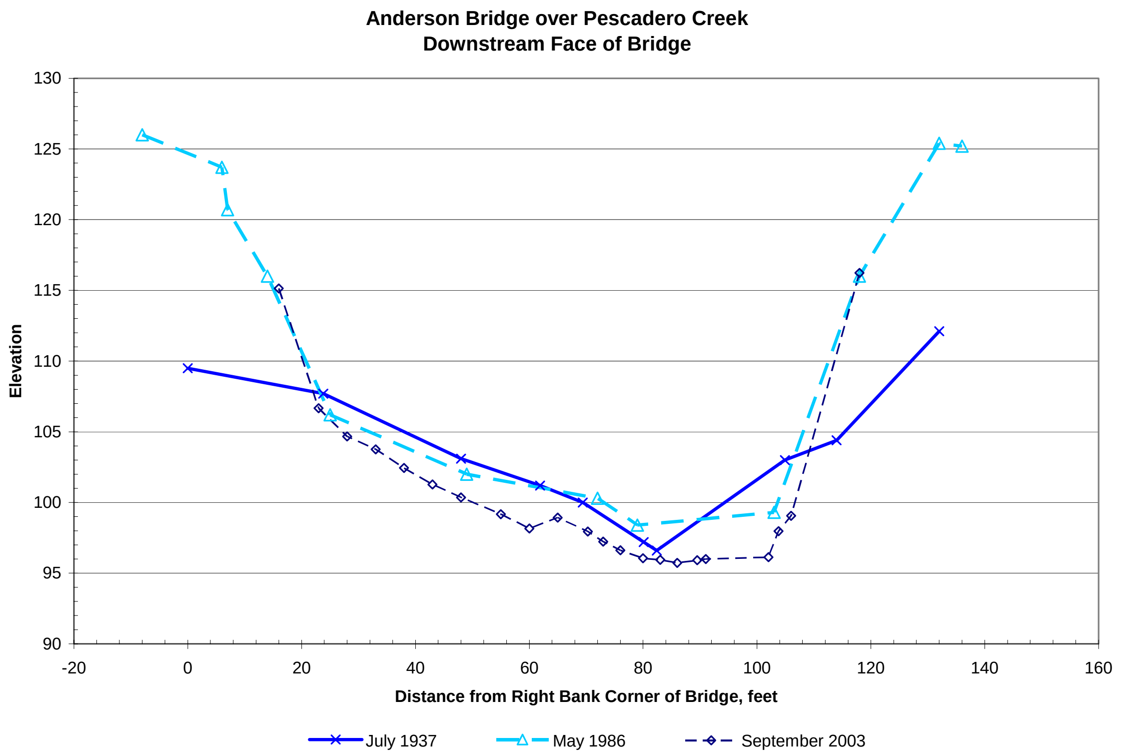

Figure 5-9: The comparison of the 1937, 1986 and 2003 cross section surveys for the downstream bridge face are shown above.

Since the 1937 cross section probably represents the pre-construction channel, no quantitative estimate was made of the average scour or deposition between 1937 and 1986. The elevation of the 1937 thalweg was probably not significantly altered by the bridge construction. The thalweg of the upstream cross section was 1.3 feet higher in 1986 than it was in 2003.

Figure 5-8 shows that between 1986 and 2003 the elevation of the entire streambed lowered between 29 feet and 106 feet on the cross section. The average depth of scour over the 77 feet of channel was about -2.7 feet.

Table 5-2 shows the upstream thalweg elevation at the time of each survey and the change in thalweg elevation between surveys for the upstream cross section. Between 1937 and 1986, the thalweg rose 1.3 feet. Between 1986 and 2003 the thalweg dropped -2.6 feet. The October 2003 water surface was found to be -0.7 feet lower than the 1986 thalweg. The entire wetted channel in 2003 was below the bottom of the 1986 wetted channel.

Figure 5-9 shows that the entire streambed at the downstream face of the bridge lowered between 1986 and 2003. The average scour, measured over a horizontal distance of about 79 feet, was -2.2 feet. The October 2003 water surface was lower than the 1986 thalweg (Figure 5-9 and Table 5-3), so the entire wetted channel in October 2003 was below the elevation of the bottom of the streambed in 1986.

TABLE 5-2
CHANGE IN THALWEG ELEVATION FOR THE UPSTREAM CROSS SECTION AT THE ANDERSON BRIDGE OVER PESCADERO CREEK

Survey	Thalweg Elevation feet	Thalweg Change feet	Overall Change feet
1937	97.4		
1986	98.7	1.3	
2003	96.05	-2.6	-1.3

TABLE 5-3
CHANGE IN THALWEG ELEVATION FOR THE DOWNSTREAM CROSS SECTION AT THE ANDERSON BRIDGE OVER PESCADERO CREEK

Survey	Thalweg Elevation feet	Change feet	Overall Change feet
1937	96.6		
1986	98.4	1.8	
2003	95.7	-2.7	-0.9

There appears to be a definite scouring of the channel at the Anderson Bridge between June 1986 and October 2003. The June 1986 survey occurred after a moderate flood in February 1986. There were no bankfull discharges from 1987 through 1991. In the ten years from 1992 through 2001, eight of the years had maximum annual discharges greater than bankfull. Moreover, 1998 had the largest flood on record. Therefore, the scour observed at the Anderson Bridge appears to be result of the many discharges greater than bankfull that occurred during the 1990s.

WURR ROAD BRIDGE

The bridge on the east end of Wurr Road was replaced in 1961. The western boundary of Memorial Park cuts through the northeast corner of the bridge. McCormick Creek enters Pescadero Creek on the right bank a short distance upstream of the bridge.

A channel cross section along the upstream face of the bridge was surveyed in October 2003. The horizontal start of the survey was the northeast corner of the bridge, on the right bank. The corresponding cross section was scaled from a 1961 contour map with two-foot contour intervals. The exact elevation of the streambed in 1961 is unknown. The construction drawings show that the thalweg runs between the 174 foot contour line along both banks. A road centerline cross section of the channel from 1961 shows the bottom of the creek to be essentially flat and is labeled +/- 173 feet.

Test borings were done under the bridge in April 1961. The borings were done downstream of the channel cross section shown in Figure 5-10. The boring logs give the approximate elevation of the top of the sandstone and shale bedrock, which are shown in Figure 5-10. The boring log drawing uses an arbitrary elevation datum. The B4 test hole was drilled in the streambed between the 174 foot contour lines. The boring log drawing shows the elevation at the top of the test hole as 66.2 feet and the water surface above the top of the test hole as 68.0 feet. Adding 106.8 feet to the elevations shown on the boring drawing sets the elevation of the top of B4 to 173 feet, the elevation of the streambed shown on a different drawing. The estimates of the elevations shown on the boring drawing are therefore probably within a foot of the true values.

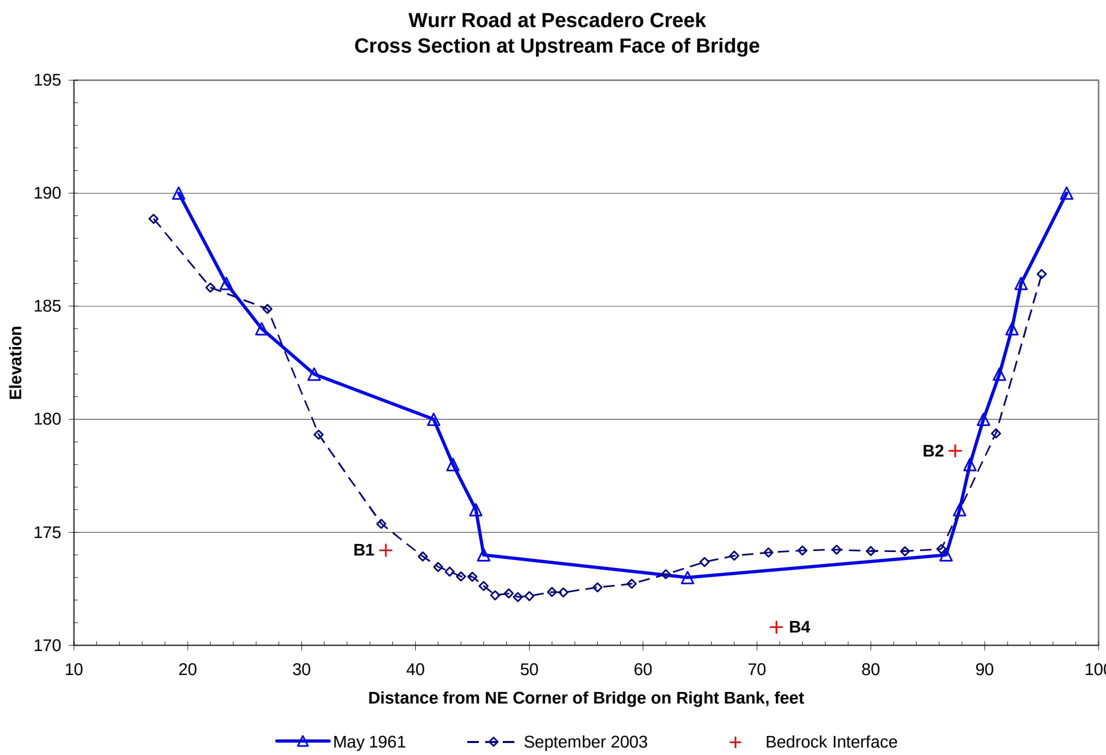

Figure 5-10: The comparison of the 1961 and 2003 channel cross sections for the upstream edge of the Wurr Road Bridge is shown above. The horizontal distance is from the right bank. The points labeled B1, B2, and B4 are the elevation of the top of bedrock shown on the boring logs. All the borings were done downstream of the cross section.

The elevation of the top of bore hole B1 is estimated to be 177.5 feet NGVD. The B1 hole was drilled about 8 feet downstream of the cross section shown in Figure 5-10. The ground surface elevation at the projected location of B1 on the 1961 cross section is over 180 feet. To investigate the apparent 2.5 foot discrepancy in elevation at bore hole B1, Photoshop software was used to overlay the location of the boreholes on the contour map used to create the 1961 cross section. The composite drawing also showed the elevation of the top of bore hole B1 to be greater than 180 feet. In addition, the elevation at the top of test hole B4 was assumed to be 173 feet. This assumption results in the elevation of the April 1961 water surface being equal to 174.8 feet, which is just 0.8 feet higher than the October 2003 water surface. The April 1961 water surface therefore appears to be reasonable, though the accuracy of the 1961 contour map on the right bank appears to be questionable.

Figure 5-10 shows an apparent significant loss of material from the right bank between 1961 and 2003. However, the contour map, from which the cross section was made, appears to be in error on the right bank, as noted above. The top of bore hole B1 was at 177.5 feet, in 1961. Figure 5-10 shows that the 2003 ground surface near B1 was about 175 feet. This indicates that about 2.5 feet of material may have been lost from the region around B1. In addition, the contour map may be based on pre-construction survey data and so may not reflect the shape of the right bank after construction. Therefore, the available data does not support an analysis of change on the right bank.

The 2003 thalweg is about -0.9 feet lower than the 1961 thalweg. The thalweg appears to have shifted from near the center of the channel to the right bank. A low gravel bar now extends from the left bank to about the center of the channel. The gravel bar is about 1.25 feet higher than the approximate elevation of the streambed in 1961. Both the scour of the thalweg and the deposition on the gravel bar are within the expected range of annual variation. Therefore, no trend in streambed elevation is apparent at the Wurr Road Bridge.

CLOVERDALE ROAD BRIDGE OVER BUTANO CREEK

A bridge over Butano Creek was built for Cloverdale Road in 1963. The creek was moved to a straight trapezoidal channel during bridge construction. The new channel was 350 feet long and had a two foot drop, resulting in a slope of 0.0057. The new trapezoidal channel had a bottom width of 20 feet and side-slopes of 1.5 to 1. The elevation of the bottom of the new trapezoidal channel was estimated to be 94.4 feet at the upstream face of the new bridge based on the channel slope and distance from the beginning of the channel change. Figure 5-11 shows the estimated 1963 channel cross section and the channel cross section surveyed in September 2003.

The 2003 thalweg is -4.7 feet lower than the estimated 1963 thalweg. The channel bottom has been uniformly eroded. Sackcrete has been placed on the sides of the banks below the bridge to protect the banks. The sackcrete is not shown on the 1963 drawings from San Mateo County.

The amount of scour from the bed of Butano Creek at Cloverdale Road is far more than would be expected from the adjustment of the creek to being moved to a new trapezoidal channel with a 20 foot bottom width, which is wider than the bottom width of the original channel. The new channel removed a bend in the creek and straightened Cloverdale Road.

Degradation is a general lowering of the land surface (streambed) by erosive processes, especially by moving water. When discussing streambeds, the term degradation is typically used to denote a trend of streambed erosion, over a period of years. The Butano Creek channel has clearly degraded since the bridge was built. Channels typically degrade when either the discharge is increased or the sediment load is decreased, over a period of years

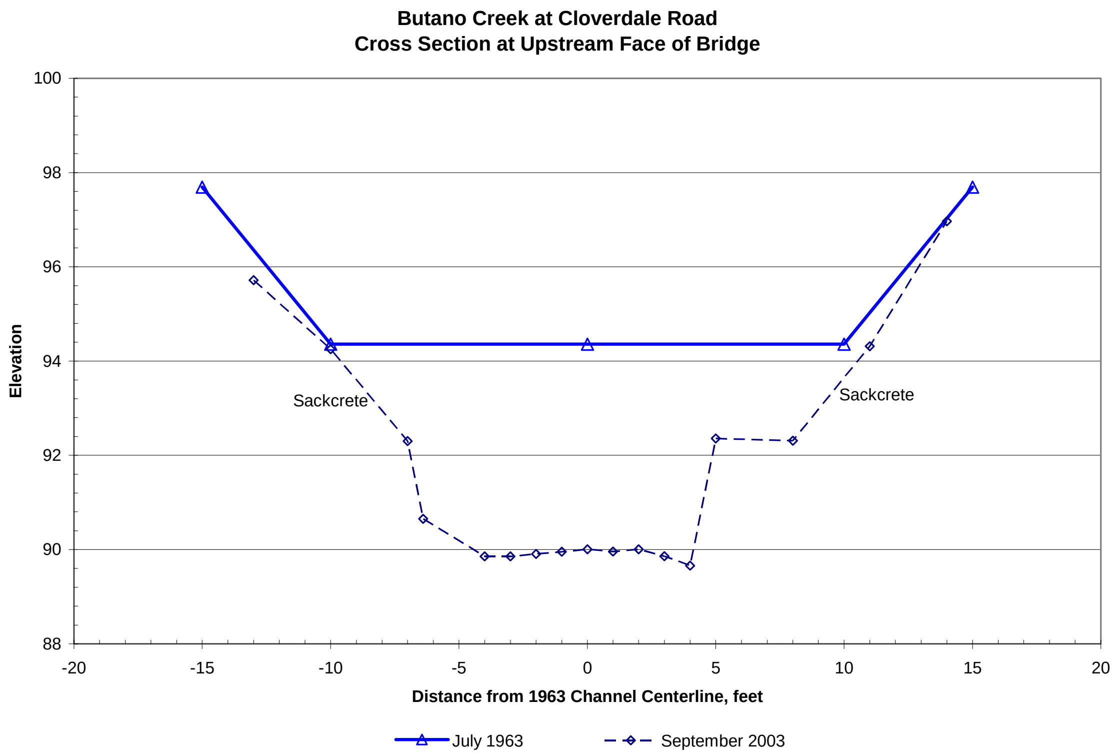

Figure 5-11: The above graph shows the channel degradation at the Cloverdale Road Bridge on Butano Creek that occurred between 1963 and 2003.

The erosion of material from the bed of Butano Creek may have generated a significant sediment load. The 7.5 minute topographic map shows that the channel slope of Butano Creek decreases downstream of the 40 foot contour line. The distance from the 40-foot contour line up to the Cloverdale Road Bridge is 2.9 miles. Erosion of 4 feet from the streambed would produce about 2.7 cubic yards of material per linear foot of channel. Assuming the erosion from the channel bed was a uniform wedge shape with its maximum loss at the Cloverdale Road Bridge and no loss at the 40 foot contour, there was an estimated total loss of 22,700 cubic yards of material from the bottom of the channel between 1963 and 2003. The channel degradation must extend further upstream. There might be a nickpoint upstream of the Cloverdale Bridge or a resistant layer in the streambed. The above calculation just considers the section of channel up to the Cloverdale Road Bridge and does not consider the loss of material above the bridge.

Note that Curry et al (1985) estimate that about 2.7 million cubic yards of sediment had been scoured from the 3.5 miles of the channel above the alder thicket between 1955 and 1985; and that Swanson estimates the volume of scour from the lower part of the channel at about 500,000 cubic yards, "probably within the past 100 years" (Swanson, 1987). The bases for these calculations in not given by either researcher, but must include much more than 4 vertical feet of incision.

Pescadero resident William Cook, in his study of lower Butano Creek, compiled the results of several past cross section surveys of Butano Creek at the Pescadero Road Bridge, and re-surveyed the channel at this location himself (Cook, 2003). Cook finds that the elevation of the streambed at this location increased about 8.5 feet between the time the bridge was built in 1961 and the time of his own survey in January 2001. Several surveys between these times indicate a continuing trend of streambed aggradation. Cook also uses an 1854 U.S. Coast Survey map to infer a much lower, broader streambed at that time.

CONCLUSION

With the exception of the channel of Butano Creek at the location of the Cloverdale Road Bridge, the re-surveyed cross sections exhibit remarkably little change over the period of record. Since there are only two data points available for most of the sites – when the bridge was built and when we conducted the surveys in the Fall of 2003 – it cannot be determined what happened in-between these times. The impression that is produced by this exercise, however, is that the bed of Pescadero Creek has been remarkably stable over time, or perhaps more accurately stated, that the creek seems to reestablish a stable elevation quickly. This is especially remarkable given the changes in land use and the large storms that have occurred since the original surveys. Again, the exception is the lower course of Butano Creek, which exhibits clear signs of major channel degradation in the area of the Cloverdale Road Bridge, and major aggradation further downstream in the area of the Pescadero Road Bridge.

Further insight could be gained from conducting additional surveys soon after a major storm event, particularly one that triggers numerous landslides and flooding. If these surveys are then repeated periodically over the next several years, much insight could be gained into the response of the stream channels to major events, and their recovery from these events.

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CHAPTER 6

SEDIMENT SOURCE INVESTIGATION

PURPOSE, SCOPE, AND METHODS

The objective of this investigation was to conduct a sediment source analysis for the Pescadero-Butano watershed and to identify the relative contributions of sediment delivered to stream channels from the various erosional processes that occur on hillslopes and in stream channels throughout the watershed. The source analysis provides gross estimates of sediment production at order-of-magnitude accuracy. The sediment source analysis was completed by Pacific Watershed Associates (PWA) and consists of six main components or tasks:

1) an aerial photo analysis of larger landslides and gullies throughout the Pescadero-Butano watershed;

2) a field inventory of 40 randomly selected 40-acre parcels to measure all identifiable past erosion and sediment delivery;

3) estimation of total basin erosion and sediment delivery based on the randomly selected sample plots;

4) combining the field plot data with the air photo data to determine total Pescadero basin sediment delivery and erosion rates; and

5) determine the percentage of past erosion that was anthropogenic or potentially controllable.

REVIEW OF DATA FROM PREVIOUS STUDIES

Very few studies of sediment production in the Pescadero-Butano watershed have been conducted, and of these, none has been quantitative field-based efforts. Published studies documenting sediment production in the Pescadero-Butano watershed include:

- Brabb and Pampeyan (1972) mapped deep-seated landslides for the Pescadero-Butano watershed, but did not address questions of sediment yield or erodibility of the various geologic units.

- Curry et al. (1985) estimated sediment yield rates for the Pescadero-Butano watershed. Using data derived from sediment studies in the nearby San Francisquito Creek watershed and from their own sampling in the headwaters of the Pescadero watershed, they estimated that the sediment yield rate for upland areas of the Pescadero-Butano watershed over the previous 30 years was 0.5 acre feet/mi2/yr. This equates to approximately 800 yds3/mi2/yr. Curry et al. also cite a 1968 dam feasibility study for Pescadero Creek by the U.S. Army Corps of Engineers that included a “conservative” estimate of twice this rate – 1 acre foot/mi2/yr or 1,600 yds3/mi2/yr, which Curry et al. state was made at a time of higher logging-related sediment yield rates. To the basin-wide estimate, Curry et al. added 2.7 million cubic yards of sediment between 1955 and 1984, which they estimated as the product of channel incision in the 3.5 miles of Butano Creek above the alder thicket (see Chapter 5 for discussion of this stream reach); and 800,000 cubic yards of sediment from incision of the lower Pescadero Creek channel during this same time period.

- The United States Geological Survey (USGS) mapped debris flows and large landslides resulting from the storm of January 3-5, 1982, and found high concentrations of debris flows in several areas of the Pescadero-Butano watershed: in the area between Bradley Creek and Honsinger Creek (up to 20 individual debris flows per square kilometer); in the Butano basin, centered just upstream of the confluence of South Fork Butano Creek and Butano Creek (up to 22.1 per square kilometer); and in the area west of the lower course of Butano Creek (up to 27.2 per square kilometer) (Ellen and Wieczorek, 1988, plate 8). The USGS report also includes a description of a large landslide, consisting of translational debris slides, at least nine of which coalesced into two debris flow tracks in the upper tributaries of Fall Creek, in Pescadero Creek County Park (Ellen and Wieczorek, 1988, plate 8 and Table 8-4). While this report provides densities and locations of debris flows and other mass wasting features, it does not attempt to quantify the amount of material displaced or delivered to stream channels.

In addition, there are a few quantitative sediment studies in neighboring basins that have been published. These include:

- Brown (1973) developed a relative erodibility rating for geologic units in the Zayante and Newell Creek basins in neighboring Santa Cruz County as part of a study of reservoir sedimentation. He examined the magnitudes and spatial distributions of various erosional processes occurring in each geologic unit and assigned a relative erosion potential rating, ranging from very low to very high. Many of the same geologic formations underlying these basins also occur in the Pescadero Creek basin.

- Macy (1976) later utilized Brown’s work in a study of sediment flux in the Upper San Lorenzo basin. Macy used measurements of sediment flux in the San Lorenzo River and gaging station records to calculate an average annual sediment yield of 10,261 yds3/year from the 6.53 mi2 basin. This equates to an annual yield of 1,571 yds3/mi2/year. Macy did not attempt to quantify erosion by geologic unit.

- Ricker and Mount (1979) also utilized the work of Brown (1973) in developing an erosion hazard rating system for the San Lorenzo River basin in Santa Cruz County. They found that erodibility of the underlying geologic unit was the most significant factor in determining the erodibility of a given area. Their system also relied on Brown’s relative measures of erodibility, and did not aim to quantify sediment yield. We have employed these relative erodibility scales in developing our field-sampling scheme and as general guidelines for expected relative sediment yields in the Pescadero-Butano watershed.

- Dvorsky (2003) utilized an existing inventory of landslides dated to over 50 years old, and quantified sediment inputs from roads as well as in-stream sediment flux to develop a sediment budget for the Aptos Creek Watershed in Santa Cruz County. Dvorsky calculated an annual rate of 2,465 tons/mi2/year for the 25 mi2 watershed, which equates to approximately 1,600 yds3/mi2/year, using a conversion factor of 1.54 tons/yd3.

- Owens et al., (2003) conducted a geomorphic and sediment assessment in the nearby Gazos Creek watershed. Among other tasks, they conducted a field inventory of major sediment sources (landslides, stream bank failures and gullies) within stream channels and upland areas throughout approximately 50% of the watershed. The inventory results were extrapolated to the remaining 50% of the watershed. The estimated annual sediment yield rate over the 20 year period between 1982 to 2001 was 1,400 yds3/mi2/year.

All of these studies utilized different methods and have limitations in the extent to which the various erosional processes operating on the landscape have been quantified. Yet they all have reported a relatively close range of upland sediment yield estimates, between 800 and 1,600 $yds^3/mi^2/year$. Most of the authors acknowledge that these values are low estimates of basin sediment yield since many of the more difficult-to-quantify types of erosion were not measured.

SEDIMENT SOURCE TIME FRAME

This assessment covers the time period of water years 1937 to 2002, a 66-year period. We chose this time period because it includes the recorded major historic flood-producing storms which were likely to have triggered large landslides or erosional processes in the watershed (see Chapter 4). It also allows a sufficiently long time period over which to average the three largest of these erosion-producing events.

In addition, while ranching, homesteading and logging have occurred throughout the watershed for over 150 years, widespread timber harvest and road construction did not begin in earnest until the 1930s. The history section of this report documents that erosion was occurring as a result of intensive land uses during this period, and the December, 1955 storm would have served as the earliest climatic event which could trigger large-scale episodic natural and land use related watershed response. We rely heavily on a set of 1956 aerial photographs to document large erosional features that can be attributed to the 1955 storm and the period leading up to it. In general, we assume that large erosional features as old as about 20 years remain visible in good quality aerial photographs. This consideration leads us back to a somewhat arbitrary starting date for the analysis of 1937. The three timeframes for the sediment source analysis are then defined as follows:

1. 1937, the earliest date that erosional features on the 1956 air photo series may be attributed to, through 1956, the time of the first high-quality air photo series available. This timeframe includes the December, 1955 storm, and spans a period of 20 years.

2. 1957, the year after the 1956 air photo series, through 1982, the time of the second air photo series used in the analysis. This series was taken immediately after the storm of January 3-5, 1982. This timeframe encompasses a period of 26 years.

3. 1983, the year after the 1982 air photo series, through 2002, the last winter before field work was completed for this project. This is a period of 20 years.

This produces three time frames of similar length, each concluding (or nearly concluding) with a major storm event. The difficulty of identifying all past erosion in the field sample plots increases as more time passes since the erosion occurred because of diffusion of the feature and re-vegetation. Within the sample plots, our ability to identify and, more importantly, attribute any land use associations to erosional features formed before the 1960s was limited. We address this limitation by combining a number of methods for estimating erosion and sediment delivery to streams during the pre-1960 time period.

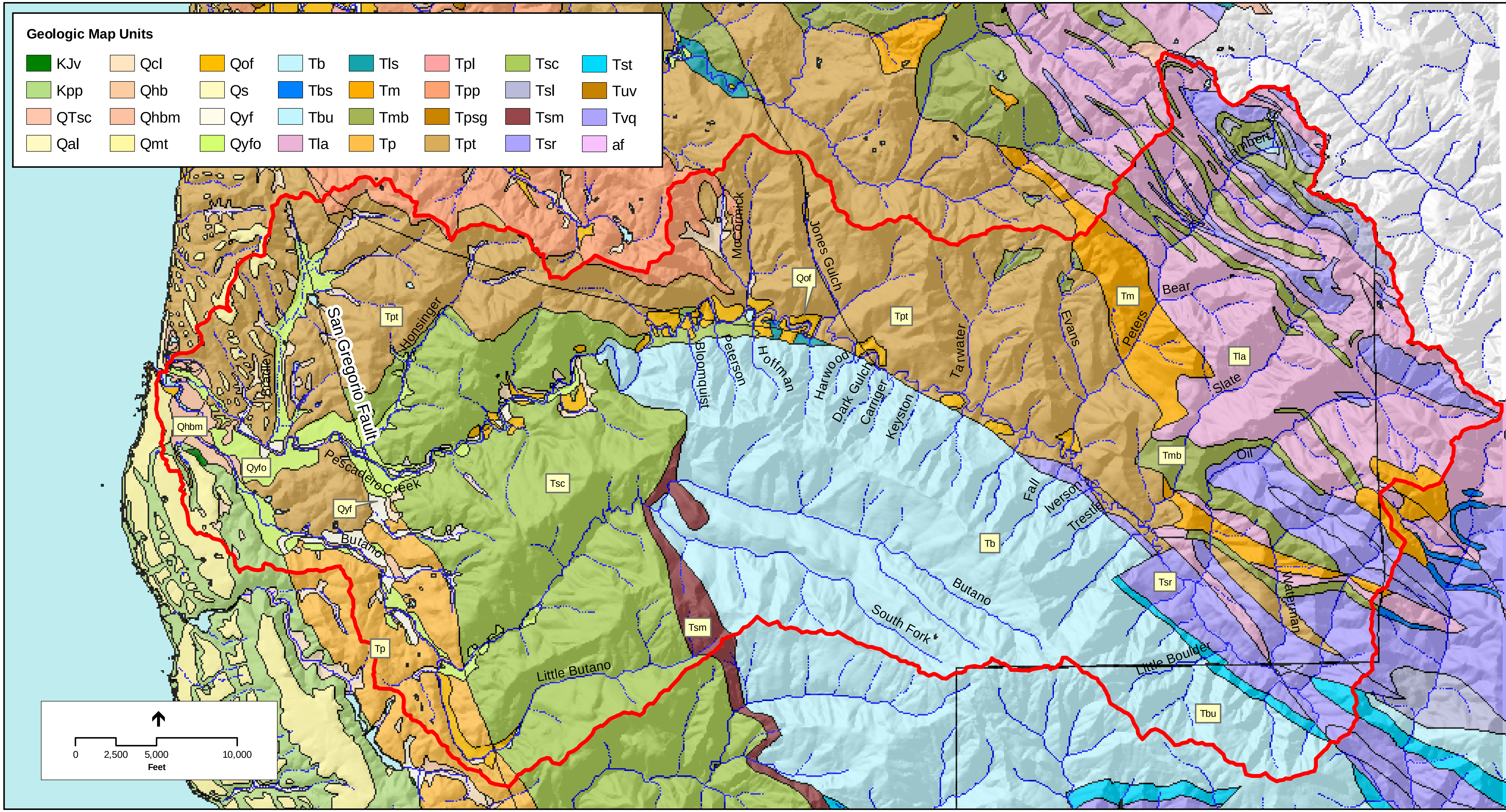
PHYSICAL SETTING

The Pescadero-Butano watershed is a coastal drainage located in San Mateo County, south of the city of San Francisco and west of the San Andreas fault zone (Map 2-1). Pescadero Creek and its major tributary, Butano Creek, flow west to the Pacific Ocean and drain an area of 81 square miles. Elevations within the watershed range from sea level to over 2,500' on the eastern crest. State Highway 1 and Skyline Boulevard are the major transportation corridors, passing along the western and eastern margins of the watershed, respectively. The Pescadero-Butano watershed is sparsely populated, with only two small towns, Pescadero and Loma Mar.

Sedimentary units (Map 6-1 and Figure 6-1) dominate the geology of the Pescadero-Butano watershed. The central part of the watershed is underlain by moderately folded, massively bedded, coarse-grained marine sandstones, including the spatially extensive Butano Formation, with erodibility ratings of moderate to very high (Brown, 1973; Brabb, et al., 1998). Shales and mudstones of moderate erodibility predominate in the west-central and southwest areas of the watershed, the Santa Cruz mudstone being the most extensive. This area is also moderately folded, but lies adjacent to the San Gregorio Fault, which cuts through the watershed from southeast to northwest along the western margin of the main exposure of the Santa Cruz Formation. West of the fault, poorly consolidated Quaternary marine terrace and alluvial deposits are common, along with upper Tertiary siltstones and fine-grained sandstones. The eastern part of the watershed lies adjacent to the San Andreas Fault Zone and has been subjected to more intense deformation. The area is characterized by extensive folding and highly fractured rocks, in a mix of units including volcanics, sandstones, shales and mudstones with a wide range of erodibility ratings (Brown, 1973).

Most of the Pescadero-Butano watershed is heavily wooded, with redwood-Douglas fir forest predominating (Map 6-2). Significant areas of mixed conifer-oak woodland also occur within the watershed, with some areas of chaparral/scrub vegetation on south-facing slopes, particularly in the southern part of the watershed. The area west of the San Gregorio Fault is dominated by grasslands and scrub vegetation, which also occur on some of the low-gradient ridge tops along the northern and eastern boundaries of the watershed.

The quantity and duration of rainfall during storm events is a major factor influencing geomorphic processes in the Pescadero-Butano watershed. The basin receives 20-50 inches of annual precipitation, almost all of which occurs between October and April. Summer fog can provide cooler temperatures throughout the basin during the summer months. High magnitude, infrequent storms can and have caused widespread mass wasting, as well as flooding in the lower basin, particularly in the area of Pescadero Marsh. Although there is not a perfect relationship between intense local rainfall events and peak mainstem flow, discharge records are the most complete and



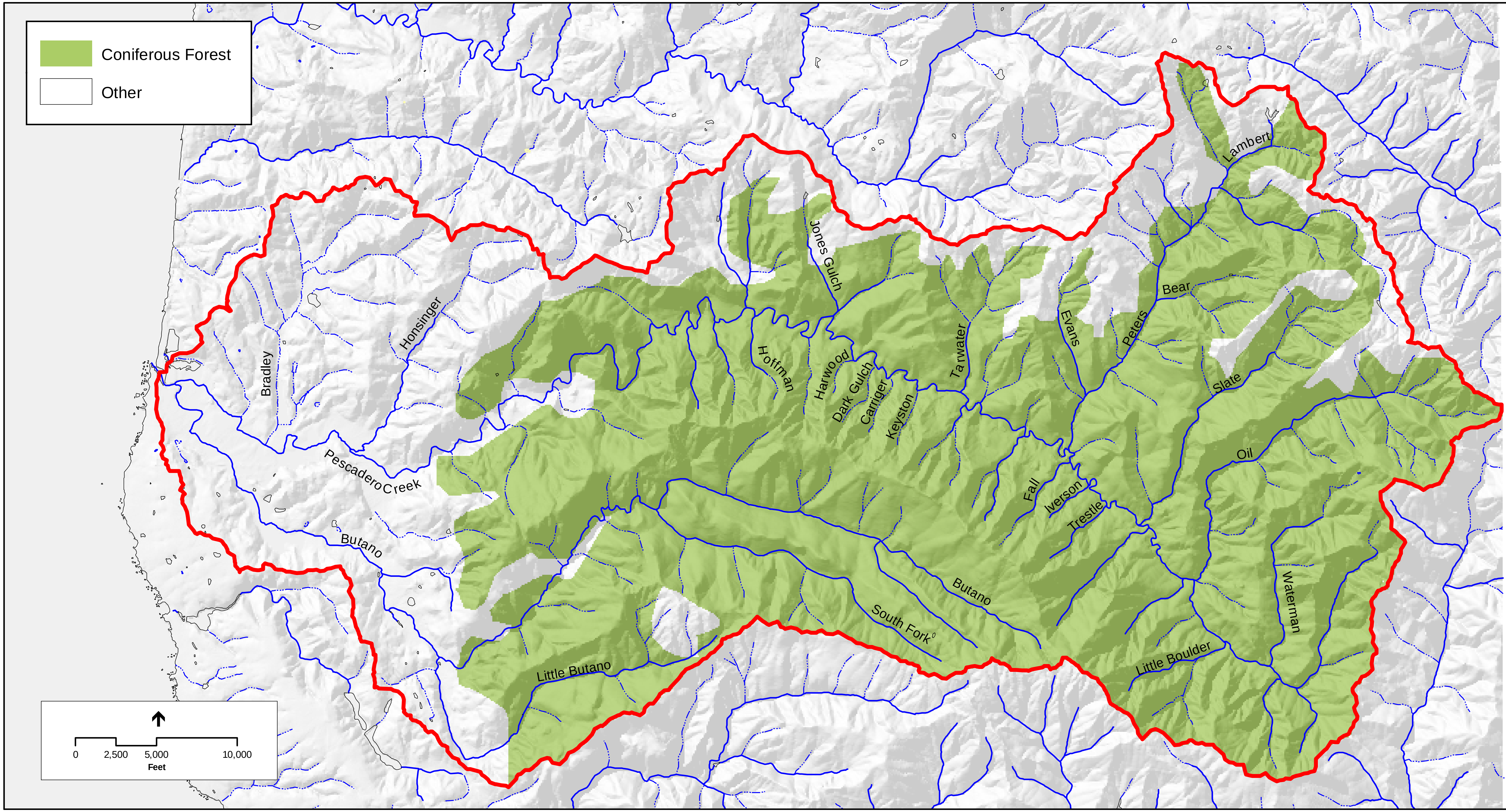
SOURCE: USGS data sets from Bay Area Regional Database

Map 6-1

Geology of the Pescadero-Butano Watershed

Figure 6-1. Description of geologic units present in the Pescadero-Butano Creek watershed, taken from Brabb, Graymer, and Jones, 1998.

Unit Symbol	Unit Name (and age)
KJv	Unnamed volcanic rocks (Cretaceous or older)
Kpp	Pigeon Point Formation (Upper Cretaceous)
QTsc	Santa Clara Formation (lower Pleistocene and upper Pliocene)
Qal	Alluvium (Holocene)
Qcl	Colluvium (Holocene)
Qhb	Basin deposits (Holocene)
Qhbm	Bay mud (Holocene)
Qmt	Marine terrace deposits (Pleistocene)
Qof	Course-grained older alluvial fan and stream terrace deposits
Qs	Sand dune and beach deposits (Holocene)
Qyf	Younger (inner) alluvial fan deposits (Holocene)
Qyfo	Younger (outer) alluvial fan deposits (Holocene)
Tb	Butano Sandstone (middle and lower Eocene)
Tbs	Shale in Butano Sandstone (lower Eocene)
Tbu	Butano Sandstone Upper Member
Tla	Lambert Shale (Oligocene and lower Miocene)
Tls	Lambert Shale and San Lorenzo Formation, Undivided (lower Miocene)
Tm	Monterey Formation (middle Miocene)
Tmb	NOT IN KEY
Tp	Purisima Formation (Pliocene and upper Miocene)
Tpl	Lobitos Mudstone Member (Pliocene)
Tpp	Pomponio Mudstone Member (Pliocene)
Tpsg	San Gregorio Sandstone Member (Pliocene)
Tpt	Tahana Member (Pliocene and upper Miocene)
Tsc	Santa Cruz Mudstone (upper Miocene)
Tsl	San Lorenzo Formation (Oligocene and upper and middle Eocene)
Tsm	Santa Margarita Sandstone (upper Miocene)
Tsr	Rices Mudstone Member (Oligocene and upper Eocene)
Tst	Twobar Shale Member (middle and upper Eocene)
Tuv	Unnamed Sedimentary and Volcanic Rocks (Miocene and Oligocene)
Tvq	Vaqueros Sandstone (lower Miocene and Oligocene)
af	Artificial fill (Historic)



SOURCE: USGS data sets from Bay Area Regional Database; Fire and Resource Assessment Program, California Department of Forestry and Fire Protection

Map 6-2

Areas of Coniferous Forest in the Pescadero-Butano Watershed reliable record of high magnitude rain events. We therefore assume that the record of peak discharge reflects rainfall events likely to result in widespread mass wasting.

The floods of 1955, 1982 and 1998 are the largest on record in the watershed (see Chapter 4). Figure 6-2 illustrates the wide variability in annual peak discharge at the USGS gage near the town of Pescadero for water years 1951 through 2002.

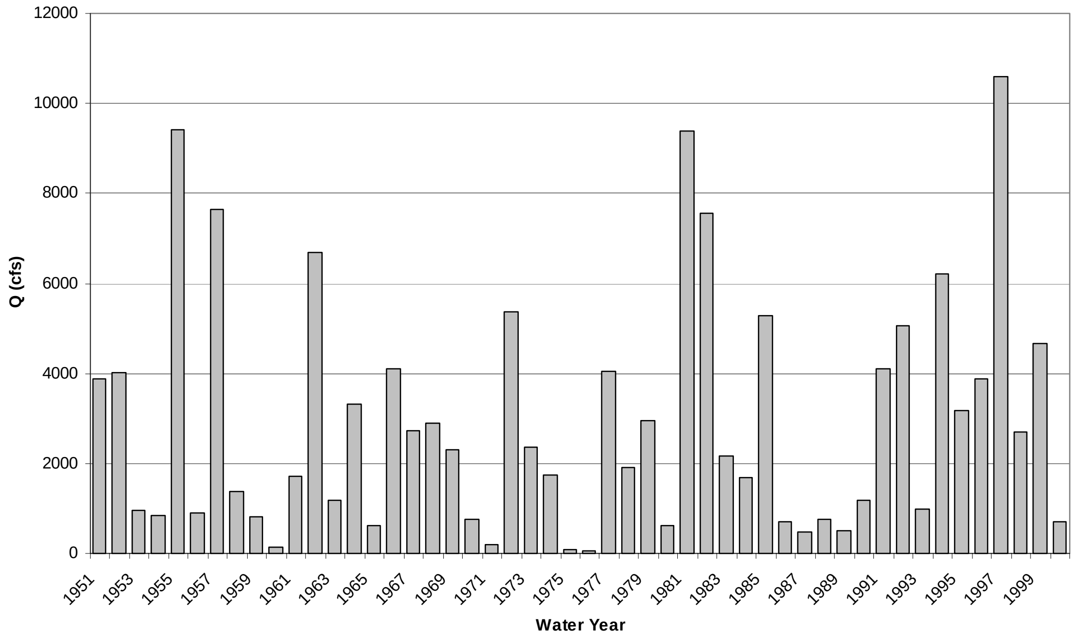


Figure 6-2. Annual Peak Discharge, Pescadero Creek near Pescadero, 1951-2000.

APPROACH TO QUANTIFYING SEDIMENT SOURCES

During the summer and fall of 2003, PWA conducted an extensive field inventory and aerial photographic analysis of sediment sources throughout the Pescadero-Butano watershed. The purpose was to estimate the magnitude of past erosion and sediment delivery, and to determine what proportion of the past erosion and delivery has some association with the variety of land management practices occurring in the watershed. The aerial photograph and field inventories focused on identifying shallow and deep-seated landslide sediment sources, as well as hillslope gully erosion, and stream channel bed and bank erosion.

In order to quantify sediment sources in the field, a stratified random sampling (STRS) scheme was used to estimate total past erosion and sediment delivery within the Pescadero Creek watershed over the past 65 years. The approach involves segmenting the watershed into similar geomorphic terrains, based on geologic, topographic and vegetation characteristics or factors.

Based on an estimate of the relative potential for the various geomorphic terrains to produce sediment, the appropriate number of sample plots was determined. After segmenting the watershed, a GIS-generated sampling grid was placed over the watershed, and the specific locations of the 40 randomly-selected sampling plots were determined within each geomorphic terrain.

This methodology has previously been used, with good results, in determining sediment source allocations for the U.S. Environmental Protection Agency in the Van Duzen River watershed (located on California's north coast) as part of developing total maximum daily load (TMDL) allocations (PWA, 1999; U.S. EPA, 1999).

A final element of our approach was to estimate the volume of surface erosion originating from the road system throughout the watershed. This was accomplished by utilizing a 2003 field inventory of all roads and trails within the three San Mateo County Parks located in the central portion of the watershed, and extrapolating the results to the rest of the watershed.

GEOMORPHIC TERRAINS

The physical characteristics of the Pescadero watershed are assumed to exert a strong influence on the spatial patterns of erosion in the basin, as well as the frequency, magnitude and rates of erosional processes. We employed available GIS data sets on geology, vegetation type and hillslope steepness to divide the watershed into units of similar characteristics, referred to as geomorphic terrains.

Brown's (1973) relative erodibility ratings were used to aggregate the geologic units present in the watershed into groupings of similar erodibility. The underlying geology frequently controls the erodibility of the rock, and also exerts a strong influence on slope steepness and soil characteristics. Predominantly massive sandstone units in the central portion of the Pescadero watershed all have high or very high erodibility ratings and were grouped into one class (Brown, 1973). The inter-bedded shale and mudstone units (mostly located east of the San Gregorio Fault) judged by Brown to have low to moderate relative erodibility ratings were also aggregated.

In the eastern portions of the watershed, the bedrock is generally older, appears more intensely fractured and deformed, and consists of many different rock types cropping out within relatively small areas. Both mixed volcanic and sedimentary rock types are present, with a variety of relative erodibility ratings according to Brown (1973). The geologic units underlying the eastern area were aggregated into a mixed lithology group. Limits to this study precluded any further differentiation of the mixed lithology group.

The western portion of the watershed (west of the San Gregorio Fault) is underlain by mostly Quaternary and, to a lesser degree, Upper Tertiary sedimentary units. The rock types are poorly lithified and far less coherent than any of the other bedrock geologies present in the watershed. The area is dominated by generally gentle rolling hills and broad valley bottoms with predominantly coastal scrub and grassland vegetation. We aggregated this area into a separate geomorphic terrain.

A digital elevation model (DEM) of the watershed was used to classify the watershed according to slope class. Initially, we desired to have a minimum of 3 slope classes, however, external limitations on the study design prevented this and we settled on using 40% as the break between steeply and gently sloping areas. The 40% slope category is based on an assumption that land that is 40% or steeper is more prone to landsliding. Wieczorek and Sarmiento (1988) noted that debris flows triggered by the 1982 storm in La Honda were located on slopes generally steeper than 25 degrees (about 55%).

Slope categories were generalized into areas of steep and gentle terrain through the use of a "nearest neighbor" function of the GIS. With this function, the region (or "neighborhood") around each point on a 10-meter grid in the watershed was examined to determine the gradient of all points in the neighborhood. The GIS program "looked at" all points within a 200-meter radius of a point and determined whether at least 600 of the possible 1,200 points had a gradient of at least 40%. If so, the point was classified as steep. Otherwise, it was classified as gentle. We experimented with various radii and cutoffs for number of neighbors within the steep category before arriving at a consensus. The results closely match (though with greater detail) an earlier manual mapping exercise in which polygons were drawn around areas of steep hillslopes. Of course, within any particular area classified as “steep” there are areas on gently sloping land, and vice-versa, but the exercise produced a usable distinction between those areas dominated by steep slopes, and those that are characterized by more gently sloping land.

Utilizing the California Department of Forestry and Fire Protection’s CALVEG vegetation data (see Appendix D), which is available as a GIS layer, the watershed was further divided into two broad vegetation types: predominantly conifer forest and predominantly non-conifer (i.e. coastal scrub, grassland or oak-woodland.

Utilizing GIS, the described geologic, slope and vegetation polygons were combined to create 16 geomorphic terrains, which will be referred to as “Hillslope Geomorphic Units” (HGUs). The initial 16 HGUs are shown on Map 6-3 and listed below:

1) Mixed lithology (mainly in the northeast part of the watershed), non-coniferous vegetation with gentle (<40%) slopes;

1a) Mixed lithology, coniferous vegetation with gentle slopes;

2) Mixed lithology, non-coniferous vegetation, with steep (>40%) slopes;

2a) Mixed lithology, coniferous vegetation, steep slopes;

3) Sandstone (mostly in the central part of the watershed), non-coniferous, with gentle slopes;

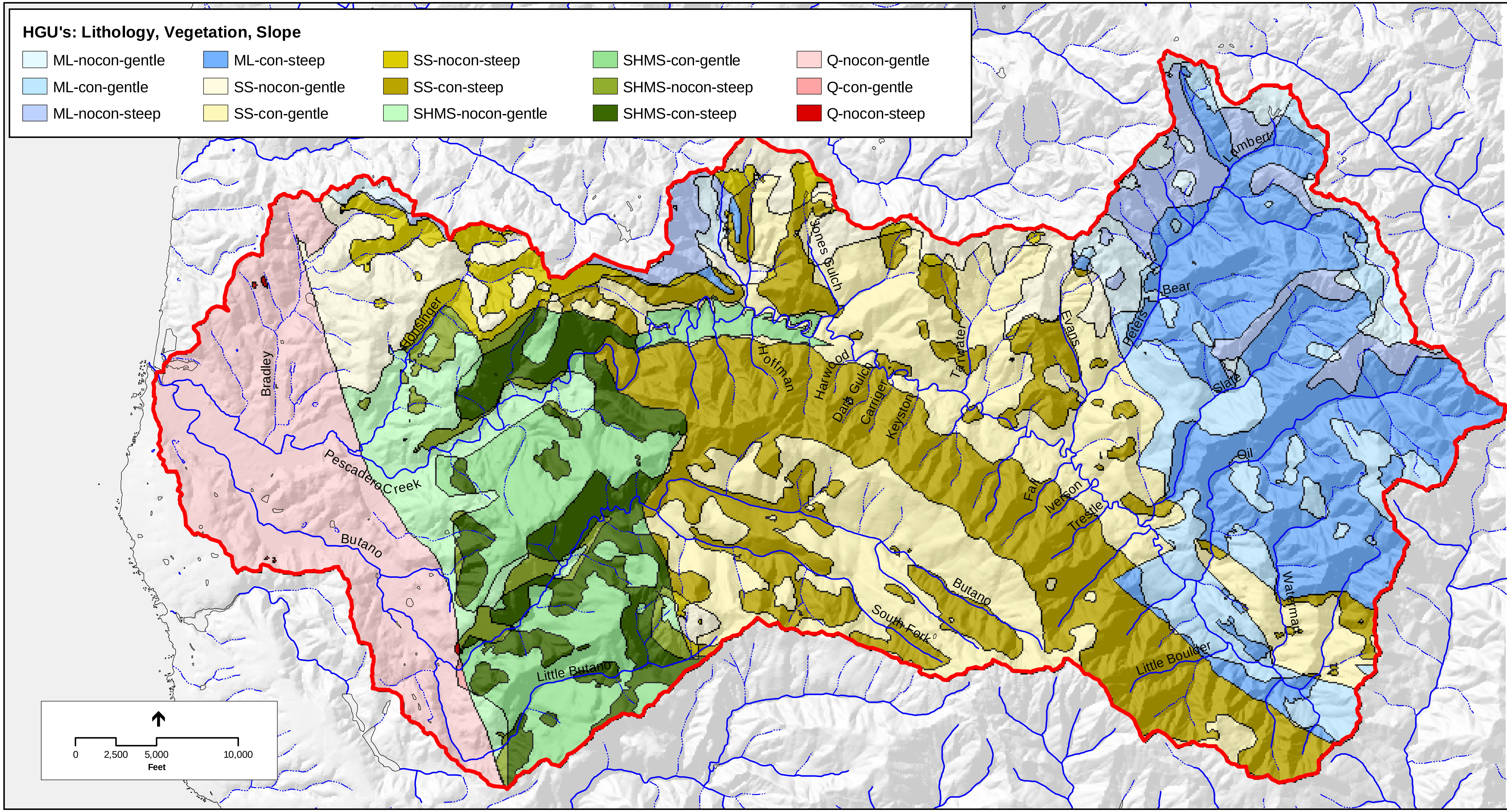
3a) Sandstone, coniferous, gentle slopes;

4) Sandstone, non-coniferous, with steep slopes;

4a) Sandstone, coniferous, steep slopes

5) Shale/mudstone (west-central and southwest parts of the watershed), non-coniferous, with gentle slopes;

5a) Shale/mudstone, coniferous, gentle slopes;



SOURCE: USGS data sets from Bay Area Regional Database; Fire and Resource Assessment Program, California Department of Forestry and Fire Protection; Pacific Watershed Associates

Pescadero-Butano Watershed Assessment / 202395

Map 6-3

Initial Hillslope Geomorphic Units

6) Shale/mudstone, non-coniferous, with steep slopes;

6a) Shale/mudstone, coniferous, steep slopes;

7) Quaternary and upper Tertiary sediments (west of the San Gregorio Fault), non-coniferous, with gentle slopes;

7a) Quaternary and upper Tertiary sediments, coniferous, gentle slopes;

8) Quaternary and upper Tertiary sediments, non-coniferous, with steep slopes; and

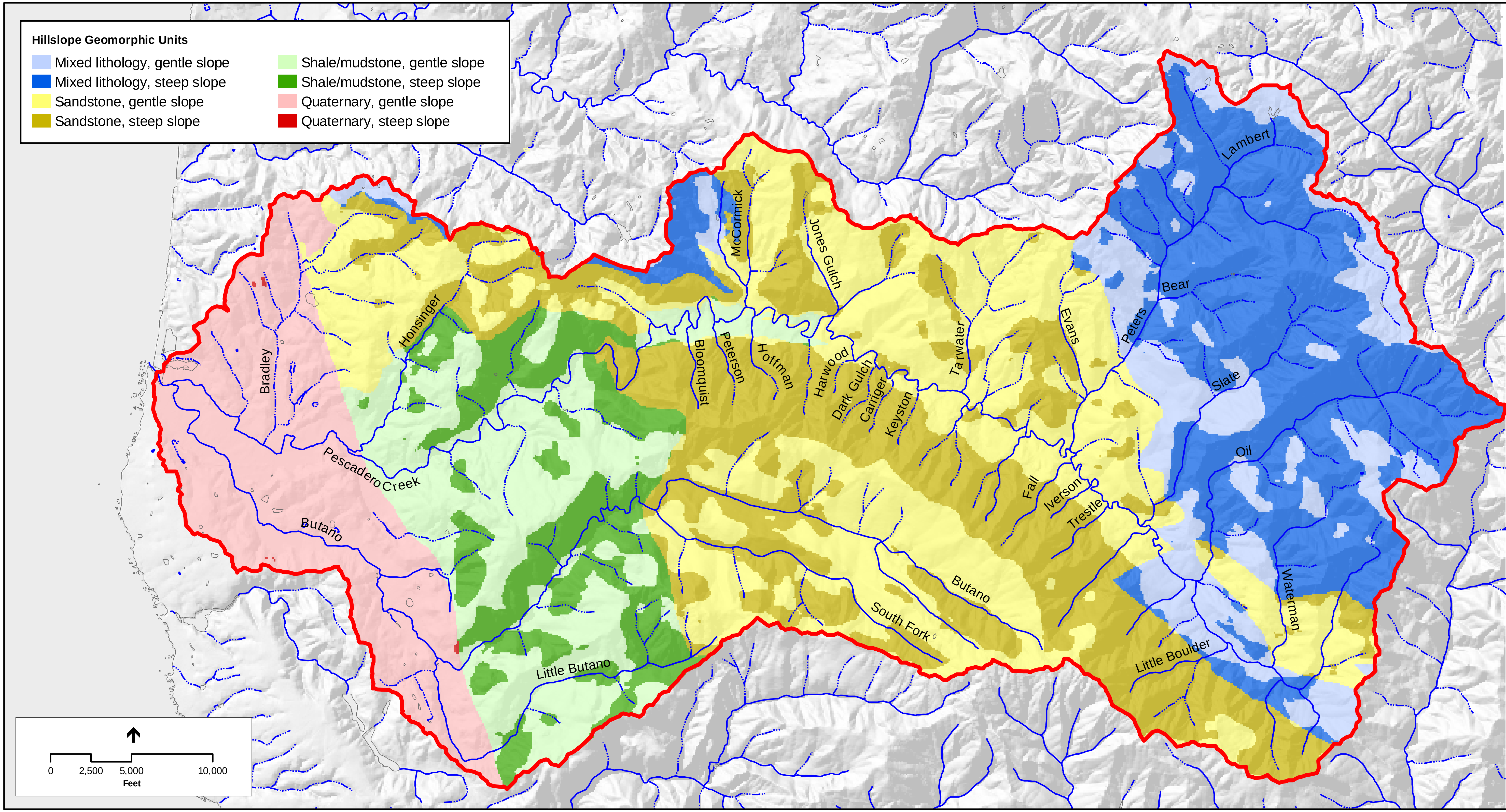
8a) Quaternary and upper Tertiary sediments, coniferous, steep slopes.

The areas of HGUs 7a, 8 and 8a in the watershed were found to be minimal (<30 acres total), so these classifications were eliminated and their areas included in HGU 7. Budgetary constraints limited the number of field sampling plots to 40, so in order to obtain a representative sample of terrain types, the vegetation classification was omitted from the classification scheme and the coniferous vegetation types were combined with the non-coniferous types, resulting in seven primary HGUs (Map 6-4). Descriptions and relative areas of the HGUs are summarized in Table 6-1. The location of each terrain type and the differences in sediment production and delivery are discussed later in this report.

TABLE 6-1
AREA OF SEVEN COMBINED HILLSLOPE GEOMORPHIC UNITS (HGU) FOR THE 81 mi^2 PESCADERO-BUTANO WATERSHED

HGU # and name	Area (mi^2)	% of basin	% of sample plots
1. Mixed lithology, gentle slope	6.8	8.4	10.0
2. Mixed lithology, steep slope	13.9	17.2	17.5
3. Sandstone, gentle	20.0	24.7	20.0
4. Sandstone, steep	16.2	20.0	20.0
5. Shale/mudstone, gentle	8.8	10.9	10.0
6. Shale/mudstone, steep	5.4	6.6	12.5
7. Quaternary sediments, gentle	9.9	12.2	10.0
Totals	**81.0**	**100**	**100**

If it is assumed that the costs associated with measuring a plot in each HGU are equal, then the optimal allocation of sampling effort would be proportional to the expected sediment delivery from each HGU. A literature search was conducted for studies of erosion rates and yields from the various lithologies present in the Pescadero-Butano watershed and adjoining basins, but no quantitative studies were found. Allocation of plots to each of the seven HGUs was therefore weighted according to the relative area of the basin lying in each HGU (Table 6-1). This weighting was adjusted according to the expected relative magnitude of erosion from each lithology based on Brown's (1973) erosion potential rating and on descriptions of the various



SOURCE: USGS data sets from Bay Area Regional Database; Pacific Watershed Associates

Map 6-4

Hillslope Geomorphic Units

geological units (Brabb et al., 1998). Plot allocation as compared to overall basin area is outlined in Table 6-1. In allocating plots we assumed that for any given erosional size class and plot area, the ratio of the standard deviation to the mean plot erosion was the same in all HGUs.

We predicted a relatively low level of error with the selected sampling strategy, especially considering the difficulty of quantifying past sediment delivery in large, wildland watersheds. However, some level of error is expected, both in the sampling of field plots, and also in the field measurement of erosion and sediment delivery volumes.

The field plot sampling design was augmented with an analysis of aerial photography sets for the entire watershed for selected years. A detailed explanation of the aerial photo analysis is included below.

Most comprehensive sediment source investigations indicate that large erosional features contribute the bulk of total past sediment delivery to streams, while representing a relatively small percentage of the total number of erosional features in a watershed (Kelsey et al., 1995; Weaver et al., 1995). By examining all identifiable features on aerial photos and field verifying a portion of their volumes, a much better estimate of their contribution should be obtained than from plot sampling alone. Additionally, by removing these features from the population estimated by plot sampling, we are further lowering the variance (Lewis, 1998, personal communication).

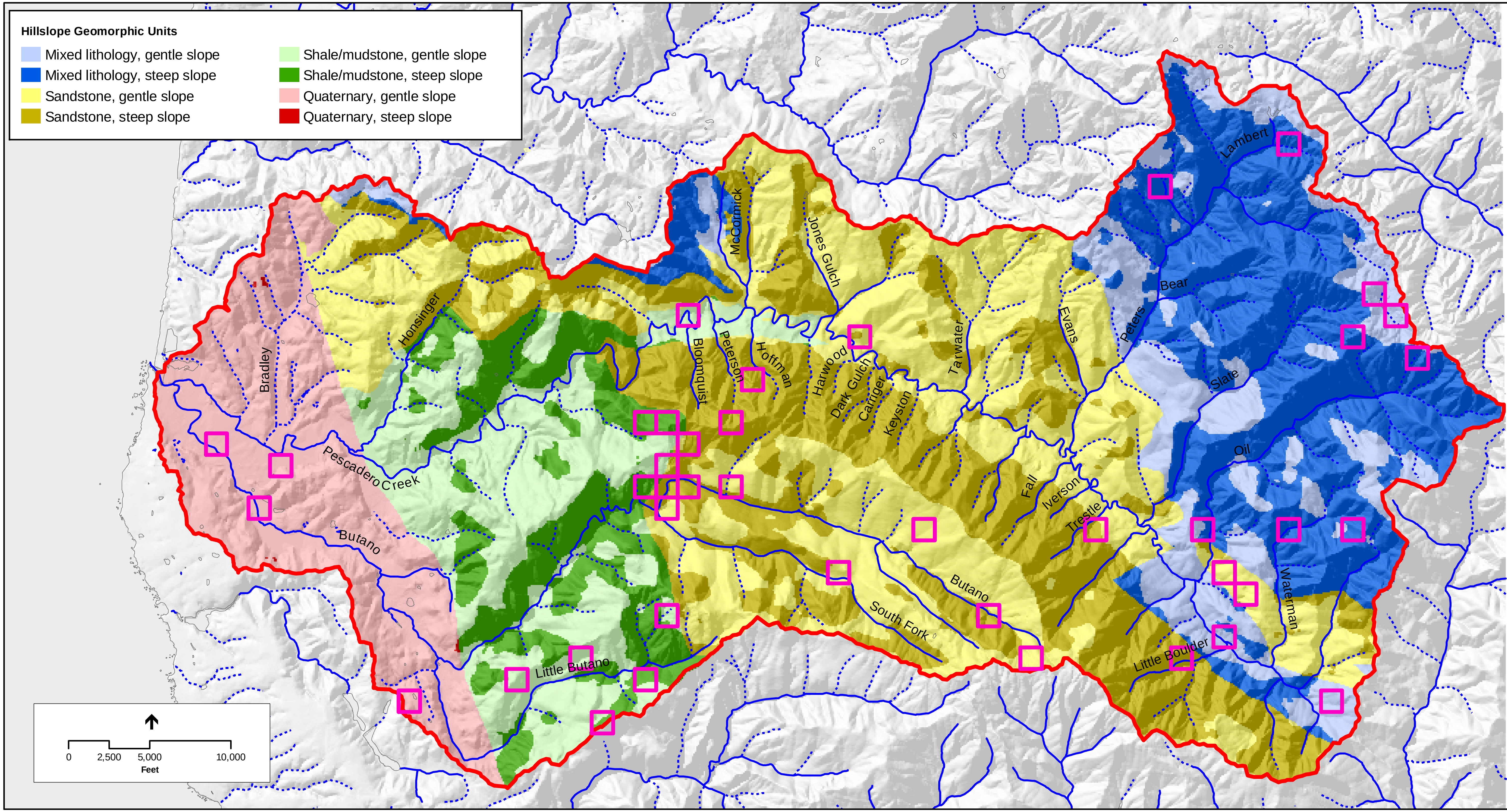
SAMPLE PLOT DETERMINATION

A grid was developed for the entire basin area with each grid cell equal to an area of 40 acres. The grid was combined with a GIS layer depicting the seven HGUs to create a layer that identified the dominant HGU for each 40-acre grid cell (Map 6-5). This determined the number of grid cells for each HGU (Table 6-2). From the cell grid for the entire basin, 200 cells were randomly sampled and landowner permission for access was sought for 40 cells on the list: the first four cells within HGU 1, the first seven in HGU 2, the first eight in HGU 3, the first eight in HGU 4, the first four cells in HGU 5, the first five cells in HGU 6, and the first four in HGU 7 (Table 6-2). When landowner permission could not be obtained, the next sequential cell on the list for the appropriate HGU was selected. The 40 plot cells obtained in this manner served as the field sample.

SEDIMENT SOURCE CATEGORIES AND DATA COLLECTION

AERIAL PHOTOGRAPH ANALYSIS

We documented the histories of larger erosion and mass wasting (landslides) features in the Pescadero-Butano watershed from three sets of vertical aerial photography: 1956 (1:24,000 scale), 1982 (1:12,000), and 2000 (1:24,000). No other complete aerial photo sets were available for the analysis.



SOURCE: USGS data sets from Bay Area Regional Database; Pacific Watershed Associates

Map 6-5

Randomly Selected 40-Acre Sample Plots

TABLE 6-2
NUMBER OF GRID CELL AND TOTAL BASIN AREA BY HILLSLOPE GEOMORPHIC UNIT (HGU), PESCADERO-BUTANO WATERSHED

HGU	Hillslope Geomorphic Unit	# of grid cells in Pescadero-Butano Watershed	Area of grid cells in Pescadero Creek (mi2)	# of grid cells sampled
1	Mixed lithology, gentle slope	109	6.8	4
2	Mixed lithology, steep slope	222	13.9	7
3	Sandstone, gentle	320	20.0	8
4	Sandstone, steep	259	16.2	8
5	Shale/mudstone, gentle	141	8.8	4
6	Shale/mudstone, steep	86	5.4	5
7	Quaternary sediments, gentle	158	9.9	4
	Total	**1,295**	**81.0**	**40**

The following types of sediment sources were quantified from the aerial photographs:

- Shallow debris slides or landslides
- Shallow debris slides which triggered debris torrents (debris flows) upon encountering a stream channel
- Debris torrent tracks, consisting of stream channels that were scoured by passage of a debris torrent
- Active, deep-seated landslides, generally larger, slow-moving features
- Gullies, or new channels created by concentration of flow on hillslopes
- Stream bank erosion

Classification of landslide types was based on the Crudden and Varnes system (Crudden and Varnes, 1996). This system is the preferred method used by the California Geological Survey. Generally, landslides fall into 2 categories: 1) shallow, rapid and 2) deep-seated, slow. Debris slides are the principal type of shallow, rapid landslide. Debris torrents or debris flows are classified as debris slides which move rapidly down the channel network and scour some length of natural stream channel or gully the hillslope down from the source area. Deep-seated landslides include rotational slides, translational slides and composite slides. Composite slides are defined as deep-seated slides that possess features or styles of movement suggestive of two or more types of sliding (e.g. rotational and translational).

Each landslide or erosional feature mapped on the photographs was assigned a unique site number and characterized using a variety of criteria. The minimum measurement resolutions for features identified on the photos was approximately 20 feet (1982) and 40 feet (1956 and 2000 photo years). Attribute data collected for each landslide included:

1) Year of appearance (photo year)

2) Feature type (debris slide, debris flow, debris flow torrent track, deep seated slide, rotational slide, translational slide, composite slide, gully),

3) Certainty of interpretation (definite, probable, questionable),

4) Feature dimensions (length, width),

5) Aspect,

6) Sediment delivery (that is, the estimated amount of eroded sediment, expressed as a percentage, that entered a stream channel)

7) Type of stream receiving deposits (perennial, intermittent, ephemeral),

8) Land use history at initiation point (road, timber harvest, advanced second growth, farm/agriculture, no apparent management),

9) Geomorphic association (inner gorge, streamside, swale, break-in-slope, headwall, etc.), and

10) The hillslope steepness passing through initiation point (from topographic map)

If an erosional feature showed obvious enlargement from one photo-period to the next, the new volume of erosion was added to the original feature.

The lengths of slides measured on the aerial photographs were corrected using a multiplier based on hillslope gradients measured from topographic maps. The scale of the aerial photo sets used in the study was such that it was not possible to determine feature depth from the photos. Depths were estimated for debris slides by fitting a feature area/depth regression equation to data points from both field-checked, aerial photo-identified features and debris slides inventoried in the field sampling phase of this study (Figure 6-3). A similar method was used for gullies, utilizing a width/depth regression (Figure 6-4). For debris torrent tracks, we employed a range of values for volume of material scoured per unit length of torrent track, based on relevant literature (Benda, 1990) and adjusted according to local conditions and torrent track width.

Information mapped on the historic aerial photographs was transferred to mylar overlays on 1:24,000 scale USGS topographic maps and digitized in ArcView GIS. Attribute data for the landslide analysis was entered in a relational database.

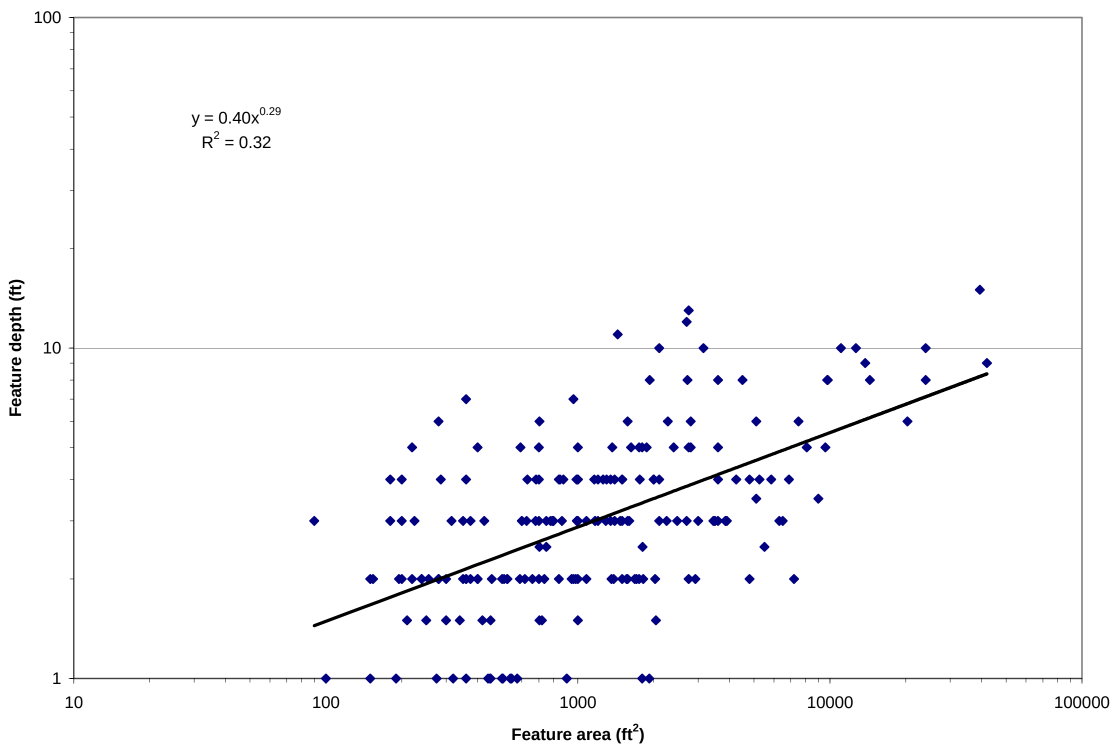


Figure 6-3: Area/depth regression for all field-inventoried debris slides

LIMITATIONS ON AERIAL PHOTO ANALYSIS

Although complete coverage of the Pescadero-Butano watershed was available for all three air photo sets, time periods between air photo periods, air photo scales, and poor quality of the photos probably affected the detail and thoroughness of the air photo analysis. For example, long time periods between aerial photos can result in the underestimation of features identified in the analysis. There was a 26-year time period between the 1956 and 1982 photo sets and an 18-year time span between the 1982 and 2000 photo sets. Road construction and new erosional features that occurred within the time span could have been obscured by vegetation by the time the subsequent aerial photo set was taken. There could therefore be an under-estimation in the number of features identified in the analysis.

In addition, small aerial photo scales can result in difficulty in identifying erosional features. Photo scales smaller than 1:12,000 make it more difficult to identify some erosional features confidently, especially smaller features such as small debris slides and gullies. The 1956 and 2000 aerial photo sets used in the analysis were taken at a scale of 1:24,000. As a result, the number of erosional features identified on the 1956 and 2000 photos may be underestimated.

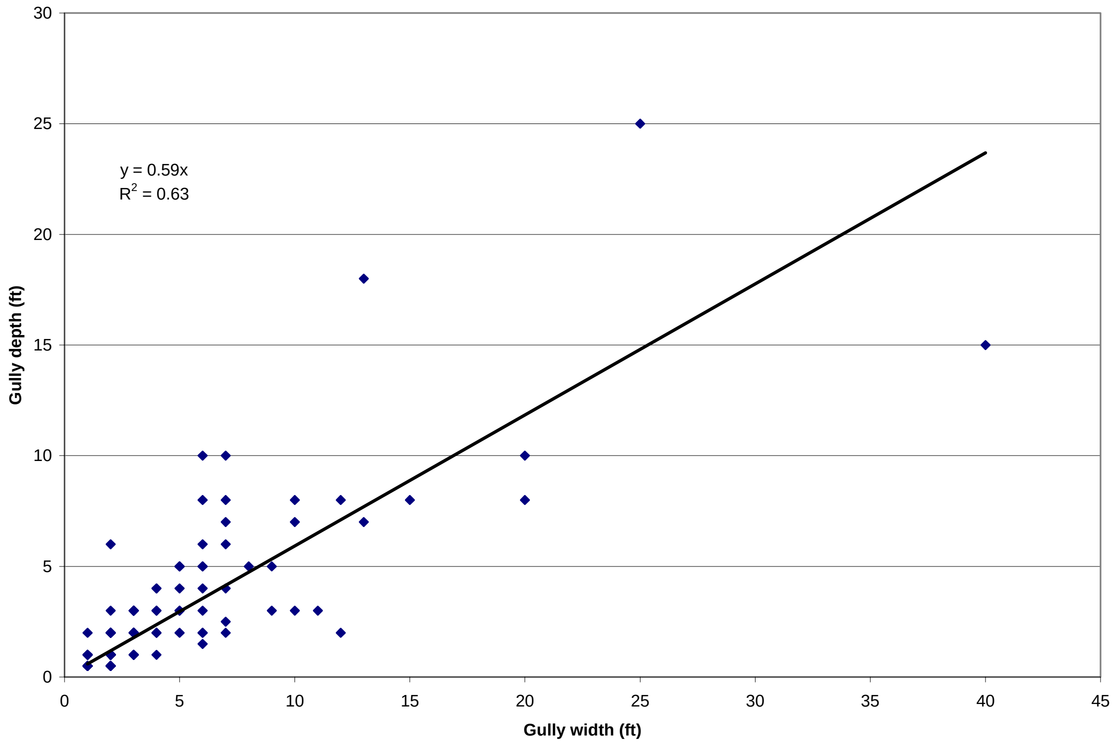


Figure 6-4: Width/depth regression for all field-inventoried gullies

The quality of the aerial photos and the time at which they were flown may also have a negative affect on the ability to accurately identify road construction and erosional features. The 1982 aerial photo set was flown during the winter (specifically, 01/07/1982 and 01/08/1982), and was underexposed. This resulted in very dark photos with deep shadows. The 1982 aerial photography was by far the most difficult to map upon, even though the scale was appropriate for feature identification (1:12,000).

FIELD SURVEY

A total of forty (40) field plots of 40 acres each were systematically surveyed for erosional features that delivered sediment to a stream channel. Survey crews concentrated their efforts on surveys in the stream channels themselves and their immediate vicinity for evidence of sediment delivery from both streamside and upslope sources, and in-stream processes. In addition, cross-slope transects were generally run to locate sediment sources from which sediment delivery may not have been apparent from the stream channel. The sediment sources mapped in the plots were classified according to the following source categories: shallow debris slides; shallow debris slides which trigger debris flows or torrents; debris torrent tracks; large and small deep-seated landslides; road, skid trail and hillslope gullying; stream bank erosion; and channel incision (down-cutting of the stream into previously deposited sediments).

All erosional features mapped on the aerial photos or within the sample plots had the same suite of collected data. These include 1) whether the feature was road, skid trail or hillslope-related, 2) HGU and dominant vegetation type, 3) type of sediment source, 4) volume of erosion, 5) an estimate of the volume of sediment delivered to the stream, 6) hillslope location, 7) any apparent land use/management associations, 8) geomorphic association and 9) average slope steepness where the erosion occurred. See Appendix A for examples and explanations of both the aerial photograph interpretation and field sample plot data forms.

To avoid double-counting of sediment sources, air photo-identified features encountered within field sample plots were not counted. However, field personnel did estimate feature depth, and verified air photo measurements of the feature surface area and other information collected on the air photo data form. While traveling to the 40 field sample plots, efforts were made to field verify and measure 5% of the air photo-identified features for verification of dimensions, volumes and attributes.

We did not attempt to quantify chronic surface erosion processes such as soil creep as a part of this study because of budgetary and time restrictions, as well as the technical difficulty of addressing it. Surface erosional processes such as soil creep and rill erosion may be significant contributors to overall erosion and sediment delivery in the Pescadero-Butano watershed, so the erosion volume and sediment delivery rates presented here should be viewed as minimum estimates.

FIELD DATA ANALYSIS

Field data were analyzed to determine the total past erosion and sediment delivery occurring in the watershed. Measured erosion and sediment delivery in the 40 sample plots was first tallied by Hillslope Geomorphic Unit, and the plot measurements were then extrapolated to the area of each HGU in the watershed to estimate total erosion and delivery for the Pescadero Creek basin. Additional data sorts were then conducted to determine the relative percent of the total volume that was controllable, as well as the primary geologic and land use associations present. For each HGU, the plot-estimated volume of erosion and sediment delivery was added to the photo-identified features in the HGU to arrive at the total for the entire Pescadero-Butano watershed. Therefore:

$$\text{Total erosion or delivery} = \text{Total plot volume (extrapolated)} + \text{Total air photo volume (directly measured)}$$

Field plot data were analyzed using S-Plus data analysis and statistics software. Estimates of total plot erosion and sediment delivery for all data were calculated for the entire basin using the following equations for estimation based on stratified random sampling (STRS) (Cochran, 1977):

(1) $\bar{\mathbf{y}}_{\mathbf{i}}$ = mean erosion or sediment delivery per plot

in HGU i = $\mathbf{(1/n_i) *} \sum_{j=1}^{n_i} y_{ij}$

where n i = total number of sampled cells in HGU i

y ij = erosion or delivery in the jth sampled cell of HGU i

(2) $\hat{\mathbf{T}}_{\mathbf{i}}$ = estimated total plot erosion or sediment delivery in HGU i = $\mathbf{N\ i * (}\ \bar{y}_i\ \mathbf{)}$

where N i = total number of plot cells in HGU i

(3) $\hat{\mathbf{T}}_{\mathbf{i}}$ = estimated total plot erosion or sediment delivery for the total basin = $\sum_{i=1}^{L} \hat{T}_i$

where L = number of HGUs (7)

Calculations were performed for each HGU and land use category to estimate the amount of controllable and uncontrollable sediment production in the Pescadero basin. Estimates of the percent controllability were calculated as the ratio of controllable plot erosion or sediment delivery to total plot erosion or sediment delivery using the following equations:

(4) $\hat{\mathbf{T}}_{\mathbf{y}} = \sum_{\mathbf{i}=1}^{\mathbf{L}} \mathbf{N_i \bar{y}_i}$

where $\hat{\mathbf{T}}_{\mathbf{y}}$ = estimated total of controllable erosion or delivery

(5) $\hat{\mathbf{T}}_{\mathbf{z}} = \sum_{\mathbf{i}=1}^{\mathbf{L}} \mathbf{N_i \bar{z}_i}$

where $\hat{\mathbf{T}}_{\mathbf{z}}$ = estimated total erosion or delivery

(6) $\hat{\mathbf{R}} = \hat{\mathbf{T}}_{\mathbf{y}} / \hat{\mathbf{T}}_{\mathbf{z}}$

where $\hat{R}$ = ratio of controllable erosion or sediment delivery to total erosion or sediment delivery in the Pescadero basin.

(7) **% controllability** = $\hat{\mathbf{R}}$ *** 100**

$\hat{\mathbf{R}}$ is sometimes called a "combined ratio", because a single ratio is estimated for all strata (Cochran, 1977; Sarndal, et al., 1992)

ANALYSIS OF AERIAL PHOTOGRAPHIC DATA

Total erosion and sediment delivery from photo-identified features were determined using a ratio estimator (Cochran, 1977; Thompson, 1992). Because determining erosion and sediment delivery volumes from air photo analysis is error-prone and subject to bias, the estimated ratio of field-measured volume to photo-estimated volume was used to correct photo-estimated volumes. This was achieved by visiting a sample of 12 air-photo identified features and recording erosion dimensions and sediment delivery information. Features were selected that were in or near field plots, but the selection was not strictly random. The following equations were used to determine the ratio estimators of total erosion and sediment delivery for the entire basin:

(8) $\hat{\mathbf{R}}_{\mathbf{w}}$ = ratio of the sample means = $\dfrac{\bar{\mathbf{y}}}{\bar{\mathbf{x}}}$

where $\bar{\mathbf{y}}$ = mean of the field measured erosion or sediment delivery

$\bar{\mathbf{x}}$ = mean of the air photo estimated erosion or sediment delivery

(9) $\hat{\mathbf{T}}$ = total air photo estimated erosion or sediment delivery = $\hat{\mathbf{R}}_{\mathbf{w}}\mathbf{T}_{\mathbf{x}} = \hat{\mathbf{R}}_{\mathbf{w}}\sum_{\mathbf{i}=1}^{\mathbf{N}} \mathbf{x}_{\mathbf{i}}$

where $\mathbf{T}_{\mathbf{x}}$ = sum of all air photo estimated erosion or sediment delivery

The above estimators are nearly unbiased under simple random sampling, but are "best linear unbiased estimators" (BLUE) if (1) the relation between y and x is a straight line through the origin, and (2) the variance of y about this line is proportional to x_i (Cochran, 1977).

SEDIMENT SOURCE ASSESSMENT RESULTS

The sediment source analysis results consist of six components which are presented below: 1)an estimate of erosion and sediment delivery from air photo-identified features, by Hillslope Geomorphic Unit (HGU); 2) compilation of the 40 stratified field sample plots by HGU; 3) STRS estimation of erosion and sediment delivery, 4) estimation of pre-1956 erosion and sediment delivery volumes, 5) analysis of total sediment delivery and sediment yield[1] by primary land use association, and 6) analysis of total sediment delivery and yield by time frames and management association. Statistical data for features inventoried in both the field survey and the air photo inventory are outlined in Table 6-3.

AERIAL PHOTO INVENTORY RESULTS

Table 6-4 summarizes the total erosion and sediment delivery by HGU and feature type from identified erosional features in the air photo inventory, and Map 6-6 shows the spatial distributions of inventoried features. The aerial photo inventory results are summarized by photo time period in Table 6-5.

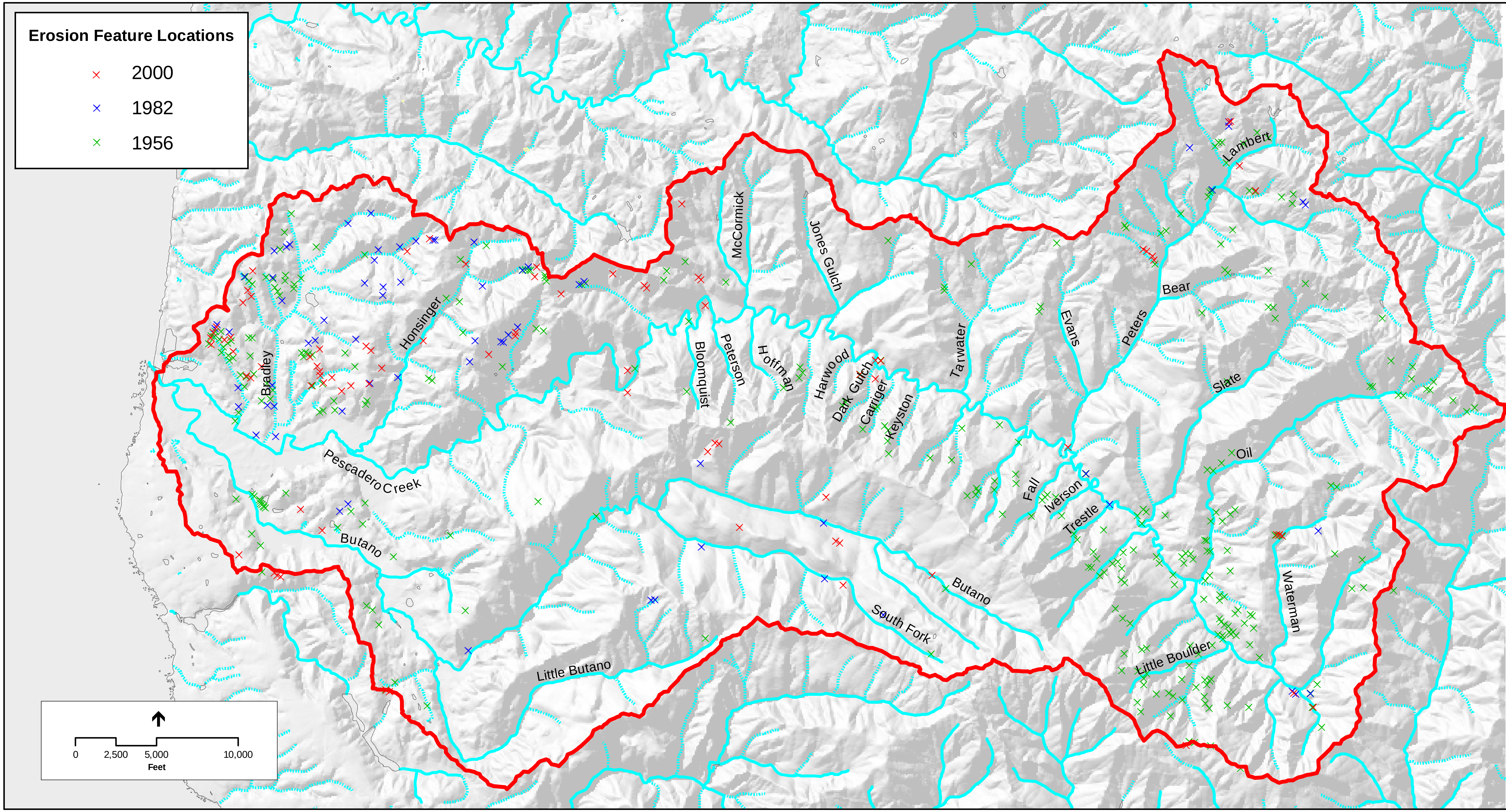
1 Sediment *delivery* refers to the amount of sediment that reaches a stream channel. Sediment *yield* is used in this report when stating normalized sediment erosion or delivery rates, in terms of volume per unit area of time.

TABLE 6-3
STATISTICAL INFORMATION ON SEDIMENT DELIVERY FOR ALL FIELD-SURVEYED AND AERIAL PHOTO-IDENTIFIED FEATURES BY HILLSLOPE GEOMORPHIC UNIT (HGU), PESCADERO-BUTANO WATERSHED

	Sample Plot Feature Delivery					Aerial photo Feature Delivery				
HGU	**Count**	**Minimum (yds^3)**	**Maximum (yds^3)**	**Median (yds^3)**	**Mean (yds^3)**	**Count**	**Minimum (yds^3)**	**Maximum (yds^3)**	**Median (yds^3)**	**Mean (yds^3)**
1	99	1	1,422	20	62	55	31	8,311	521	1,019
2	281	1	5,333	17	87	101	31	10,343	388	833
3	222	1	1,707	27	80	61	30	38,147	605	2,741
4	197	1	2,334	30	92	155	12	38,827	409	1,822
5	46	1	1,137	15	79	13	12	1,416	222	338
6	57	1	569	21	70	19	53	5,478	103	756
7	0	0	0	0	0	133	25	55,430	1,034	3,855
Entire watershed	**902**	**1**	**5,333**	**22**	**82**	**537**	**12**	**55,430**	**502**	**2,087**

TABLE 6-4
TOTAL ESTIMATED EROSION AND SEDIMENT DELIVERY (in yds^3) OF IDENTIFIED AERIAL PHOTO FEATURES BY HGU AND EROSIONAL FEATURE TYPE, PESCADERO-BUTANO WATERSHED

Erosional feature type	Number of aerial photo features by HGU 1	2	3	4	5	6	7	# of features	Estimated erosion (yds^3), and % of total	Estimated sediment delivery (yds^3), and % of total
Debris slide (DL)	31	61	38	92	11	15	43	291	532,818 (31.1%)	258,473 (23.1%)
Debris torrent source (DT)	12	20	5	34	1	3	8	83	285,404 (16.7%)	165,403 (14.8%)
Debris torrent track (TT)	10	11	6	25	1	1	1	55	187,134 (10.9%)	172,297 (15.4%)
Gully (GU)	2	9	12	4	0	0	81	108	706,204 (41.3%)	522,669 (46.7%)
Total # of features	**55**	**101**	**61**	**155**	**13**	**19**	**133**	**537**	**–**	**–**
Total erosion volumes	**102,675**	**165,207**	**258,815**	**467,478**	**9,101**	**26,011**	**682,273**	**–**	**1,711,560**	**–**
Total delivery volumes	**56,066**	**84,191**	**164,490**	**282,542**	**4,405**	**14,367**	**512,781**	**–**	**–**	**1,118,842**



SOURCE: USGS data sets from Bay Area Regional Database; Pacific Watershed Associates

Map 6-6

Erosion Features Mapped From Aerial Photographs, 1956, 1982, 2000

TABLE 6-5
TOTAL ESTIMATED EROSION AND SEDIMENT DELIVERY (in yds^3) OF IDENTIFIED AIRPHOTO FEATURES BY PHOTO YEAR AND HGU, PESCADERO-BUTANO WATERSHED

	Number of air photo features by HGU									
Photo year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**# of features**	**Estimated erosion (yds^3), and % of total**	**Estimated sediment delivery (yds^3), and % of total**
1956	50	81	28	124	9	6	82	380	1,205,892 (70.5%)	785,784 (70.2%)
1982	2	9	16	11	3	8	21	70	67,990 (4.0%)	44,723 (4.0%)
2000	3	11	17	20	1	5	30	87	437,678 (25.6%)	288,335 (25.8%)
Total # of features	55	101	61	155	13	19	133	537	–	–
Total erosion volumes	102,675	165,207	258,815	467,478	9,101	26,011	682,273	–	1,711,560	–
Total delivery volumes	56,066	84,161	164,490	282,572	4,405	14,367	512,781	–	–	1,118,842

A total of 537 individual erosional features were identified and quantified in the inventory, with 317 (59%) occurring within three HGUs: HGU 2 (mixed lithology, steep slope), HGU 3 (sandstone, gentle slope), and HGU 4 (sandstone, steep slope) (Table 6-4). These HGUs account for 52% of the total erosion and 47% of the sediment delivery to channels in the air photo inventory. However, 25% of the erosional features identified in the inventory were located in HGU 7, Quaternary sediments, accounting for 40% of the total erosion and 46% of the sediment delivery. This result stands in contrast with the field survey results, and this disparity will be discussed below[2].

Debris slides were the most common features in the inventory, comprising 54% of the total, but accounting for only 31% of the total erosion and 23% of sediment delivery. Gullies comprised only 20% of the features, but accounted for 41% of the total erosion and 47% of the sediment delivery in the air photo inventory. Gullies were most heavily concentrated in HGU 7, Quaternary sediments.

The 1956 photo set contained the greatest volumes of both erosion and sediment delivery of any of the three time periods examined, accounting for 70% of both the total erosion and sediment delivery volumes quantified on the three sets of aerial photos (Table 6-5). In contrast, the 1982 photo set accounted for only 4%, and the 2000 photo set accounted for about 26% of both total erosion and sediment delivery.

While large, infrequent storms have been shown to trigger episodic erosion, these results are not necessarily a reflection of the relative magnitude of the storms of 1955, 1982 and 1998. A number of other factors influence both the magnitude and frequency of erosional features on the landscape. Rainfall intensity can play an important role in influencing spatial patterns of erosion and can show extreme local variation in any large storm. Antecedent soil moisture can also modify the effects of rainfall amount and intensity. A large precipitation event occurring when soils are saturated is much more likely to cause mass failures than one occurring on soil with less antecedent moisture. In addition, patterns of land use and intensities of land use practices can strongly influence erosion. The influence of land use in the Pescadero-Butano watershed will be discussed below.

FIELD SURVEY RESULTS

Map 6-5 shows the locations of inventoried field survey plots. Most of the field sample plots occurred on either commercial timberland or public lands. Of the 40 plots, only six were located wholly or partially on non-timber private lands. Three of these (plots 20, 43 and 60) were in HGU 7, Quaternary sediments, and all of these were on low-gradient floodplain lands adjacent to Pescadero or Butano Creek and dominated by riparian woodland, scrub and grassland vegetation. Five plots were located within Butano State Park (plots 300, 370, 389, 433 and 456), and all but one of these were forested with dense undergrowth. All of these plots occurred in HGUs 5 and 6

[2] Not included in the air photo inventory or elsewhere in the sediment source analysis is an estimate of the volume of sediment produced by the apparent recent incision of the lower channel of Butano Creek. This is discussed earlier in this chapter and in Chapter 5.

(shale/mudstone, gentle and steep, respectively), and the forested plots generally contained some old growth and evidence of old logging, as well as short stretches of fire road. Two plots were completely within San Mateo County parkland in HGUs 3 and 5 (sandstone, gentle and shale/mudstone, gentle, respectively), both containing reaches of the mainstem of Pescadero Creek. These two plots had been logged over 50 years ago.

Twenty plots were located in commercial timberlands, occurring in HGUs 1 through 4 and 6. These plots were dominated by second growth forest ranging in age from roughly 15 to 75 years, and generally with dense undergrowth. Only one plot in the commercial timberlands had experienced logging within the past five years, and this plot was selectively harvested and marked by extensive areas of disturbed ground and almost no undergrowth. Six plots in HGUs 1 and 2 (mixed lithology, gentle and steep, respectively) were located on Mid-Peninsula Open Space District land, and these plots were dominated by grassland and oak woodland with some redwood-fir forest on the steeper plots. Most plots contained short lengths of either forest, ranch or fire roads, and use of these roads was generally very light. Ten plots had no roads at all. All the plots in commercial timberlands, the two plots on San Mateo County parkland, and the two plots that were mostly on private land in HGU 2 contained extensive networks of old skid roads that had been naturally re-vegetated to varying degrees.

In order to derive an estimate of total basin erosion and sediment delivery over the last 66 years, all erosional features measured within the sample plots were first tabulated. Table 6-6 summarizes, by HGU, the total measured erosion and sediment delivery from within the 40 randomly selected sample plots. The type of erosional feature further subdivides the results.

A total of 902 individual erosional features were measured in the field survey. Of these, 700 (78%) were found in HGUs 2, 3 and 4 (mixed lithology, steep; and gentle and steep sandstones, respectively). A total of 112,660 yds^3 of past erosion and 72,797 yds^3 of past sediment delivery occurred within the 40 sample plots. Approximately 83% of the measured erosion and 82% of the measured delivery occurred within HGUs 2, 3 and 4. A total of 103 (11%) erosional features were inventoried within the two HGUs characterized by shale and mudstone (HGUs 5 and 6), and these made up only 10% of both the total erosion and sediment delivery. No erosional features were measured within the four plots located within HGU 7, Quaternary sediments.

Bank erosion and channel incision sites each account for 30% of the total number of erosional features in the plots, but only approximately 17% and 23%, respectively, of the total sediment delivery (Table 6-6). Debris slides comprise 20% of the total number of erosional features in the survey plots, but account for 56% of the measured erosion and 46% of the total sediment delivery. Gullies also were relatively common in the survey plots, accounting for 18% of the total number of sites, but only 10% of the total sediment delivery. Earthflows, debris torrent source sites and torrent tracks were scarce in the survey plots.

Field-measured erosion and sediment delivery volumes were also summarized by time period, based on an estimated age assigned to each feature in the field (Table 6-7). Even though the storm of 1955 is the second-largest in the historical record and produced the largest volume of erosion and sediment delivery of the three aerial photo sets analyzed, very few features from the

TABLE 6-6
TOTAL MEASURED EROSION AND SEDIMENT DELIVERY (in yds^3) WITHIN THE 40 FIELD SAMPLE PLOTS BY HGU AND EROSIONAL FEATURE TYPE, PESCADERO-BUTANO WATERSHED

Erosional Feature Type	Number of Field Measured Features by HGU							# of features	Erosion (yds^3), and % of total	Sediment delivery (yds^3), and of total
	1	2	3	4	5	6	7			
Bank erosion (BE)	28	102	76	51	9	4	0	270	14,467 (12.8%)	12,426 (17.1%)
Channel incision (CI)	34	93	57	52	6	25	0	267	16,689 (14.8%)	16,689 (22.9%)
Debris slide (DL)	12	50	36	49	15	20	0	182	63,193 (56.1%)	33,423 (45.9%)
Debris torrent source (DT)	0	1	0	0	0	0	0	1	89 (0.1%)	71 (0.1%)
Debris torrent track (TT)	0	1	0	0	0	2	0	3	1,060 (0.9%)	849 (1.2%)
Gully (GU)	25	27	45	43	15	6	0	161	8,743 (7.8%)	7,560 (10.4%)
Deep-seated slide (SSD)	0	4	8	1	0	0	0	13	8,326 (7.4%)	1,718 (2.4%)
Other sites	0	3	0	1	1	0	0	5	93 (0.1%)	61 (0.1%)
Total # of features	**99**	**281**	**222**	**197**	**46**	**57**	**0**	**902**	**–**	**–**
Total erosion volumes	**7,356**	**36,474**	**27,443**	**30,150**	**4,950**	**6,270**	**0**	**–**	**112,660**	**–**
Total delivery volumes	**5,819**	**24,452**	**17,306**	**18,091**	**3,321**	**3,808**	**0**	**–**	**–**	**72,797**
Total # of plots/terrain type area in mi2	***4/6.8***	***7/13.9***	***8/20.0***	***8/16.2***	***4/8.8***	***5/5.4***	***4/9.9***	**–**	**–**	**–**

TABLE 6-7
TOTAL EROSION AND SEDIMENT DELIVERY (in yds^3) OF FIELD-IDENTIFIED FEATURES BY TIME PERIOD AND HGU, PESCADERO-BUTANO WATERSHED

Time period	Number of field-identified features by HGU 1	2	3	4	5	6	7	# of features	Erosion (yds^3)	Sediment delivery (yds^3)
pre-1956	3	9	19	13	0	0	0	44	5,949	4,091
1956-1982	33	89	104	88	22	20	0	356	46,646	30,484
1983-2002	63	183	99	96	24	37	0	502	60,065	38,222
Total # of features	**99**	**281**	**222**	**197**	**46**	**57**	**0**	**902**	**–**	**–**
Total erosion volumes	**7,356**	**36,491**	**27,443**	**30,150**	**4,950**	**6,270**	**0**	**–**	**112,660**	**–**
Total delivery volumes	**5,819**	**24,452**	**17,306**	**18,091**	**3,321**	**3,808**	**0**	**–**	**–**	**72,797**

period before 1960 were identified in the field. This is probably a result of the difficulty in identifying erosional features with increasing age. Most erosional features identified in the field survey were too small to be located on aerial photos, and many occurred under forest canopy. Features older than 40-50 years are often masked by revegetation, and can also be obscured by changes in vegetative cover and more recent land use activities. It is also possible for some features to be reactivated by more recent erosion and to appear to be younger than they actually are. Consequently we believe that the erosion and sediment delivery volumes for the pre-1956 time period are substantially underestimated. This underestimation will be addressed below.

NOTE ON LOCATIONS OF DEBRIS SLIDE OCCURRENCE

A total of 473 debris slides were identified and mapped 291 in the aerial photo inventory and 182 in the field surveys (Table 6-8). More than half (51%) of the debris slides occurred at "streamside geomorphic locations", which are defined for this investigation as hillslopes less than 65% in steepness that are immediately adjacent to a stream. In contrast, 123 debris slides (26%) occurred on streamside hillslopes which meet the slope criteria of 65% or steeper, so as to be classified as "inner gorge" landslides (Table 6-8). Documenting fewer debris slides on inner gorge verses streamside hillslopes is atypical for forested coast range watersheds in northern California. Generally speaking, as streamside hillslopes increase in steepness, the frequency of debris slides increases. By our definition, inner gorge slopes are present throughout the watershed. The higher frequency of debris slides on hillslopes classified as "streamside in steepness" may reflect the inherent low strength of the various bedrock geologies in the watershed.

The occurrence of debris slides in steep headwall swale areas (i.e. the upslope extent of small first order streams) was relatively common, with 81 individual slides or 17% of the total (Table 6-8). Steep headwall swale areas in the watershed are locations where debris slides frequently evolve into debris torrents or flows.

Steep inner gorge areas were present in all HGUs, including those defined by a gentle (<40%) average gradient. Further classification of these areas to remove them from the gently sloping HGUs might result in a more accurate picture of the spatial patterns of erosion in the Pescadero-Butano watershed. It would, however, be difficult to isolate these areas as a separate HGU type because of their widespread occurrence in the basin and their limited spatial extent. Although slides were concentrated in inner gorge areas, fewer slides occurred overall in gently sloping HGUs than in steep HGUs (Table 6-8). In light of time and budgetary constraints, we believe the study design provides an accurate first estimate of the relative levels of erosion and sediment delivery in the basin.

TABLE 6-8
DEBRIS SLIDE LOCATIONS
BY GEOMORPHIC ASSOCIATION AND HGU

	HGU	Geomorphic Association: Inner gorge	Streamside	Head wall swale	Other	Totals
1	Mixed lithology, gentle slope	5	29	7	2	43
2	Mixed lithology, steep slope	41	45	23	2	111
3	Sandstone, gentle	17	50	6	1	74
4	Sandstone, steep	38	64	32	7	141
5	Shale/mudstone, gentle	13	11	0	2	26
6	Shale/mudstone, steep	9	14	5	7	35
7	Quaternary sediments, gentle	0	30	8	5	43
	Totals:	**123**	**243**	**81**	**26**	**473**
	Debris slides occurring in gently sloping HGUs	35	120	21	10	186
	Debris slides occurring in steep HGUs	88	123	60	16	287
	Totals:	123	243	81	26	473

STRS FIELD-BASED ESTIMATION OF BASINWIDE EROSION AND SEDIMENT DELIVERY

The statistical methods outlined above were utilized to extend the field survey data to the entire basin, based on the area of each HGU. Extrapolated field erosion and sediment delivery volumes are summarized by time period in Table 6-9. The bulk of all erosion and sediment delivery falls into HGUs 2 (mixed lithology, steep slope), 3 (sandstone, gentle) and 4 (sandstone, steep). These three units combined account for 87% of the total extrapolated erosion volume and 86% of the total sediment delivery. HGU 2 accounts for the largest proportion of erosion and sediment delivery for the basin, while HGUs 1 (mixed lithology, gentle slope), 5 (shale/mudstone, gentle), 6 (shale/mudstone, steep) and 7 (Quaternary sediments, gentle) together comprise less than 15% of both the erosion and sediment delivery for the basin as calculated using these methods. Results for HGU 7 reflect the fact that no erosional features were inventoried in the field survey plots for this HGU.

Table 6-9 indicates estimated erosion and sediment delivery is higher in HGU 3 (sandstone, gentle) than in HGU 4 (sandstone, steep). We would have expected higher volumes of sediment delivery from the steeper terrain, given the same primary bedrock geology. However, a larger number of erosional features were mapped within the gentle sandstone plots than in the steep sandstone plots (Table 6-6). As would be expected, the number of debris slides is higher in HGU 4 (sandstone, steep), but Table 6-6 indicates a larger number of bank erosion, channel incision and gully erosional features occurred in HGU 3 (sandstone, gentle). Given the types of erosional processes present in the gentler HGU 3, it is possible that the higher volume of erosion and sediment delivery reflects a relatively higher level of ground disturbance associated with older logging practices, including tractor logging up and down smaller stream channels, than on the steeper HGU 4 sandstone slopes.

ESTIMATION OF PRE-1956 EROSION AND SEDIMENT DELIVERY

To compensate for the perceived under-estimation of erosion and sediment delivery in the pre-1956 time period, a revised volume estimate was developed. The approach was to use the volumes quantified in the analysis of the 1956 aerial photo set, and the relationship between the air photo-quantified and extrapolated field survey volumes from the most recent time period (i.e. 1983 to 2002). We used this relationship as the basis for estimating the pre-1956 erosion and sediment delivery volumes from plots or field-based efforts because we believe the numbers developed from analyses of the most recent time period are the most accurate in the study. Note that Table 6-9, which shows the extrapolated results of the field surveys, has zero erosion and sediment delivery for all time frames for HGU 7. Yet the 1956 aerial photos documented the highest number of erosion features, and the highest volume of erosion and sediment delivery in any of the three time frames for this HGU (Table 6-5).

In calculating the revised pre-1956 volumes, we assumed that the ratios of the extrapolated sample plot volumes to the aerial photo volumes remain constant through time (T. Spittler, 2003, personal communication). We calculated ratios for both erosion and sediment delivery for the 1983-2002 data as follows:

(10) $\mathbf{R_e} = \mathbf{APe_{2000}}/\mathbf{Fe_{2000}} = 0.228$

(10a) $\mathbf{R_d} = \mathbf{APd_{2000}}/\mathbf{Fd_{2000}} = 0.236$

where $\mathbf{APe_{2000}}$ = the volume of erosion for the 2000 photo set;

$\mathbf{APd_{2000}}$ = the volume of sediment delivery for the 2000 photo set;

$\mathbf{Fe_{2000}}$ = the extrapolated survey plot erosion volume for the period 1983-2002;

$\mathbf{Fd_{2000}}$ = the extrapolated field survey plot sediment delivery volume for the period 1983-2002;

and $\mathbf{R_e}$ and $\mathbf{R_d}$ = the air photo volume to extrapolated field survey volume ratios for erosion and sediment delivery, respectively.

TABLE 6-9
EROSION AND SEDIMENT DELIVERY VOLUMES (in yds^3) STATISTICALLY EXTRAPOLATED FROM FIELD-MEASURED FEATURES, BY TIME PERIOD AND HGU, PESCADERO-BUTANO WATERSHED

HGU	Time period: Pre-1956 Erosion	Pre-1956 Delivery	1956-1982 Erosion	1956-1982 Delivery	1982-2002 Erosion	1982-2002 Delivery	Total erosion (yds^3)	Total sediment delivery (yds^3)
1. Mixed lithology, gentle slope	41,938	41,938	62,866	51,257	95,647	65,373	200,451 (5.4%)	158,568 (6.6%)
2. Mixed lithology, steep slope	76,336	20,012	351,965	219,463	728,985	536,003	1,157,286 (31.1%)	775,478 (32.3%)
3. Sandstone, gentle slope	43,760	43,480	658,700	405,960	395,260	242,800	1,097,720 (29.6%)	692,240 (29.0%)
4. Sandstone, steep slope	29,429	27,001	429,794	294,305	516,883	264,390	976,106 (26.3%)	585,696 (24.5%)
5. Shale/mudstone, gentle slope	0	0	76,334	55,025	98,154	62,040	174,488 (4.7%)	117,065 (4.9%)
6. Shale/mudstone, steep slope	0	0	22,885	15,162	84,959	50,336	107,844 (2.9%)	65,498 (2.7%)
7. Quaternary sediments, gentle slope	0	0	0	0	0	0	0 (0%)	0 (0%)
Totals	**191,463**	**132,431**	**1,602,544**	**1,041,172**	**1,919,888**	**1,220,942**	**3,713,895**	**2,394,545**

In other words, the ratio of the air photo-inventoried erosion volume to the extrapolated field survey erosion volume is 22.8%, and the ratio of the air photo-inventoried sediment delivery volume to the extrapolated field survey sediment delivery volume is 23.6%. Corrected erosion and sediment delivery field volumes for the pre-1956 period were then calculated using these ratios and the volumes from the 1956 aerial photo inventory as follows:

(11) $\mathbf{Fe_{1956} = APe_{1956}/0.228}$,

(11a) $\mathbf{Fd_{1956} = APd_{1956}/0.236}$.

The volumes developed using the methods are summarized in Table 6-10. These estimated volumes should be considered with due caution. In particular, we believe that this method overestimates the volumes for HGU 7 (Quaternary sediments). HGU 7 is dominated by grasslands and agricultural lands, and has historically lacked significant amounts of forested land. These conditions were even more pronounced in the pre-1956 time period than today. Given this fact, the aerial photo analyses for this HGU probably captured a higher percentage of the total number of erosional features than in any other HGU. Consequently, the AP/F ratio for this area is probably greater than for the watershed as a whole. The field survey did not identify any erosional features in this HGU, but we believe this is partly due to the locations of the field plots (discussed below).

The volumes estimated using the AP/F method were substituted for the pre-1956 volumes derived from the field survey. These volumes were then combined with the aerial-photo-estimated volumes and the post-1956 extrapolated field volumes to arrive at a total erosion and sediment delivery volume for each HGU for each time period (Table 6-11).

BASINWIDE EROSION AND SEDIMENT DELIVERY

The total erosion and sediment delivery volumes for each HGU were normalized by HGU area and time to estimate average annual erosion rates and sediment yields for each HGU and for the basin as a whole (Table 6-11 and Map 2-2). The numbers presented in this section have been calculated or estimated using a variety of methods, as previously discussed, and are rounded to reflect a gross level of precision of the data.

Several broad patterns emerge in these results. The Quaternary sediment unit (HGU 7) is the most productive overall, with an erosion rate and sediment yield of 4,500 and 2,700 yds^3/mi^2/year, respectively (Table 6-11). Rates for HGU 7 are probably overestimated; but given the extensive management of this HGU during the first half of the last century (see history section), we would expect sediment yield rates in HGU 7 to be similar to HGUs 2 and 4 (mixed lithology and sandstone, steep, respectively). Steep HGUs are more productive than gently sloping units in the same geology, while sandstones are more productive than mixed lithology units in the same slope class. HGUs 5 and 6 (shale/mudstone) are the least productive in the watershed.

TABLE 6-10
REVISED FIELD PLOT VOLUMES OF EROSION AND SEDIMENT DELIVERY (in yds^3)
FOR THE PERIOD 1937-1956, BASED ON CALCULATIONS (10) AND (11),
BY HGU, PESCADERO-BUTANO WATERSHED

HGU	1	2	3	4	5	6	7	Estimated erosion (yds^3)	Estimated sediment delivery (yds^3)
Erosion volumes	394,560	596,283	329,099	1,620,959	35,386	52,595	2,260,801	5,289,683	–
Delivery volumes	189,072	279,428	249,124	941,860	17,934	27,750	1,622,200	–	3,327,368

TABLE 6-11
ESTIMATED PAST EROSION AND SEDIMENT DELIVERY (in yds^3 and $yds^3/mi^2/year$), BY HILLSLOPE GEOMORPHIC UNIT, FOR THE PERIOD 1937 TO 2002, PESCADERO-BUTANO WATERSHED

	Estimated pre-1956 volumes[1]		Features identified on survey plots[2]		Air photo-identified features[3]		Total erosion and sediment delivery (yds^3), erosion rate and sediment yield ($yds^3/mi^2/yr$) by HGU for the period 1937-2002[4].			
HGU	Erosion (yds^3)	Sediment delivery (yds^3)	Erosion (yds^3)	Sediment delivery (yds^3)	Erosion (yds^3)	Sediment delivery (yds^3)	Erosion	Erosion rate	Sediment delivery	Sediment yield
1. Mixed lithology, gentle slope	394,560	189,072	158,513	116,630	102,675	56,066	655,000	1,500	362,000	800
2. Mixed lithology, steep slope	596,283	279,428	1,080,950	755,466	165,207	84,191	1,840,000	2,000	1,119,000	1,200
3. Sandstone, gentle slope	329,099	249,124	1,053,960	648,760	258,815	164,490	1,640,000	1,200	1,062,000	800
4. Sandstone, steep slope	1,620,959	941,860	946,677	558,695	467,478	282,542	3,040,000	2,800	1,783,000	1,700
5. Shale/mudstone, gentle slope	35,386	17,934	174,488	117,065	9,101	4,405	219,000	400	139,000	200
6. Shale/mudstone, steep slope	52,595	27,750	107,844	65,498	26,011	14,367	186,000	500	108,000	300
7. Quaternary sediments, gentle slope	2,260,801	1,622,200	0	0	682,273	512,781	2,940,000	4,500	2,135,000	3,300
Totals[4]	**5,290,000**	**3,327,000**	**3,520,000**	**2,260,000**	**1,710,000**	**1,120,000**	**10,520,000**	**2,000**	**6,710,000**	**1,250**

[1] Pre-1956 volumes are estimated using an aerial photo/field volume ratio based on the 2000 aerial photos and the 1982-2002 field survey volumes.
[2] Erosion and sediment delivery estimates are calculated from a combination of the equations in Method 1 for field-inventoried features dated to the post-1956 time period, and an estimate based on the 1956 aerial photo volumes for the pre-1956 time period.
[3] Aerial photo analysis assessed all identifiable features within an 81 mi^2 area on three air photo sets for the years 1956, 1982 and 2000.
[4] Total volumes and rates are rounded to reflect the level of precision of the data.

Overall basin erosion volume was calculated to be 2,000 yds^3/mi^2/year, and sediment delivery to stream channels was calculated at 1,250 yds^3/mi^2/year (Table 6-11). This latter figure is somewhat low when compared to Macy's (1976) estimate for sediment yield in the upper San Lorenzo watershed, which was 1,571 yds^3/mi^2/year. This is not surprising since Macy used an entirely different methodology, measuring sediment yield at gauging stations rather than sediment inputs. This estimate is also low compared to the 1,600 yds^3/mi^2/yr. calculated by Dvorsky (2003) for the Aptos Creek Watershed, and compared to the 1,400 yds^3/mi^2/year calculated by Owen, et al. (2003) for the Gazos Creek watershed. However, HGU 7 notwithstanding, we consider this estimate for the Pescadero-Butano watershed to be a minimum yield since we did not measure surface erosion from bare soil areas and road beds throughout the watershed, or soil creep. In addition, we believe that the small scales on two of the aerial photo sets and the poor quality of the third set resulted in some undercounting of landslides and gullies, particularly in the forested areas.

To address one of these shortcomings, an estimate of surface erosion from roads throughout the basin will be presented later in Table 6-12. The estimate is based on a recent road sediment source assessment conducted on the three San Mateo County Parks located in the watershed (PWA, 2003). The assessment documented the extent of road bed "hydrologic connectivity" to stream channels within the county park lands.

DISCUSSION

Erosion and sediment yield results largely conform to expectations based on field observations, erodibility ratings and descriptions of geologic units. Approximately 28% of the total watershed erosion volume and 30% of the sediment delivery occurs in HGU 7, Quaternary sediments with gentle slopes (Table 6-11). The erosion and sediment yield rates in this HGU are the highest in the study, at 4,500 yds^3/mi^2/year and 3,300 yds^3/mi^2/year respectively. All of the erosion in HGU 7 was either inventoried during or extrapolated from the air photo analysis. No erosional features were identified in the survey of field plots in HGU 7 (Table 6-11). The seeming disparity between the air photo inventory and the field survey at least partly resulted from the random selection of survey plots.

HGU 7 is confined to the western part of the Pescadero-Butano watershed, west of the San Gregorio Fault. This part of the watershed is largely in private ownership, and access was not available to field crews on a total of five sample plots in this HGU. Three of the four plots that we were able to access in HGU 7 were located on flat or gently sloping floodplain lands adjacent to either Pescadero Creek or Butano Creek. In this type of environment, mass movement and gullying are rare. The fourth survey plot in this HGU was located in an upland area, but no erosional features were discovered. Comparison of these results to the air photo analysis data appears to indicate that the four survey plots are not a representative sample of this HGU. However, HGU 7 is primarily grassland, coastal scrub and current or former agricultural land, and even small erosional features tend to be visible on aerial photos. Consequently we believe that the aerial photo analysis of HGU 7 is more complete than for the other HGUs because of the relative lack of tree canopy.

Our estimate of pre-1956 field plot-based erosion and sediment delivery was based on the aerial photo volumes for the same pre-1956 period, divided by the ratio of the 2000 aerial photo inventory volumes to the 1982-2002 field survey volumes. Because we believe that the survey plots in HGU 7 are not necessarily representative of the HGU, and because land use patterns change over time, this calculation was carried out for the watershed as a whole, rather than for individual HGUs. Calculation of the proportion of the total volume for each HGU was based on the proportion of the volume in each HGU in the analysis of the 1956 aerial photos. In HGU 7 this process very likely resulted in a large over-estimation of both the erosion and sediment delivery volumes. For the reasons outlined above, in this HGU we did not expect to locate many erosional features in the field surveys that had not been inventoried in the aerial photo analysis. Consequently, the ratio used to estimate the pre-1956 volume is probably too large.

Erosion and sediment delivery in HGU 7 are dominated by gullies, which comprise 61% of the individual erosional features inventoried and account for 86% of the aerial photo-inventoried erosion volume and 64% of the sediment delivery in the HGU (Table 6-4). Gullies in HGU 7 tended to be large, averaging 5,459 yds^3 of sediment delivery each, and included two gullies with over 50,000 yds^3 of delivery each - the largest individual features in the study. Debris slides were also common in this unit, but were much smaller contributors of sediment, averaging 1,138 yds^3 of delivery each and accounting for only 5% of the total sediment delivery. In this mostly gently sloping unit, most erosional features occurred in headwall swales or on relatively steep slopes adjacent to stream channels.

HGU 7 is mostly coastal scrub and grassland underlain by easily eroded sediments, and much of the area has been intensively grazed and/or cultivated for 170 years. Of the 133 individual erosional features identified in HGU 7, all but five are associated with past grazing or other agricultural land uses.

The erosion rate and sediment yield for HGU 3 (sandstone, gentle slope) were estimated to be 1,200 yds^3/mi^2/year and 800 yds^3/mi^2/year, respectively. HGU 4 (sandstone, steep) was roughly twice as productive, with an erosion rate of 2,800 yds^3/mi^2/year and a sediment yield of 1,700 yds^3/mi^2/year. HGUs 3 and 4 were more productive than units underlain by either mixed lithology (HGUs 1 and 2) or shale/mudstone (HGUs 5 and 6) in the same slope class (Table 6-11). This result is in line with expectations, as the most spatially extensive geologic unit in these HGUs is the Butano Formation, a marine sandstone of very high erodibility (Brown, 1973). In HGUs 3 and 4, debris slides dominated in terms of measured volume in the field plots, and both volume and numbers of features identified in the air photo analysis. In both the steep and gentle HGUs, most debris slides occurred on locally steep inner gorge areas ranging from 65% to over 100% in steepness.

In-channel processes (bank erosion and channel incision) also provided important contributions to sediment delivery for the sandstone units in the field survey results, accounting for 36% of the total delivery measured in HGU 3 and 26% in HGU 4 (Table 6-6). This large proportion may in part be a reflection of past land management practices (i.e. pre-1974 and the inception of the California Forest Practice Act). Fourteen of the 16 field sample plots in the sandstone HGUs were located in commercial timberlands, most of which were intensively logged from the 1930s through the 1970s.

Many first, second, and third-order streams in the sandstone units showed evidence of having been disturbed by tractor activity in the past. Mechanically introduced and naturally deposited channel-stored sediments were locally abundant in some plots. Over the decades, subsequent storm flows have to varying degrees incised into the accumulations of unconsolidated sediments, as the smaller streams work to re-occupy their natural stream beds. In such situations, most of the erosion tends to occur during the first ten to twenty years after disturbance (PWA, 1999a). In the Pescadero-Butano watershed, however, many small channels in HGUs 3 and 4 still contain locally significant quantities of sediment, which continue to contribute fine sediment to the stream system annually.

In HGUs 3 and 4, the larger stream channels (3rd order and higher) were generally flowing on or near bedrock, but showed evidence of locally extensive past aggradation in the form of historical terrace remnants and former log jams. Many of these remnant features were interpreted to be associated with either past land management activities and/or earlier debris flows. These relatively high-gradient, intermittent and perennial streams are very efficient at transporting sediment, especially particles in the sand size class.

Hillslope Geomorphic Unit 2 (mixed lithology, steep) had an erosion rate of 2,000 yds^3/mi^2/year and a sediment yield of 1,200 yds^3/mi^2/year. Mixed lithology is composed of a variety of severely deformed geologic units, exhibiting a range of erodibility ratings. The four most extensive geologic formations in the mixed lithology HGUs are the highly erodible Lambert shale and Vaqueros sandstone, and the generally resistant Mindego basalt and Monterey mudstone (Brown, 1973). This mix of units appears to contribute to a large variability in local conditions with regard to erosion. One factor that likely contributes to the high sediment yield for HGU 2 is its proximity to the San Andreas Fault. The eastern portion of the Pescadero-Butano watershed is mapped as a series of steeply folded anticlines and synclines. The extensive deformation, coupled with the highest topographic relief in the watershed, may pre-dispose the mixed lithology hillslopes more than other HGUs to bedding plane failures. Tables 6-4 and 6-6 show that a large number of debris slides occurred in the mixed lithology HGUs (HGUs 1 and 2).

Debris slides were the most important feature type in HGU 2, accounting for 35% of the estimated sediment delivery in the air photo inventory, and 39% of total measured delivery in the survey plots (Tables 6-4 and 6-6). Channel processes (bank erosion and channel incision) also proved to be very important in the field survey of this HGU, accounting for 40% of the total field measured sediment delivery. Just under half of the erosion from channel processes was associated with historic tractor logging.

Debris slides dominated in HGU 1 in terms of both erosion and sediment delivery in the air photo analysis, accounting for 50% of the total erosion volume and 55% of the sediment delivery. Debris slides were much less significant in the field survey, comprising only 28% of the total measured erosion and 11% of the sediment delivery. Channel incision again accounted for a greater proportion of the field-measured erosion, at 50%, with sediment delivery at 64%.

Two of the four plots surveyed in HGU 1 were located on Mid-Peninsula Open Space District lands. Based on numerous old terracettes and cattle trails, these plots appeared to have been extensively grazed in the past. The other two plots in HGU 1 were located on former commercial timberlands; one of these plots had been selectively logged within the last five years. Sediment delivery volume due to channel incision was split about evenly between the grassland and timberland areas. The timberland areas showed evidence of past tractor filling of small stream channels, but the frequent occurrence of channel incision in the grassland areas is not easily explained. It is difficult to discern whether filling of channels on grasslands (in the absence of mass movements) is related to the effects of past grazing, such as trampling and compaction, or whether it is the consequence of higher natural rates of surface erosion and soil creep in these areas.

HGUs 5 and 6 exhibited the lowest erosion rates and sediment yields in the study, with erosion rates of 400 yds^3/mi^2/year and 500 yds^3/mi^2/year and sediment yields of 200 yds^3/mi^2/year and 300 yds^3/mi^2/year, respectively. This result is to be expected, as the geologic formations in these HGUs have low or moderate erodibility ratings (Brown, 1973). HGU 6 (shale/mudstone, steep slope) is slightly more productive than HGU 5, which has gentler slopes. In both HGUs, debris slides were by far the most important features in terms of both erosion volume and sediment delivery, but channel processes proved to be significant sources of sediment in HGU 6.

ROAD-RELATED SURFACE EROSION AND FINE SEDIMENT DELIVERY

To estimate sediment delivery volumes for chronic surface erosion of roads, ditches and cutbanks in the Pescadero-Butano watershed, we relied on an inventory of road-related erosion and sediment delivery for the three San Mateo County Parks in the watershed (PWA, 2003). Road erosion occurs by several mechanisms: 1) cutbank erosion delivering sediment to the ditch triggered by dry ravel, rainfall, freeze-thaw processes, cutbank landslides and brushing/grading practices; 2) inboard ditch erosion and sediment transport; 3) mechanical pulverizing and wearing down of the road surface; and 4) erosion of the road surface during wet weather periods.

The road network in the San Mateo County Parks complex consists of 35 miles of gravel or dirt roads and five miles of paved roads, and includes both county-maintained roads and former logging haul roads. Forty-four percent (44%) of the total length of gravel roads, and 43% of the total length of paved road in the park complex were found to be “hydrologically connected” to the stream system, meaning that they are delivering fine sediment to nearby stream channels. The report estimated an average sediment delivery rate of 34 yds^3/year for each mile of paved road, and 148 yds^3/ year for each mile of unpaved road. These rates are averages that apply only to those road segments that are hydrologically connected to the stream system. The remaining lengths of road are likely eroding at similar rates, however the sediment is being captured and stored on the hillslopes or on terraces, and not being delivered to nearby stream channels.

We derived total road lengths for the watershed from a GIS road layer to calculate total lengths of paved and unpaved road for the entire Pescadero-Butano watershed (see Appendix D). For the period of 1983-2002, we applied the rate of 34 yds^3/mi/year to 30 miles of paved road (i.e. 43% of the total of 70 miles of paved road) in the watershed, and applied the rate of 148 yds^3/mi/year to 141 miles of unpaved road (i.e. 44% of the total of 325 miles of unpaved road). This calculation yielded an estimate of 22,019 yds^3/year of sediment delivery from chronic road surface lowering for the 1983-2002 period. For the period of 1937-1982, we used a higher percentage of connectivity (60% for paved roads and 80% for unpaved roads) for the same lengths of both paved and unpaved road to calculate the yearly sediment delivery rate. These estimates were then multiplied by the number of years to arrive at a total sediment delivery volume for road surface erosion for the study periods.

This estimate should be viewed with caution, but is probably a minimum estimate for several reasons. Road densities were probably much higher during the peak periods of ranching, agriculture and logging in the watershed. While the total length of road in the Pescadero-Butano Watershed has undoubtedly changed since 1937, the amount of sediment being delivered has most likely decreased over time. This is likely because there are more paved roads today than in the past; improvements have been made in road construction and maintenance techniques; and many former ranch and logging roads are no longer being actively used and have re-vegetated. We believe the relatively large sample of current conditions along roads in the County parks is a good indicator of overall road connectivity throughout the watershed.

ANALYSIS OF RESULTS BY PRIMARY LAND USE ASSOCIATION AND CONTROLLABILITY

All erosional features mapped in the field sample plots or on the aerial photos were assigned a primary land use association. The assignment of a land use association was based on field or air photo evidence that a particular land use activity was observed which may have contributed to the initiation of a feature. Each surveyed erosional feature was assigned one of the following land use associations:

1) no apparent land use linkage, i.e. naturally occurring erosion;
2) road-related, whether a logging, ranch, driveway, county road or state highway;
3) skid trail-related;
4) either tractor or cable clear-cutting;
5) either tractor or cable partial harvests;
6) advancing second growth forests, which are defined as formerly logged forests, with second growth generally greater than 30 years old at the time of the erosion;
7) agricultural uses, generally cultivated areas;

8) grazing;

9) homestead or ranch uses; and

10) urban or suburban development.

For ease of analysis and presentation, erosion features were then grouped into one of three broad land-use associations: not associated with land use (category 1 from the list presented above); associated with active land uses (categories 2-5 and 7-10; also referred to as “managed”); or associated with advanced second-growth forest (category 6).

Advanced second growth forest (ASG) is a unique category in that it describes land that was previously logged but on which the vegetation had substantially recovered by the time the erosion occurred. The inference is that the subsequent erosion is weakly, if at all, associated with the previous timber harvesting activity. In either the air photo inventory or the field survey, the selection of advanced second growth forest (ASG) as a land use association for an erosional feature indicates that the surveyor judged that the previously logged forest was in ASG when the erosion occurred.

Both road-related and skid trail-related sediment delivery include failed or washed-out stream crossing erosion; gullies along the road and/or ditch; hillslope gullies associated with stream diversions; and road, skid trail or landing cut or fill failures. As discussed above, estimates of surface erosion and sediment delivery from roads, ditches and cut banks (i.e. lowering of road and skid trail surfaces and other bare areas) were extrapolated from an inventory of road-related erosion in the three San Mateo County Parks in the watershed.

Results of this analysis are summarized in Table 6-12. The managed category is by far the largest contributor of sediment to the Pescadero-Butano stream system, accounting for over 90% of the nearly 9,000,000 yds^3 of total sediment delivery during the period 1937-2002. Erosional features judged not to be associated with management account for only 6% of the total. Erosion in ASG is generally considered not to be associated with management, and accounts for only 3% of the total sediment delivery to streams in the Pescadero-Butano watershed during the study period.

Designating an erosional feature as potentially controllable implies that the erosion is either preventable through a modification of land use practices or erosion prevention treatment, or capable of being controlled through a proactive effort of erosion control once the erosion has begun. In the case of timber harvest-associated erosion, incorporating preventative avoidance or modified silvicultural practices on potentially unstable hillslopes can potentially reduce or control the frequency and extent of erosion. This is extremely important, since once hillslope failure has been initiated, either as a result of management activities or natural events, the erosion is rarely controllable. In relation to roads and skid trail erosion, most erosion can be prevented or, to a lesser degree, controlled after it has been initiated. Modifications to where and how roads or skid trails are located, designed, constructed, reconstructed, maintained, or closed can lead to substantial reductions of anthropogenic erosion and sediment delivery (PWA, 1994; Weaver and Hagans, 1999).

TABLE 6-12
SEDIMENT DELIVERY (YDS^3) AND SEDIMENT YIELD ($YDS^3/MI^2/YEAR$) TO STREAM CHANNELS BY PRIMARY LAND USE ASSOCIATION FOR THE PERIOD 1937 - 2002, PESCADERO-BUTANO WATERSHED

Sediment sources, delivery volumes (in yds^3) and total sediment yield ($yds^3/mi^2/year$)	Not Associated With Land Use	Associated With Land Use	Advanced Second Growth (ASG)	Total Sediment Delivery
Air photo sediment sources	53,650	957,212	107,980	1,120,000
Plot sediment sources (extrapolated)	392,839	1,831,956	37,319	2,260,000
Pre-1956 volume (estimated)	133,095	3,094,453	99,821	3,325,000
Chronic road surface erosion	0	2,280,000	0	2,280,000
Total sediment delivery volume (yds^3)	580,000	8,160,000	245,000	8,985,000
Total sediment delivery(percent)	6%	91%	3%	100%
Total sediment yield ($yds^3/mi^2/year$)	110	1,500	50	1680

Most erosional features observed on hillslopes that were selectively or clearcut harvested in the past were given a harvest association and inferred to be potentially controllable. Field personnel exercised professional discretion when the erosional feature was so large in relation to the area harvested as to weaken the linkage or association between the two. In the latter case, the erosional feature was judged to have no land use association. We acknowledge that identifying most landslides on harvested hillslopes as having a management association probably overestimates the amount of sediment delivery attributable to timber harvesting. However, given the difficulty in getting professional consensus on which of many variables most influences the incidence of hillslope failure, we chose to make the “land use association” interpretation as repeatable as possible. In the Pescadero-Butano watershed, 1,985,000 yds^3, or 22% of the total controllable sediment delivery, was associated with logging activities (Table 6-13). However, 90% of this total was related to timber harvesting practices no longer in widespread use in the basin, such as tractor clearcutting and tractor yarding in stream channels.

In the sample plots, grazing was identified as the land use category if there was evidence of grazing activities occurring at the time of the erosion. Erosional features that could be specifically related to grazing comprised a relatively insignificant fraction of the total sediment delivery for the watershed, accounting for only 70,800 yds3, or less than 1% of the total controllable delivery. In the air photo inventory, however, erosional features were assigned to a broad ranch/agricultural land use category when they occurred on lands whose primary use was either grazing or other agricultural activities, such as cultivation. The aerial photo inventory did not specifically identify grazing as a land use category due to the difficulty of making such a determination from aerial photos, especially at a relatively small scale. Total sediment delivery associated with the ranch/agriculture land use category during the 66 years covered by the study was 2,315,000 yds3, or 26% of the total controllable delivery (Table 6-13). Of this total, 86% occurred in HGU 7 (Quaternary sediments) in the western part of the watershed. Because grazing and cultivation were intensive and widespread in the past in this area, it is assumed that a significant portion of this total has a management association. However, nearly 80% of the ranch/agriculture-related sediment delivery occurring in HGU 7 occurred in the pre-1956 period. This may indicate that ranching and agriculture-related land use practices have improved since that time. In addition, historical accounts indicate that there has been a substantial reduction in ranching and agricultural activities throughout the basin.

Road-related erosion is perhaps the most easily treatable type of controllable erosion. Upgrading of stream crossings and improvement of road drainage function can dramatically reduce sediment delivery to streams. In the Pescadero-Butano watershed, road-related sediment delivery to streams totaled 3,860,000 yds3, or 43% of the total controllable sediment delivery (Table 6-13).

ANALYSIS OF RESULTS BY PRIMARY LAND USE ASSOCIATION AND TIME PERIOD

Sediment delivery volumes are further broken down by specific types of land use and by time frame in Table 6-13. The volumes in this table include results from the air photo inventory, the extrapolated field plot data, the estimated pre-1956 volumes, and estimated volumes contributed by chronic road surface erosion. Sediment delivery volumes are divided according to time periods determined by the aerial photo years.

The sediment delivery volumes, rates and yields compiled in Table 6-13 should be considered minimum estimates. Assigning ages to field-identified erosional features tends to have an increasing margin of error the older the feature is. Older erosional features associated with currently managed lands can be reactivated or otherwise disturbed by management activities, masking or obliterating evidence of the older erosion. Likewise evidence of erosion associated with roads can be hidden by road maintenance or re-construction activities, or can be reactivated by changes in road drainage patterns. In unmanaged or formerly managed lands, natural recovery processes can also mask evidence of older erosion, although we consider this effect to be much less significant in causing under-estimation of erosion and sediment delivery volumes.

It is likely that under-estimation of sediment delivery in the 1957-1982 time period resulted from limitations in the quality of the 1982 aerial photo set. This photo set was taken in January, resulting in deep shadows in the forested and high relief areas of the Pescadero-Butano watershed. We believe this caused an under-counting of erosional features in forested areas on these photos, and hence an under-estimation of sediment delivery volumes.

Even with these potential sources of error, Table 6-13 reveals some patterns in the timing of sediment delivery associated with various land use categories. The results from the timber harvest and agriculture/grazing categories are most striking. Erosion associated with timber

TABLE 6-13
TOTAL SEDIMENT DELIVERY VOLUME (in yds^3), DELIVERY RATE (in yds^3/year) AND YIELD (in yds^3/mi^2/year) BY TIME FRAME[1] AND PRIMARY LAND USE ASSOCIATION

Time period	Primary land use association										Totals		
	Roads[2]		Timber harvest[3]		Agriculture/ Grazing		Advanced second growth		No management association				
	Delivery volume	**Delivery rate**	**Delivery volume**	**Delivery rate**	**Delivery volume**	**Delivery rate**	**Delivery volume**	**Delivery rate**	**Delivery volume**	**Delivery rate**	**Delivery volume**	**Delivery rate**	**Yield**
1937-1956	1,497,400	74,870	1,030,507	51,525	2,098,514	104,926	120,198	6,010	166,818	8,341	4,910,000	245,500	3,000
1957-1982	1,356,213	52,612	582,974	22,422	41,283	1,588	21,117	812	124,149	4,775	2,125,000	81,759	1,000
1983-2002	1,007,581	50,379	373,656	18,683	176,562	8,828	103,805	5,190	288,617	14,431	1,950,000	97,511	1,200
Totals	**3,860,000**	**58,500**	**1,985,000**	**30,100**	**2,315,000**	**35,100**	**245,000**	**3,700**	**580,000**	**8,800**	**8,985,000**	**136,000**	**1,700**

[1] The 1937-1956 volume is an estimate partially based on a calculated field volume extrapolated from the aerial photo analysis for the 1956 aerial photo set.
[2] Roads include erosion associated with paved and unpaved roads and logging roads, including chronic surface erosion from road beds, fills, cut banks and ditches, as well as fill failures, gullies and stream crossing erosion.
[3] Timber harvest includes erosion associated with all types of timber harvest and with skid trails.

harvest shows a marked decline in annual sediment delivery from the 1937-1956 period to the 1957-1982 period, and a further decline in the most recent period. This is likely due to several factors: the overall decline in timber harvesting in the Pescadero and Butano watersheds; a decline in the use of tractor logging; increased use of more resource-protective harvest and road practices; and vegetation recovery on previously logged lands.

In the agriculture and grazing category, the total volume of sediment delivered to streams was overwhelming in the earliest period, but has declined by 90% in the most recent period. This is most likely a result of the marked decline in types and intensity of agricultural uses (see Chapter 3.). Landslides and gullying were widespread on the 2000 aerial photos, although the frequency and magnitudes of these features was much less than on the 1956 photo set. Even though grazing and cultivation in this area are currently much less intensive than in the early to mid-20th century, there may be a legacy of large-scale vegetation change and other effects of agriculture influencing the frequency and severity of mass movement and gullying. In addition, the lack of an extensive tree canopy and the relatively high erodibility of the geologic units in this area may cause it to be naturally more susceptible to erosion in severe, large return interval storm events. It should be noted that 75% of the 1937-1956 volume is derived from a calculated estimate based on the aerial photo-inventoried volume (equations 10 and 11), and for reasons outlined above, this is probably an overestimation.

Annual sediment delivery volumes associated with roads show only a slight decrease through the three time periods. While construction and maintenance practices with regard to roads are steadily improving, there are many miles of unused and/or abandoned secondary roads on both public and private lands that have not been properly upgraded or decommissioned commensurate with the decrease in management intensity in the basin. Many of these roads may be poorly designed with regard to drainage. Even though chronic fine sediment production decreases as the roads become vegetated, roads can deteriorate with age, becoming more susceptible to many forms of erosion, including culvert plugging and subsequent stream crossing failure, stream diversion and gullying, as well as failure of both road and landing fills. On many forest and ranch roads located on both public and private lands, periodic maintenance occurs in the absence of an attempt to address chronic, localized erosion problems. In such cases, grading of poorly drained roads and repair of failed fills and stream crossings can simply reload the site for the same erosion to occur again.

Annual sediment delivery associated with advanced second growth forest (ASG) shows an increase through time, but these volumes make up only a small percentage of the total sediment delivery for the Pescadero-Butano watershed. While there is likely some underestimation of volume for the earlier periods, sediment delivery may have increased simply because there currently is more ASG on the landscape, and because the storm of record occurred during the most recent period. The same is true for sediment delivery not associated with management.

A review of Table 6-13 suggests that watershed-wide sediment yield rates appear to be declining over the three time frames. This is especially true if one agrees with our interpretation that the volume of sediment delivery from the occurrence of debris slides during the 1982 storm was underestimated. Based on this study we estimated a sediment yield rate of 1,000 yds^3/mi^2/year for the period from 1957 to 1982 (Table 6-13). However, we believe the upper limit estimate of basin-wide sediment yield developed by the Army Corps of Engineers for their 1968 dam study of approximately 1,600 yds^3/mi^2/year (as cited in Curry et al., 1985) may be quite close to the true yield for this time period.

For the 1982 to 2002 period, which includes the 1998 storm, we estimate the average sediment yield rate to be about 1,200 yds^3/mi^2/year (Table 6-13). Our Pescadero-Butano estimate is similar to but lower than estimates of sediment yield for approximately the same time frame in the nearby Aptos Creek (Dvorsky, 2003) and Gazos Creek (Owens et al., 2003) watersheds. In reviewing the two other studies, we believe our study may have accounted for a greater percentage of the dominant erosional processes occurring in the Pescadero Creek watershed. Consequently, the similar but generally lower estimate of basin-wide sediment yield in Pescadero Creek may reflect the different levels of active and past land use occurring in the various watersheds, or may simply represent the natural range of variability in sediment yield rates in central California coastal watersheds.

LIMITATIONS OF SEDIMENT SOURCE ANALYSIS

One of the primary natural and anthropogenic sources of erosion and sediment delivery that was not quantified during the Pescadero-Butano watershed sediment source investigation was surface erosion on non-road bare soil areas. This process of erosion occurs on landslide surfaces, on bank erosion sites, and on other bare soil areas on the hillslopes associated with controlled burns and wildfires, timber harvesting, rural and urban developments, and with grazing and agricultural activities. The specific erosion processes include: soil which is detached by rainfall impact, freeze thaw processes operating across the landscape, tree throw, bioturbation by burrowing organisms, and wind erosion.

The results of this survey may have been influenced by lack of access to private lands. Because of difficulties in obtaining access to some small private landholdings, sample plots were concentrated on parks and other public lands, and on commercial timberlands. HGUs 5, 6 and 7 lie mostly in non-timberland private holdings. The lack of access meant that the sample plots on these lands occurred on parkland or were concentrated on a small number of parcels with a common owner. Consequently, the sample plots may not capture the range of land uses or conditions with regard to erosion and sediment delivery.

CONCLUSIONS

The 81 mi^2 Pescadero-Butano watershed is estimated to have produced an average of 2,000 yds^3/mi^2/year in erosion over the period 1937 to 2002, of which an average of 1,250 yds^3/mi^2/year were delivered to streams in the watershed (Table 6-11 and Map 2-2). Including our estimate of chronic road surface erosion, the average sediment delivery increases to between 1,680 and 1,700 yds^3/mi^2/year (Tables 6-12 and 6-13). The relative amounts of both erosion and sediment delivery from the various terrain types in the watershed quantified in this study are in line with expectations, with more highly erodible geologic units and steeper areas generally producing the largest quantities of sediment.

Erosional features associated with land management account for by far the greatest sediment delivery volumes from the watershed. In order of importance, roads, agricultural/grazing and timber harvest land use associations account for the largest percentage of the total sediment delivery. Intensive land use practices have contributed to accelerated, human-caused erosion throughout the watershed, resulting in increased sediment loading of the streams. Over the past 50 years, subsequent sediment transport within the upland stream channels has, in all likelihood, contributed to downstream, lowland aggradation and sedimentation issues.

Analysis of aerial photos indicates that commercial timberlands accounted for a large amount of sediment during the earlier years covered in this investigation. The 1956 air photo set revealed widespread occurrence of mass movements in timberlands that had been subjected to clear-cutting using tractors for skidding. However, mass movements were much less widespread in these areas on both the 1982 and 2000 photo sets. While poor photo quality may have played a role in concealing some mass movements on the 1982 photos, we believe it is much more likely that improved land use practices are the central factor in reducing erosion and sediment delivery on commercial timberlands. However, field observations indicate that there may be substantial quantities of sediment stored in smaller streams in timberlands previously subjected to tractor logging. Consequently, the sandstone and mixed lithology HGUs that underlie much of the forested area of the watershed may continue to produce relatively large quantities of sediment for some time.

The area of the watershed encompassed by HGU 7, west of the San Gregorio Fault, accounts for a significant proportion of the erosion and sediment delivery documented in this investigation. While the bulk of this area lacks forest canopy cover and may be naturally more susceptible to erosion, it has also seen some of the most intensive land management activities, particularly farming and grazing. The aerial photo analysis of these areas was performed at a scale that did not allow for a specific attribution of erosion to land management activities other than to observe a broad land use category. Most mass movements and gullying in this area occur in relatively steep hillslope areas, and these areas were largely inaccessible to field crews because of time limitations and access issues.

In general, land use practices have been steadily improving in the Pescadero-Butano watershed. Harvest practices employed by timber companies active in the watershed over the last twenty years are less intensive, and are far more sensitive to issues of erosion and water quality. Farmers and ranchers in the watershed have been working with the Natural Resources Conservation Service and the Farm Bureau to prevent erosion and improve both water quality protection measures and road maintenance practices in cultivated, rangeland and forest settings. In addition, the area of protected lands continues to increase with the acquisition of ranch and timberlands for parks and open space. Such acquisitions generally terminate intensive management of these lands, and the various parks and open space agencies have shown strong interest in addressing ongoing and potentially controllable erosion problems. While erosion and sediment delivery resulting from past management will likely continue for some time, there should be an overall decrease in sediment delivery to stream channels as land use practices continue to improve and as degraded lands recover both naturally and through proactive treatments.

RECOMMENDATIONS FOR FUTURE STUDY

Specific recommendations can be made with regard to improving the quality of future iterations of this sediment source inventory. In particular, aerial photography flights should be performed during the summer to reduce undercounting of erosional features due to shadows. Such flights should produce photography at an appropriate scale to ensure an accurate inventory and quantification of erosional features, such as 1:12000 or smaller scales.

Erosional features older than 45-50 years become increasingly difficult to identify in field survey plots. The growth of vegetation, changes in land use types and practices, and the re-activation of erosional features, among other factors, tend to obscure or complicate the dating of field-identified erosional features. The field studies performed for this assessment support this assertion since anomalously low volumes of both erosion and sediment delivery were documented for the pre-1956 period. For earlier time periods, estimation of missing field volumes may be accomplished by using methods employed in this study to arrive at a more realistic estimation of overall erosion and sediment delivery volumes and rates through time. However, these methods should be used with caution since there is no objective method to verify their accuracy.

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CHAPTER 7
STREAM CHANNEL ASSESSMENT

OBJECTIVES

The initial workplan for this portion of the Pescadero-Butano Watershed Assessment focused on modeling sediment transport and routing at a few selected stations in the watershed. During initial project meetings, the assessment team decided that given the overall project emphasis on characterizing fish habitat at the watershed scale, an alternative approach would be more appropriate. The alternative approach that we elected to pursue with concurrence from the Technical Assistance Committee was a watershed-scale reconnaissance of channel geomorphic conditions in selected stream reaches (the reach selection process is described elsewhere in the assessment). Surveys of fluvial geomorphology (channel forms and processes) complemented watershed scale investigations pertaining to erosion and fish habitat by other members of the assessment team. The reconnaissance protocol was also designed to develop data providing perspective on both fish habitat issues and sediment transport and routing at the watershed scale.

METHODS

OVERVIEW

The following definitions describe a channel survey protocol based on systematic quantitative and qualitative observations of channel conditions at a given survey reach. It is comparable to versions of Form E-4 presented in the Washington Department of Natural Resources methods (WDNR 1997), but has been streamlined for efficiency. It differs from the WDNR standard protocol in form, but provides equivalent descriptors of channel conditions pertaining to the streambed composition, form and process in the active channel, and the interaction between the channel and its banks and flood plain. These survey data were collected in reaches of not less than 20 bankfull width equivalents (i.e. if the channel had a bankfull width of 5 m, the channel length surveyed was at least 100 m).

In this protocol designed for the Pescadero-Butano Creek watershed assessment, we have added significantly to quantitative data collection pertaining to large woody debris, gravel bars, and sediment size distribution. When combined with the fish habitat assessment data, including quantitative data on pools, the data set can be used to characterize the key parameters relating stream morphology to fish habitat. In addition, most of the qualitative data can be summarized as rank data (e.g., small, medium, large), allowing for a simplified semi-quantitative presentation of qualitative data. These data typically express the relative magnitude of a process or channel characteristic (e.g., floodplain continuity, bedrock abundance in the bed). Rank data (also known as "ordinal" data in a statistical context) are identified as such in the protocol. Other types of qualitative data are descriptors that do not have an ordinal sense (e.g., roughness elements, historical channel disturbance).

CHANNEL AND VALLEY GEOMETRY

Channel geometry was characterized based on a scale cross-section sketch of a representative location in the channel, typically in a relatively straight portion of the channel with few obstructions, at a riffle where bankfull flow hydraulics are expected to be relatively uncomplicated. Following is a description of the specific data collected at the representative cross-section location as determined in the field. The term "bankfull flow" in this context corresponds to flow levels that occur at recurrence intervals of 2 years or less.

Average Slope: [%] Slope was measured as rise over run using a hand level and stadia rod to measure change in elevation, and tape or hip chain to measure horizontal distance at the cross-section location.

Channel Confinement: [L/L] Confinement class is determined in the field using the "entrenchment ratio" defined by Rosgen (1994). The ratio is calculated by dividing the flood prone width (defined as the horizontal surface at an elevation twice the "bankfull" depth as determined by field observations; not literally the top of the bank in most locations) by the bankfull channel width (BW). Channel confinement is then classified using the ratio as follows:

C = Confined: Channel is prevented from changing its location by valley or terrace walls that are resistant to erosion; entrenchment ratio is < 2.

MC = Moderately Confined: Channel is able to erode its banks and move laterally in many locations, but streambanks that effectively resist erosion also constrain channel substantially; the entrenchment ratio is between 2 and 4.

U = Unconfined: Channel is able to move laterally in virtually all locations; entrenchment ratio is > 4.

Flood Prone Width: [#] Defined by (Rosgen 1994) as the width of the horizontal surface at an elevation twice the "bankfull" depth. The flood prone zone is defined by the intersection of the horizontal plane at 2 times bankfull depth and the ground surface of a hillslope or terrace. The valley width does not always coincide with the flood prone width. This information is typically provided in a valley cross-section sketch.

Bankfull Channel Width: [#] Number is the measured width (m) of the "bankfull" channel, defined by high-water marks indicated by strand lines, fluvial sediment deposits, and the boundary formed by vegetation at the channel margin; the bankfull channel typically has a morphological expression. This width is intended to approximate stream stage corresponding to "effective discharge" proposed by Wolman and Miller (1960). This width is often somewhat less than the width defined by a horizontal line connecting the tops of opposite banks. When a portion of the bankfull width of the channel contains riparian vegetation, the bankfull width is apportioned into "vegetated" and "active" components.

Bankfull Channel Depth: [#] Number is the measured average depth (m) of flow at "bankfull" stage corresponding with field evidence defining bankfull width (i.e., "effective discharge") at the representative cross-section location. Not normally equal to the top of the bank, which is often the elevation of the low terrace or flood plain.

Terrace Heights: [#] Average measured height of terrace surfaces above average elevation of channel bottom. Includes an observation for the flood plain, and an observation for any terrace surfaces present. A zero indicates that the given terrace was absent. The relative positions of terraces are typically represented in a cross-section sketch of the valley in field notes.

Definition Sketch for Channel and Valley Geometry

Legend

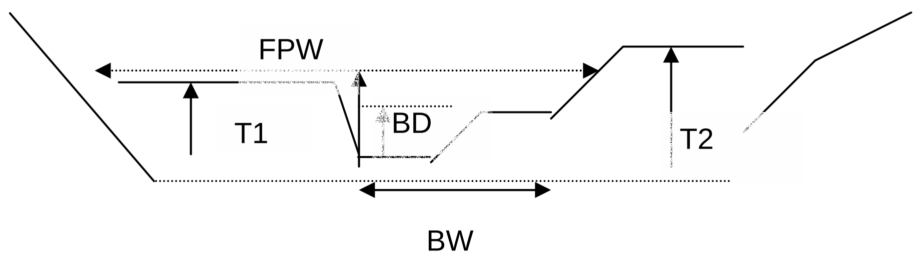
BD = bankfull depth

BW = bankfull width

T1 = height of terrace 1

T2 = height of terrace 2

FPW = flood prone width (measured @ twice BD)



RIPARIAN, FLOOD PLAIN, AND BANK CONDITIONS

The following qualitative data supplement data collected in the California Rapid Bioassessment Protocol pertaining to riparian zone and streambank conditions in the Fish Habitat Assessment. Similar data collected in the channel protocol in other projects were eliminated to avoid duplication of effort.

Floodplain: [Ls] Letter represents the observed distribution of vegetated flood plain that is occupied during periods of peak flows substantially greater than bankfull flow. For purposes of this survey, the floodplain considered here is substantially higher than the bar top elevations that are often formed during bankfull flows (2 year recurrence interval or less). Evidence indicating flood plain extent includes side-channels, strand lines, sediment deposits, and vegetation; when prominent evidence of overbank flow is observed, the lowercase "ob" is included. Where overbank side-channels are observed, the lowercase "sc" is added. The longitudinal continuity and presence or absence of an active flood plain are assessed. In channels steeper than about 4% slope, the "flood plain" may consist of poorly sorted coarse sediment and debris laying in bars adjacent to the channel deposited during episodes of peak flow. The descriptors below are ordinal with respect to extent of flood plain.

N = No flood plain or terrace (i.e., a severely confined channel)

T = Terrace (no evidence of historic flow **)**

D = Discontinuous but significant flood plain

C = Continuous or nearly continuous flood plain

ob = significant evidence of overbank flow; e.g., deposits, strand lines
sc = side-channels, overbank/overflow channels present

Disturbance: [LLLL] Letters represent the observed disturbances that may have affected the condition of the channel or the riparian zone. *These are given in no particular order,* are not ordinal in character, and are intended merely to note historic disturbances that could be influential.

L1 = First entry logging of "old growth;" large-diameter redwoods with cut ends are present and/or remnants of skid roads or railroads

L2 = Second-growth logging; smaller-diameter LWD prominent in channel and/or evidence of bulldozer skidding in or adjacent to channel

D = Debris flow as per Cruden and Varnes (1996); this type of mass wasting is not particularly common in the Pescadero-Butano study area

IG = Inner gorge mass wasting, typically "debris slides" as per Cruden and Varnes (1996); debris slides are the dominant large-scale mass wasting process reported in Chapter 6

F = Flood (severe)

R = Riprap channel banks

Rd = Road

Fr = Fire

N = None

Streamside Mass Wasting: [LL] Criteria similar to those for bank erosion. It should be acknowledged that the distinction between bank erosion and streamside mass wasting can be difficult to determine. However, streamside mass wasting is usually associated with a landform (e.g., inner gorge) or material type (e.g., lacustrine clay), and appears to be caused by at least one mechanism other than bank erosion. This observation can be important to assessment of sediment supply to channels. These features are of a scale that rarely can be seen in aerial photography, and are unlikely to be recognized in other assessment modules. The size of streamside mass wasting features is scaled by the ratio of their height relative to average bank height (bh) as defined below.

Abundance (ordinal):

None
Sparse = erosion features <5% of reach length
Common = erosion features 5 to 20% of reach length
Abundant = erosion features >20% of reach length

Size (ordinal):

Small = height > bh, up to 5(bh)
Medium = 5(bh) ≤ height ≤ 10(bh)
Large = height > 10(bh)

STREAM CHANNEL AND STREAMBED CHARACTERISTICS

The following qualitative data supplement data collected in the California Rapid Bioassessment Protocol pertaining to riparian zone and streambank conditions in the Fish Habitat Assessment (Chapter 8).

Bedrock/Parent Material: [L...] Letter (and additional notes) represents the presence, absence, and extent of bedrock exposed in the channel bed and channel margins observed in the field. If other types of parent material are observed, this is noted; the key observation is exposure of non-alluvial material, supplemented by either a descriptive note (e.g., competent sandstone) or an abbreviation for the geologic formation, if known. These are ordinal data.

N = None observed
M = Present but minimal
C = Common
D = Dominant

Channel Roughness Elements: [LLLLL] Letters represent the channel elements that provide resistance to flow at bankfull stage in descending order of importance; the dominant element is listed first. If elements are equally influential, they are separated by a "/". These data are not ordinal.

B = Boulders
C = Cobbles
V = Live woody vegetation
R = Bedrock
Bk = Banks and Roots
W = Large woody debris
F = Bedforms (large gravel bars or step-pool sequences)

Channel Type: [LL/LL] Letters indicate the dominant and subdominant (or co-dominant) channel reach types as defined by Montgomery and Buffington (1997), and briefly described in the main text. Two types are often necessary to characterize the morphology of a given location. These data are not ordinal.

C = cascade
SP = step-pool
PB = plane bed
(f)/PR = (forced) pool-riffle
R = regime
Co = colluvial
BR = bedrock

STREAM POWER INDEX

Indices of stream power are computed from field observations, and are used to help differentiate channels of like characteristics. Stream power indices used are defined below. These data are included in the protocol to emphasize that they are computed upon entry of field data.

SPI: [#.#] The steam power index is the product of bankfull depth (m), bankfull width (m), and mean channel slope (%), and is a quantitative index of total stream power.

Unit SPI: [#.#] The steam power index is the product of bankfull depth (m) and mean channel slope (%), and is a quantitative index of the average total shear stress for a given site.

QUANTITATIVE SURVEY DATA-WOODY DEBRIS, GRAVEL BARS AND SEDIMENT SIZE DISTRIBUTION

The following data sets were collected to provide data pertaining to fish habitat conditions (woody debris abundance) and data upon which limited inference may be drawn pertaining to sediment transport and routing processes (gravel bar size and abundance, surface sediment size distributions).

Large Woody Debris: A count survey of LWD was collected to provide data on the abundance of LWD that would be expected to contribute significantly to the quality of fish habitat. LWD was counted when a piece at least 1 ft (0.3 m) diameter and 6 ft (1.8 m) long was encountered within the bankfull channel. Minimal additional information was collected for each piece of LWD tallied, including:

Species Class

C = Conifer (typically redwood or douglas fir)
D = Deciduous (broadleaf species, typically oak, bay laurel, or alder)
U = Undetermined

Age Class

L = Live tree within the bankfull channel
F = Freshly recruited wood including; leaves and twigs on branches
S = Sound but weathered wood; some branches or bark, decay not significant
D = Significant decay, little or no bark, no branches

Gravel Bars: A count of gravel bars was collected to provide data on the abundance of sediment being actively routed through the channel. Bars are recognized in the field by their topographic relief relative to the thalweg and the finer distribution of sediment on the bar surface relative to the framework sediment found in riffles and the thalweg. In other words, it is expected that bars represent a depositional sediment facies with bar median size finer than channel thalweg/riffle median size, excluding pools. Where sand is abundant, the size criterion may be relaxed. Minimum bar size for this survey was one horizontal dimension at least one bankfull width equivalent and the other horizontal dimension at least one-third bankfull width equivalent. Bars meeting the minimum size and facies criteria were classified by size as follows:

S = Small; longest dimension < 2 bankfull widths
M = Medium; longest dimension 2-4 bankfull widths
L = Large; longest dimension > 4 bankfull widths

Surface Sediment Size Distribution: Surface sediment size was characterized using systematic random methods (Bunte and Abt 2001). Where maximum grain size was generally < 128 mm, a heel-toe sampling technique were used. Where maximum grain size was generally > 128 mm, a grid system was used with survey tapes to avoid sampling bias. 100 point pebble counts were conducted at two locations. One was collected across the bankfull width at the cross-section survey site, and spanned a distance of one bankfull width (one-half width above and below the cross-section site). The other pebble count was conducted on the surface of the downstream bar (subject to minimum size criteria as described above) nearest the cross-section site. These pebble counts were expected to specify the median size for each location within 15% of the true median, as well as estimates of the 16th and 84th percentile of the size distribution of surface sediment.

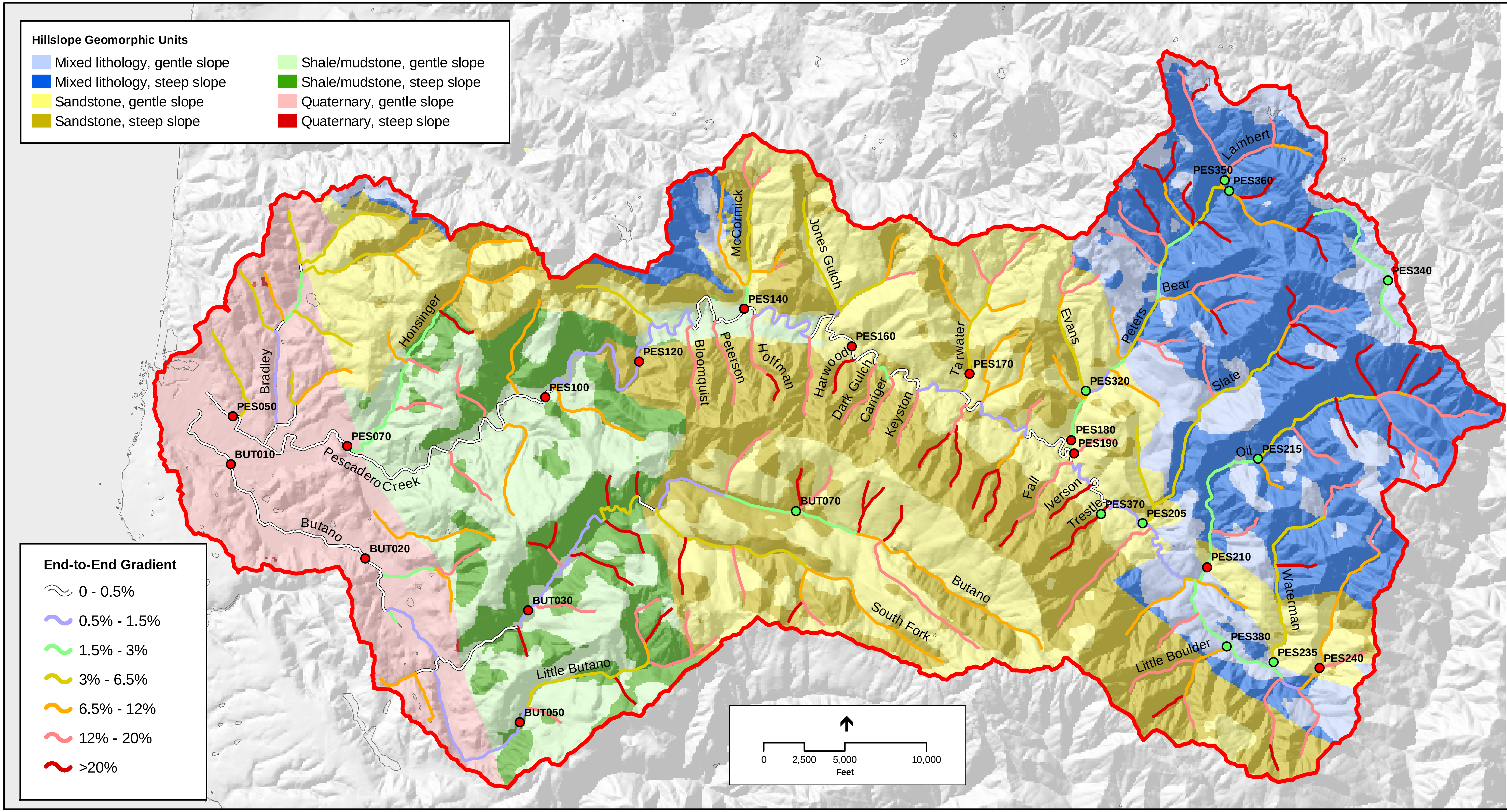
Sediment particles were categorized according to the sieve mesh diameter upon which the particle would be captured by measuring the intermediate axis of the particle with a ruler. The minimum size discriminated for this survey was 4 mm; the diameter classes in millimeters were < 4, 5.6, 8, 11, 16, 22, 32, 45, 64, 90, 128, 180, 256, 360, 512, 720, 1024 etc.

RESULTS

OVERVIEW

A total of 23 stream reaches were surveyed, covering a total of 4.1 km of stream channel (Map 7-1*)*. Most of the data are summarized by channel slope class in Table 7-1. The complete data set is included in Appendix B. Field sites represent a wide range of drainage area, channel size and slope, and geologic and management histories. A notable exception was tributary streams in the westernmost portion of the watershed mantled by Quaternary deposits. Although we probably have not exhausted the variety of channel types or conditions likely to exist in the watershed, we believe we have generated a data set that is reasonably representative of current conditions. Results are reported in terms of observed trends rather than inference based on formal statistical analyses owing to the high statistical variance associated with stream channel surveys of this type. A substantially larger data set would be required to provide statistically significant descriptive statistics pertaining to distinctive channel types. Not all of the data collected are discussed at the same level of detail. Rather, we focus on what we believe are the most important conclusions relevant to watershed scale occurrence of fish habitat and sediment routing processes that can be substantiated. The data collected has not been analyzed to its full potential, and may serve as a resource for further work in the watershed.

Survey data collected from stream channel reaches distributed throughout a watershed can be evaluated in at least two ways to derive interpretations that can be generalized. One is to consider patterns as a function of contributing drainage area at each reach, and the other is to consider patterns as a function of channel classes (e.g. slope class or combined bedrock type-slope class). Results are presented with respect to both of these modalities, as each offers useful perspective.



SOURCE: USGS data sets from Bay Area Regional Database; San Francisco Bay Regional Water Quality Control Board; Environmental Science Associates; O'Connor Environmental

Map 7-1
Channel Geomorphic Units and Sampling Stations

TABLE 7-1
SUMMARY OF STREAM CHANNEL DATA STRATIFIED BY CHANNEL SLOPE CLASS
(See Methods for detailed description of each data field, including units if not stated)

Slope class		number of sites	total reach length (m)	average reach length (m)	Drainage Area (km^2)	channel slope (%)	SPI	Unit SPI	FPW @ 2bfd (m)	Active BF width (m)	BF depth (m)	Confinement class	Entrenchment Ratio (FPW:BFW)
Marsh	mean	2	450	**225**	**129**	**0.4**	**4.0**	**0.3**	**62.5**	**11.8**	**0.9**	**3.0**	**5.4**
	std dev			77.8	109	0.0	1.8	0.0	17.7	4.6	0.1	0.0	0.6
	std error			55.0	77.1	0.0	1.3	0.0	12.5	3.3	0.1	0.0	0.4
0-0.5	mean	6	1835	**305.8**	**92.1**	**0.6**	**13.3**	**0.9**	**23.1**	**14.8**	**1.6**	**1.2**	**1.6**
	std dev			99.4	37.0	0.4	12.6	0.7	9.5	4.8	0.5	0.4	0.4
	std error			40.6	15.1	0.2	5.2	0.3	3.9	2.0	0.2	0.2	0.2
1.5-3	mean	4	530	**132.5**	**11.3**	**1.1**	**5.5**	**1.0**	**11.3**	**7.7**	**1.0**	**1.8**	**1.9**
	std dev			47.2	10.6	0.7	1.1	0.5	1.5	5.0	0.3	0.5	0.9
	std error			23.6	5.3	0.4	0.5	0.2	0.8	2.5	0.1	0.3	0.5
3-6.5	mean	4	590	**147.5**	**5.0**	**2.3**	**14.7**	**2.6**	**10.3**	**5.9**	**1.1**	**1.3**	**1.8**
	std dev			49.9	2.1	1.0	5.8	1.1	0.6	1.3	0.3	0.5	0.5
	std error			25.0	1.1	0.5	2.9	0.6	0.3	0.7	0.1	0.3	0.3
6.5-12	mean	5	525	**105.0**	**5.0**	**3.1**	**20.8**	**2.9**	**8.6**	**6.7**	**0.9**	**1.0**	**1.4**
	std dev			48.5	2.3	2.4	18.6	2.6	4.0	3.9	0.3	0.0	0.2
	std error			21.7	1.0	1.1	8.3	1.1	1.8	1.8	0.1	0.0	0.1
12-20	mean	2	150	**75.0**	**2.8**	**3.4**	**9.1**	**2.0**	**6.5**	**3.8**	**0.6**	**1.5**	**1.8**
	std dev			35.4	2.5	1.8	9.9	1.7	2.1	1.8	0.2	0.7	0.3
	std error			25.0	1.8	1.3	7.0	1.2	1.5	1.3	0.2	0.5	0.2

TABLE 7-1 (Continued)
SUMMARY OF STREAM CHANNEL DATA STRATIFIED BY CHANNEL SLOPE CLASS
(See Methods for detailed description of each data field, including units if not stated.)

Slope class	**Floodplain height (or tce) (m)**	**Tce height #1 (m)**	**Tce height #2 (m)**	**TH:BFD**	**Floodplain**	**SSMW abundance**	**SSMW size**	**Bedrock rating**	**Bar rating**	**Bars per BFW**	**Total # LWD**	**LWD #/BFW**	**Reach Average D16 (mm)**	**Reach Average D50 (mm)**	**Reach Average D84 (mm)**
Marsh	**1.5**	**1.5**	**8.0**	**1.7**	**4.0**	**1.5**	**0.5**	**0.5**	**9.5**	**0.5**	**47.5**	**2.4**	**7.1**	**13.0**	**24.0**
	0.4	0.4		0.2	0.0	2.1	0.7	0.7	6.4	0.1	12.0	0.6	4.3	12.7	22.6
	0.3	0.3		0.2	0.0	1.5	0.5	0.5	4.5	0.1	8.5	0.4	3.1	9.0	16.0
0-0.5	**7.0**	**8.0**	**3.5**	**5.6**	**2.8**	**0.8**	**1.2**	**0.7**	**13.5**	**0.6**	**57.5**	**2.9**	**12.8**	**36.9**	**78.2**
	6.6	6.9		6.3	1.2	0.8	1.0	0.8	5.9	0.3	22.9	1.1	7.4	21.6	43.5
	2.7	3.1		2.6	0.5	0.3	0.4	0.3	2.4	0.1	9.3	0.5	3.0	8.8	17.8
1.5-3	**4.4**	**2.1**	**3.9**	**3.7**	**3.2**	**1.8**	**2.0**	**1.3**	**5.8**	**0.3**	**38.8**	**1.9**	**14.5**	**41.3**	**99.5**
	5.3	1.7	2.0	4.3	0.8	0.5	0.8	1.0	4.2	0.2	23.2	1.2	7.3	18.7	39.3
	2.7	0.8	1.0	2.1	0.4	0.3	0.4	0.5	2.1	0.1	11.6	0.6	3.6	9.3	19.7
3-6.5	**5.0**	**5.0**	**3.3**	**4.5**	**1.9**	**1.3**	**1.3**	**2.0**	**11.0**	**0.6**	**56.5**	**2.8**	**15.0**	**38.3**	**76.9**
	3.6	3.6	1.8	2.8	1.0	0.5	0.5	0.8	3.2	0.3	38.2	1.9	4.4	8.5	20.2
	1.8	1.8	0.9	1.4	0.5	0.3	0.3	0.4	1.6	0.1	19.1	1.0	2.2	4.2	10.1
6.5-12	**2.4**	**2.4**	**4.6**	**2.8**	**2.4**	**1.2**	**1.2**	**1.0**	**12.4**	**0.6**	**32.0**	**1.6**	**13.5**	**39.7**	**120**
	2.2	2.2	3.0	1.8	0.9	0.4	0.4	0.7	6.1	0.5	17.0	0.9	6.6	14.8	72.6
	1.0	1.0	1.3	0.8	0.4	0.2	0.2	0.3	2.7	0.2	7.6	0.4	2.9	6.6	32.5
12-20	**0.9**	**0.9**		**1.5**	**3.0**	**1.5**	**1.5**	**1.0**	**11.0**	**0.6**	**20.0**	**1.0**	**17.0**	**44.0**	**103**
	0.7	0.7		0.7	0.0	0.7	0.7	0.0	11.3	0.1	5.7	0.3	5.7	7.8	9.5
	0.5	0.5		0.5	0.0	0.5	0.5	0.0	8.0	0.0	4.0	0.2	4.0	5.5	6.8

We initially evaluated the channel data according to channel slope classes (0-0.5%, 0.5-1.5%, 1.5-3%, 3-6.5%, 6.5-12%, and 12-20%) determined from digital elevation maps in the project GIS, combined with geologic-landform classes developed for erosion surveys, however, the number of field observations per category was too small to be interpreted effectively (Map 7-1). Hence, we evaluated data according to channel slope classes alone, with one exception. One reach in each Butano Creek and Pescadero Creek was surveyed within the upper limits of the Pescadero Marsh; these two reaches were grouped together apart from other reaches with slopes in the 0-0.5% range.

By a fluke of the site selection process, no sample reaches in the 0.5-1.5% slope class were sampled. This probably does not represent a significant data gap because these reaches generally occur in the mainstem of Pescadero Creek which was subject to relatively intensive and well-spaced sampling, and because slope classes determined from DTM’s consistently overestimated channel slope compared to field measurements (see discussion below).

DEVIATIONS FROM SAMPLING PROTOCOL

Owing to constraints of resources available for field reconnaissance, two elements of the field protocol presented in the Quality Assurance Project Plan prepared for this study were omitted during field implementation. These were measurements of valley wall slopes at the channel cross-section location in each reach, and the collection of channel slope observations other than that at the cross-section location. While all field data is of value, we believe that these data were not critical.

With respect to channel slope data, the previously-planned additional slope observations would have been collected with a clinometer where channel slope was >2%; a high proportion of surveyed reaches were <2% slope, hence clinometer data would have been unreliable in a high proportion of sites. The slope data presented are thus relatively accurate. In addition, slope data were collected at a representative channel cross-section where a riffle and gravel bar could be located nearby for purposes of measuring surface size distributions. This aspect of the protocol may have caused a slight bias toward locations with somewhat lower slope within sample reaches in that steeper locations would not tend to provide the conditions specified in the protocol. This sacrifice of strictly random sampling technique was necessary for efficiency in the field.

An additional data field presented in the report was derived from two other data fields. The ratio of terrace height to bankfull depth was developed to provide an index of relative channel capacity. This ratio is somewhat analogous to the entrenchment ratio which is computed as the floodprone width (channel width at flow depth equivalent to twice the bankfull depth) divided by bankfull width.

Another additional data field was developed to represent most effectively our survey of gravel bars. Gravel bars were counted in size classes determined by bar length in units of bankfull channel width; size categories were <2, 2-4, and >4 bankfull widths in length. To provide a single metric for these data, a bar “rating” score was developed counting small bars as “1”, medium bars as “3”, and large bars as “5”. Each of these scores gives an approximation of total bar length in bankfull width units. The score for each reach was the sum of bar scores. To provide this score with more intuitive meaning, we divided the score by the reach length of 20 bankfull widths. The resulting metric, described as an index of bar length per unit channel length, describes the proportion of reach length in which gravel bars are present. For example, a value of 0.3 indicates that bars occur in 30% of the reach length. Scores of >1.0 occurred in some instances, suggesting that bars may occur on both sides of the channel in some locations (certainly a physical possibility), but these may also reflect the ordinal character of these data.

CHANNEL CHARACTERISTICS AS A FUNCTION OF DRAINAGE AREA

The relationship between fundamental channel parameters such as slope, bankfull width and bankfull depth in a watershed is generally referred to as the “hydraulic geometry.” These three parameters of channel geometry are presented as a function of drainage area in Figures 7-1, 7-2 and 7-3 respectively. As is generally the case, slope is inversely correlated with drainage area, however with substantial scatter in the relationship for smaller drainage areas. For larger drainage areas (> 10 km sq.), however, slope is relatively consistent and rarely exceeds 1%. Bankfull width is strongly and positively correlated with drainage area, although with considerable scatter. For larger drainage areas (> 10 km sq.), observed bankfull width ranged from 5 to 20 m. Bankfull depth is correlated with drainage area, but to a lesser degree than bankfull width. For larger drainage areas (> 10 km sq.), bankfull depth varied from about 0.8 to 2.2 m (Figure 7-3). The marsh channel reaches have relatively low bankfull depth for streams of comparable drainage area, based on field indicators. Note that bankfull depth field indicators typically provide the approximate depth of a 2-yr recurrence interval flow, but do not indicate the depth of flow at river flood stage. A comparison of field interpretation of bankfull flow at PES100 with hydrologic analysis of the USGS gauge record for elevation of a 2-yr flood showed that the field interpretation was accurate. In addition, we found that the 1998 flood elevation in that location was several feet higher than twice bankfull depth, a metric used to determine flood prone width (Figure 7-4) and entrenchment ratio (Figure 7-5). Channel and floodplain morphology in the lower reaches of Pescadero and Butano Creeks relevant to flood hazards are further described in Figures 7-4, 7-5, 7-19, and 7-20.

In addition to the conventional elements of channel geometry described above, a few somewhat unconventional channel parameters are presented in Figures 7-4 and 7-5. These are flood prone width and entrenchment ratio, each as a function of drainage area. Floodprone width has a strong positive correlation with drainage area, similar to bankfull width. For larger drainage areas, the channel width during a flow that is twice the bankfull depth ranges from about 10 to 35 m. However, in the marsh reaches, these widths range from about 50 to 75 m. Entrenchment ratios (Figure 7-5) are generally about 2 or less, indicating moderately to strongly incised channels. The marsh reaches, in contrast, have large entrenchment ratios (>5), suggesting relatively frequent episodes of overbank flows and

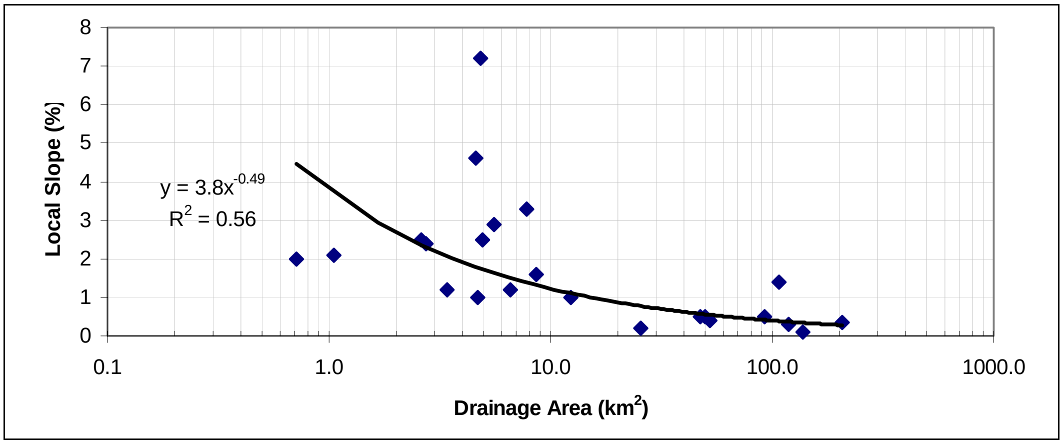


Figure 7-1: Channel slope as a function of drainage area.

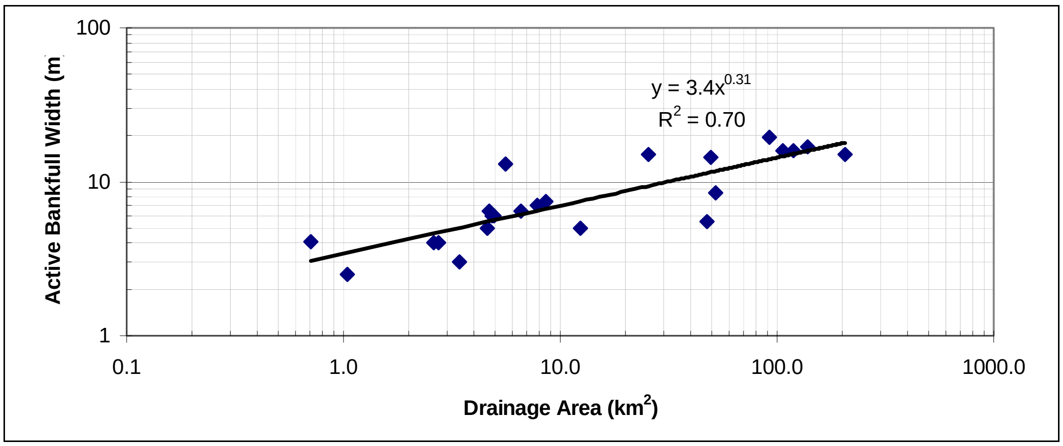


Figure 7-2: Bankfull width as a function of drainage area.

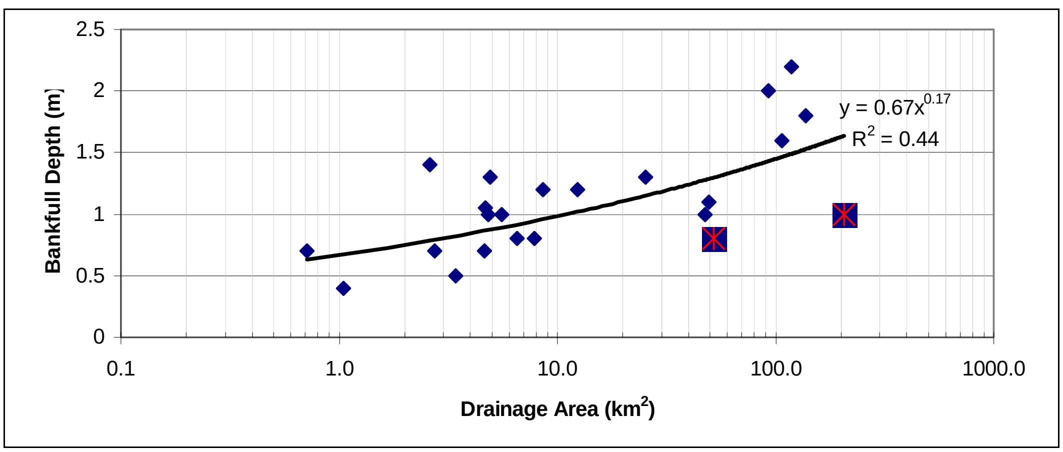


Figure 7-3: Bankfull depth as a function of drainage area. The highlighted points represent “marsh” sites in lower Pescadero and Butano Creeks where bankfull depth lies at the extreme low end of the observed distribution for larger drainage areas.

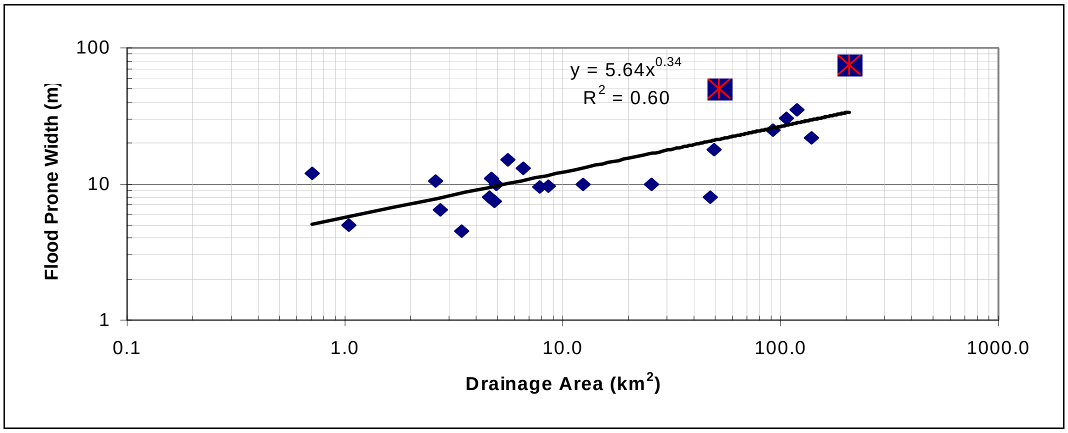


Figure 7-4: Flood prone width as a function of drainage area. The highlighted points represent "marsh" sites in lower Pescadero and Butano Creeks where bankfull depth lies at the extreme high end of the observed distribution for larger drainage areas.

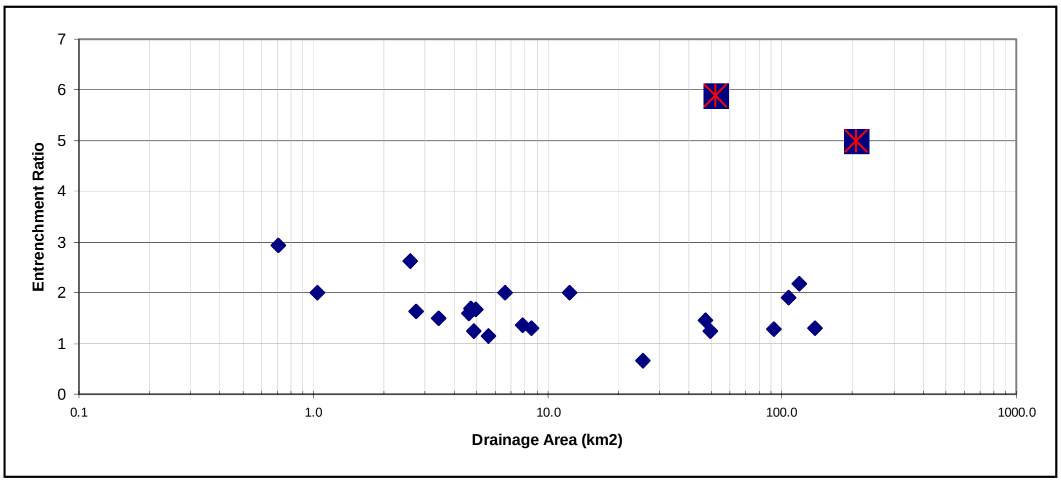


Figure 7-5: Entrenchment ratio as a function of drainage area. The highlighted points represent "marsh" sites in lower Pescadero and Butano Creeks where the entrenchment ratio lies at the extreme high end of the observed distribution for larger drainage areas.

overbank deposition. The foregoing results suggest watershed products such as water and sediment are delivered through a relatively confined channel network that has a strongly depositional floodplain environment in the lowest reaches of the watershed near the Pescadero Marsh.

The "unit stream power index"(Figure 7-6) is inversely correlated with drainage area but with considerable scatter, similar to slope. The product of slope and bankfull depth, the unit stream power index is a measure of stream energy potentially available for sediment transport or channel erosion. This index, however, does not account for diverse flow resistance factors that affect actual tractive forces applied to the streambed and banks that are available for sediment transport or bank/bed erosion. Nevertheless, it is reasonable to hypothesize that the

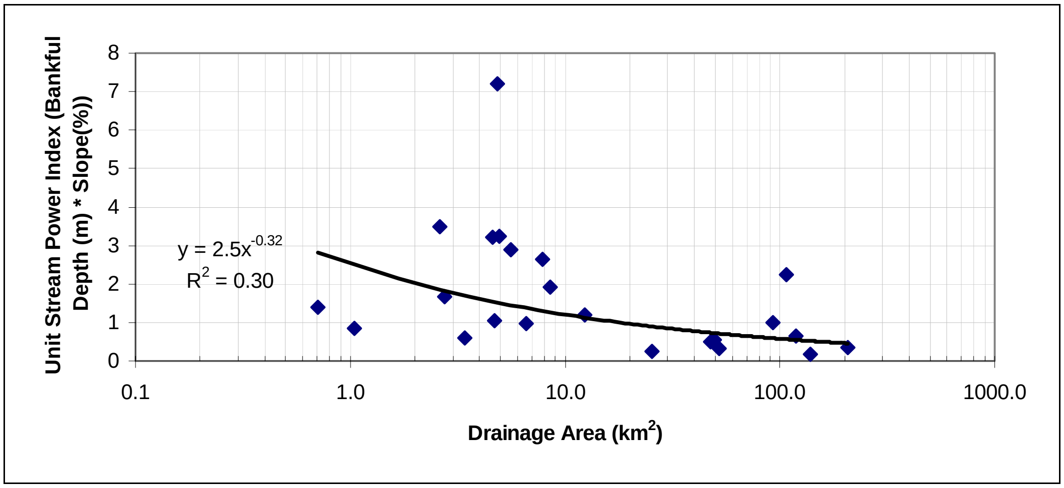


Figure 7-6: Unit stream power index as a function of drainage area. This index provides a measure of relative stream energy as it may apply to sediment transport or erosive capacity.

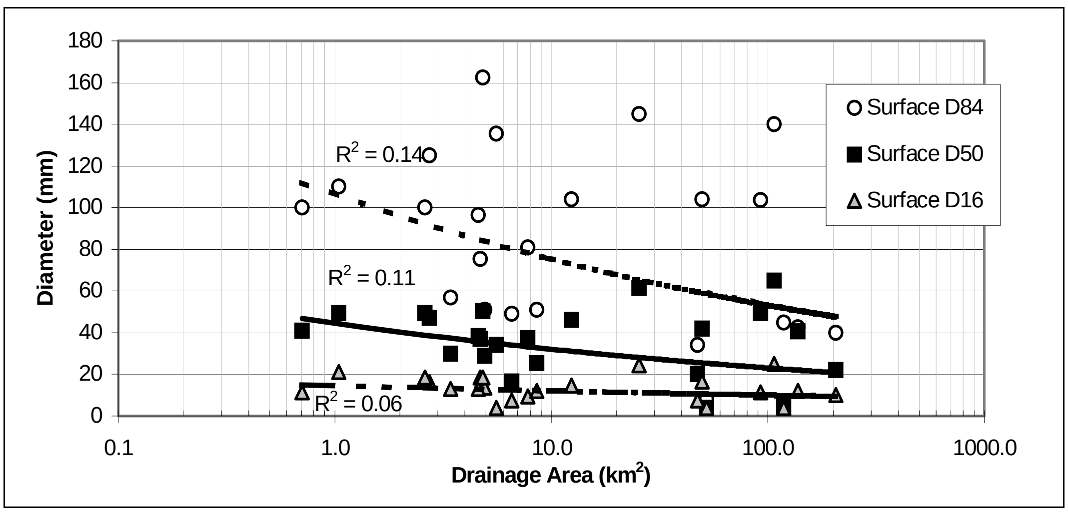


Figure 7-7: Diameters of D16, D50 and D84 as a function of drainage area.

stream power index might correlate with measures of sediment transport and storage such as median sediment size or gravel bar abundance. For example, more powerful streams might have a coarser sediment size distribution and/or few gravel bars because transport capacity might be more likely to exceed sediment supply.

Plots of sediment size as a function of unit stream power (not shown), do not reveal a strong relationship with grain size. Although the marsh reaches have notably finer sediment sizes and D84's tend to be greater in the two steepest slope classes (Figure 7-13), the predominant condition is a relatively uniform distribution of sediment sizes and sediment storage throughout the channel network. Based on Bunte and Abt (2001), sediment size percentiles for pebble counts of n=200 are accurate to about +/- 10%. As can be seen in Figure 7-7 (D16, D50 and D84 as a function of drainage area) and Figure 7-8 (gravel bar abundance as a

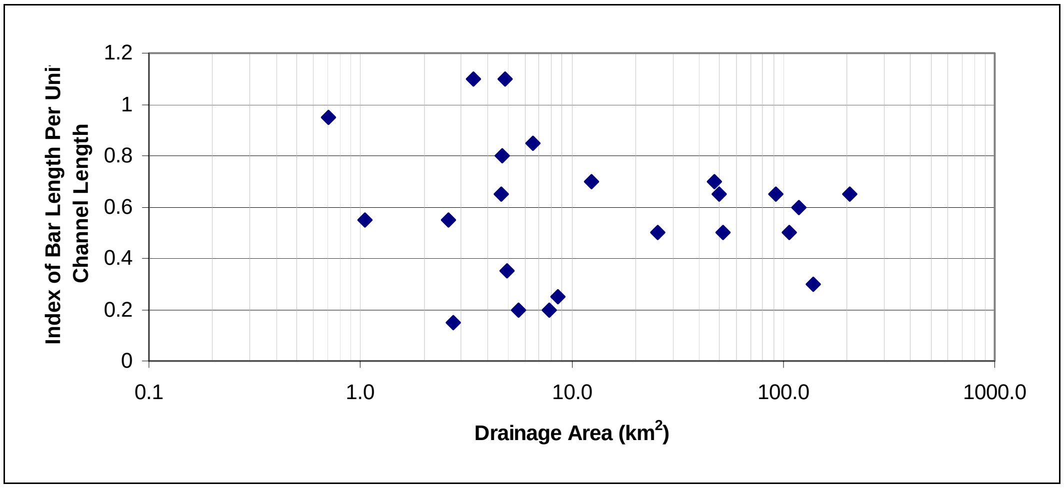


Figure 7-8: Gravel bar proportion per unit channel length.

function of drainage area), there are not strong correlations between these parameters and drainage area (nor stream power). Although there is a trend toward decreasing sediment size with drainage area, there is a more pronounced uniformity of sediment size, regardless of drainage area. Gravel bar abundance becomes less variable with increasing drainage area, and varies over a wide range for smaller drainage areas. The latter observation suggests that there may be substantial variation in sediment supply at the small drainage basin scale (~ < 10 km sq), but that at larger drainage basin scales, the cumulative inflow from smaller basins creates a relatively uniform sediment supply.

Large woody debris (LWD) abundance in many studies in the Pacific Northwest has been found to be inversely correlated with channel width (and drainage area). Similar studies in northern California have not found this inverse relationship. As shown in Figures 7-9 and 7-10, LWD abundance shows a weak positive correlation with both drainage area and slope. These data provide only an index of relative abundance within the watershed. However, it may be useful to compare these data to data from the Garcia River (O'Connor Environmental 2000), where mean LWD frequency was about 6 per unit channel length expressed in bankfull width units (range 1 to about 22) in channels with mean bankfull width of about 15 m (range about 8 to 30 m). In the Garcia study, however, the minimum diameter of measured LWD was 10 cm (versus 30 cm or 1 ft in Pescadero-Butano), and the median diameter was about 1 ft. Hence, for comparison, the Garcia data for LWD abundance should be reduced by about half to compensate for the difference in minimum diameter surveyed. The adjusted Garcia data for LWD frequency have a mean of about 3 per bankfull width. For comparable channel widths in Pescadero-Butano, mean LWD frequency is about 2.5 per bankfull width ranging from about 1 to about 5. This suggests that Pescadero-Butano channels have comparable LWD abundance relative to Garcia River channels of comparable size. These levels of LWD are, however, thought to be significantly less than what was present prior to European settlement and logging in the region.

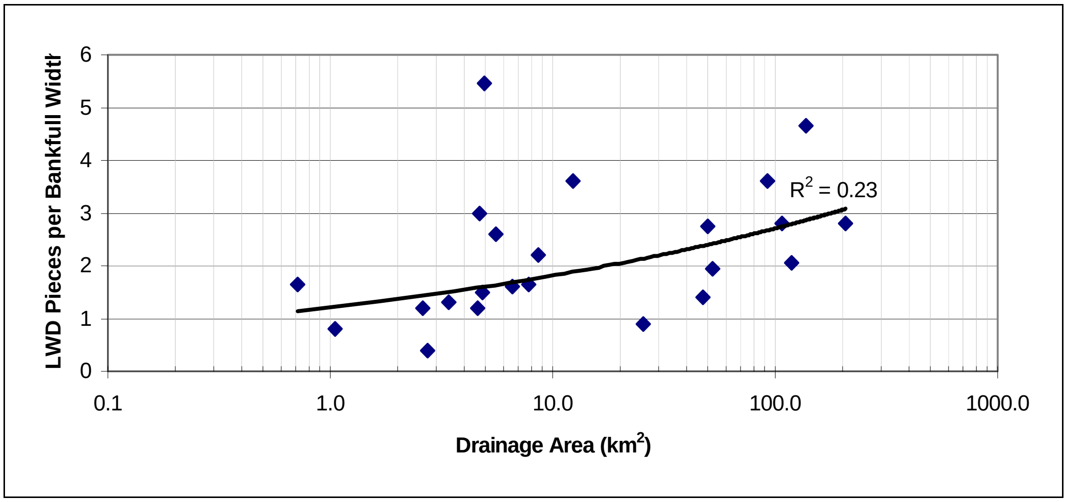


Figure 7-9: Large woody debris pieces per unit channel length as a function of drainage area. Channel length is expressed in units of bankfull width.

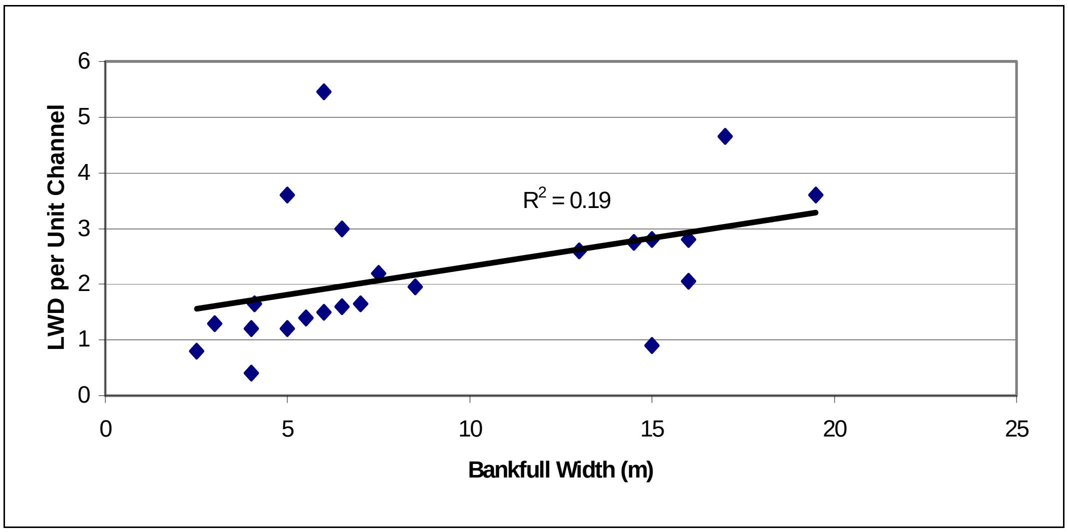


Figure 7-10: Large woody debris pieces per unit channel length. Channel length is expressed in units of bankfull width.

CHANNEL CHARACTERISTICS AS A FUNCTION OF CHANNEL SLOPE CLASS

As shown above, there is an inverse correlation between drainage area and slope. As shown in Figure 7-11, most of the channel classes separate into fairly distinct ranges of drainage area, with the exception of the 3-6.5% and 6.5-12% classes. Recall that the marsh class is a subset with slopes in the 0-0.5% class. As a result, the relationships between slope class and various channel parameters may be expected to resemble the relationships between these same parameters and drainage area previously discussed. Montgomery and Buffington (1997) assert that channels within similar slope classes typically have distinct morphological

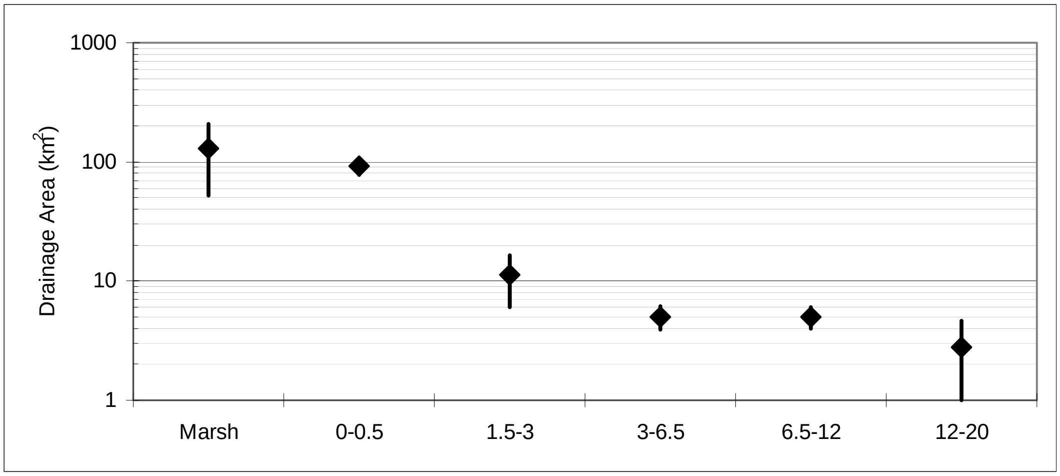


Figure 7-11: Drainage area as a function of channel slope class. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

characteristics: < 1.5% = pool-riffle, 1.5-3% = plane bed or forced pool-riffle, 3-6.5% = step-pool, and 6.5-20% = cascade. We have found, in prior watershed-scale studies, that these slope classes provide a reasonable and consistent *a priori* basis for stratifying watershed scale channel survey data.

In the following discussion, we present data stratified by channel slope class. Most of the data plots are in the style of box and whisker plots; in this case, we display the mean and the range of one standard error around the mean to represent the central tendency and variability of the data. Rather than simply repeat the same set of plots with this different mode of analysis, we avoid repetition of graphs that lead to similar conclusions as the drainage area plots and present data that provides additional insights to geomorphology and fish habitat in the watershed.

Channel slope classes were developed from USGS DEM's for the study area and manipulated in the project GIS. As is typically the case using these data, map estimates of channel slopes are substantially greater than observed channel slope (Figure 7-12). The channel slope class data do faithfully represent relative channel slope differences, however, the discrepancy between measured channel slope and predicted channel slope increases with channel slope class. The reader should recall the caveat that channel slopes measured in the field are probably somewhat (but not extremely) biased toward lower slopes. The primary significance of Figure 7-13 is that it shows that channels with slopes suitable for salmonid fish are extensively distributed throughout the watershed, even in tributaries far upstream in slope class 12-20%. Consequently, the potential distribution of fish habitat may be largely determined by migration barriers.

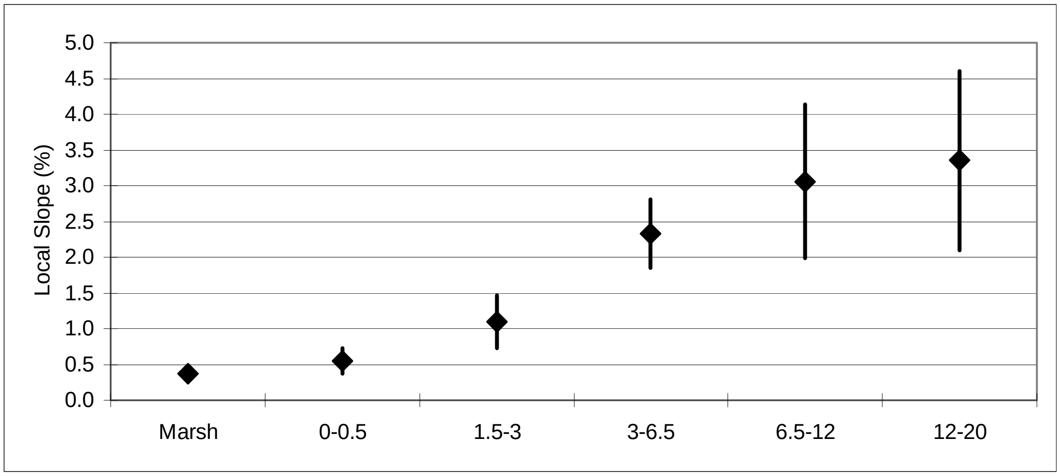


Figure 7-12: Local channel slope measured in the field as a function of channel slope class. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

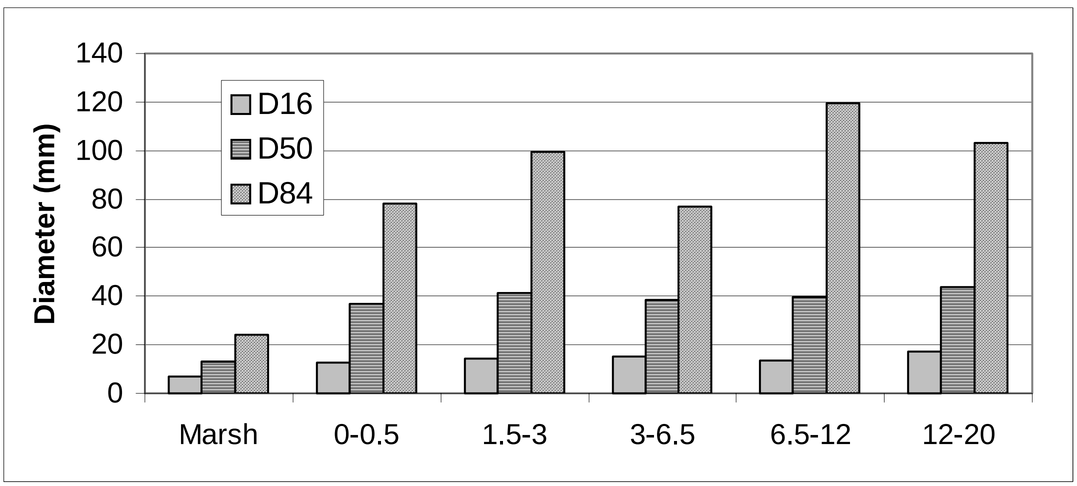


Figure 7-13: Mean values of D16, D50 and D84 as a function of channel slope class.

Given the foregoing indication that suitable stream channel slopes that are potentially suitable for salmonids exist in all observed nominal slope classes, we assess whether the same conclusion may be drawn from sediment size data. As shown in Figure 7-13, the typical median (D50) sediment diameter throughout most of the channel network is about 40 mm, which is generally suitable for spawning for steelhead trout. This reaffirms the suggestion that salmonid habitat is potentially widely distributed in the watershed channel network.

The sediment size distributions summarized in Figure 7-13 also show that D16, a portion of the size distribution that is highly mobile, is also narrowly distributed between about 10 and 20 mm throughout most of the watershed. D50 is expected to be a relatively mobile size in most gravel bed streams. It can thus be inferred from these data that sediment in the size range of D16 to D50, which varies little across the slope classes, represents the most rapidly transported size fraction of bed material in the watershed. The relative uniformity of the size distributions across the watershed suggests that sediment supply to the channel network is relatively uniform as well. This supposition is supported by the gravel bar data in Figure 7-14. As suggested previously, however, stream power (Figure 7-15) does not correlate with indicators of sediment storage (compare Figure 7-15 with Figures 7-13 and 7-14). High stream power does not correlate with large sediment sizes and/or low sediment storage, suggesting that sediment supply is large enough to prevent evidence of size selective transport. Size selective transport leads to channel bed coarsening as sediment supply diminishes. These data further support the notion that the channel network is relatively well supplied with sediment.

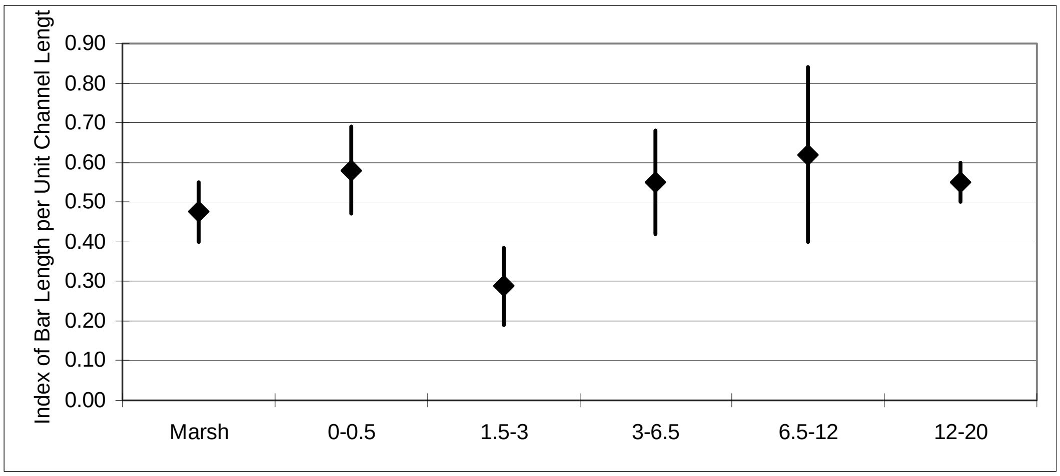


Figure 7-14: Index of bar length per unit channel length as a function of channel slope class. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

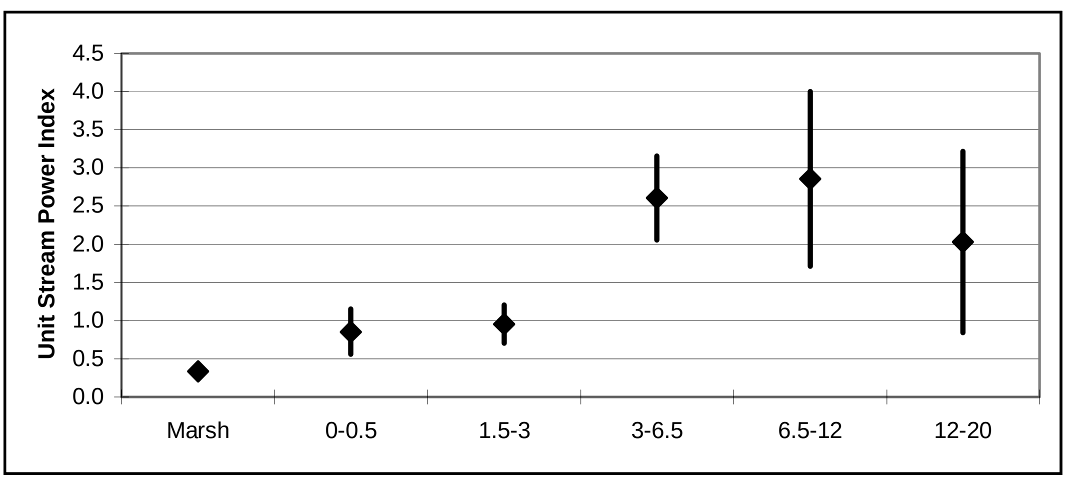


Figure 7-15: Unit stream power index (the product of bankfull depth and channel slope) as a function of channel slope class. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

Data not previously discussed include some of the ordinal data from stream reach field observations. One of these of particular interest with respect to geomorphology is the prevalence of bedrock in stream channels (Figure 7-16). The data suggest that reaches in the 1.5-3% and 3-6.5% classes have relatively high bedrock abundance, the latter slope class in particular. The stream power index increases dramatically for the 3-6.5% slope class (Figure 7-15), consistent with Figure 7-16. However, bedrock abundance declines in steeper slope classes, despite comparable stream power. It may be that the 3-6.5% slope class channels have a combination of slope and drainage area that provides a long-term ability to scour channels to bedrock more frequently. Debris flow processes could contribute to this phenomenon; field observations of this channel slope class indicate that they tend to occur in relatively steep-walled canyons of tributaries to Pescadero Creek. We speculate that these channels may represent an area in the watershed where long-term channel incision caused by long-term tectonic uplift may have its greatest expression.

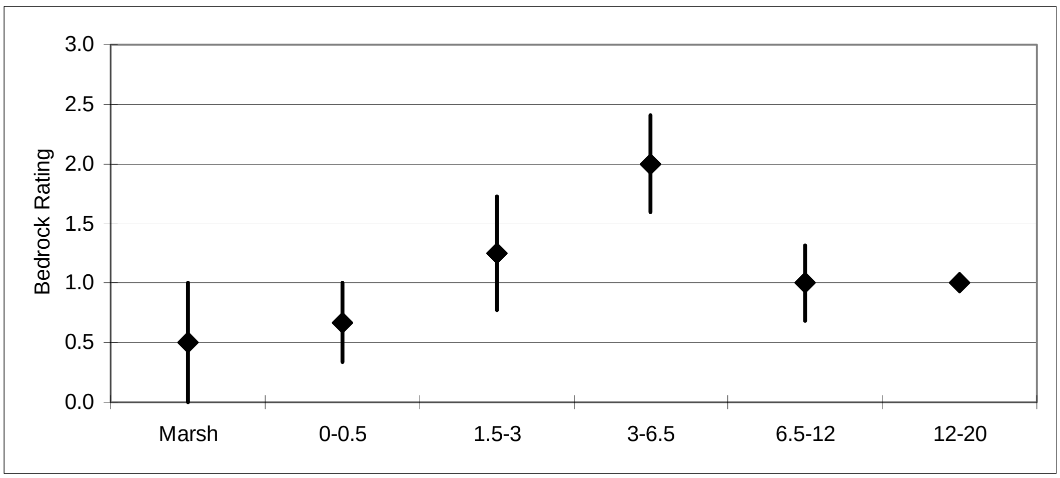


Figure 7-16: Extent of bedrock exposure in stream channels as a function of channel slope class. A value of 1 indicates bedrock is present in the reach, a value of 2 indicates that bedrock is common, and a value of 3 indicates abundant bedrock exposures. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

The frequency (Figure 7-17) and size (Figure 7-18) of streamside mass wasting features (smaller near channel debris slides and rotational landslides) was also documented during field surveys and expressed as ordinal data. Field data indicate that the larger, more common streamside landslides tend to be in slope class 1.5-3%, and that streamside landslides are relatively evenly distributed across channel classes. This adds somewhat to the weight of evidence suggesting that sediment sources are relatively abundant and evenly distributed throughout the watershed.

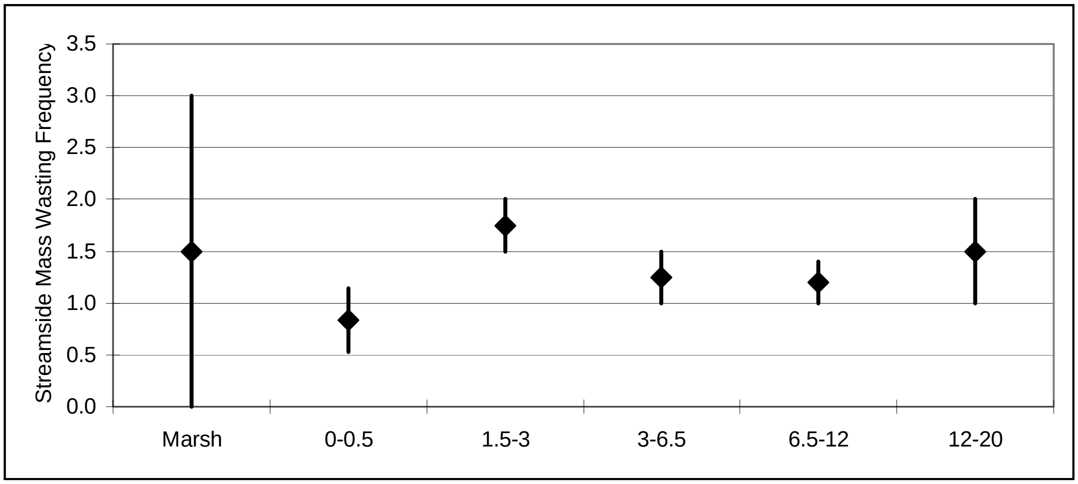


Figure 7-17: Frequency of streamside mass wasting (SSMW) features in stream channels as a function of channel slope class. A value of 1 indicates SSMW features are present in the reach, a value of 2 indicates that SSMW features are common. The diamond indicates the mean value; the line represents the range of one standard error around the mean. The small sample size for the “marsh” reaches (n=2) and high variance reflect divergent data from the two sample sites; the mean value is the more representative metric for this channel stratum. Note that for the 12-20 slope class, a small sample size (n=2) did not result in similarly wide variance, but generated the same mean value as the “marsh” reaches.

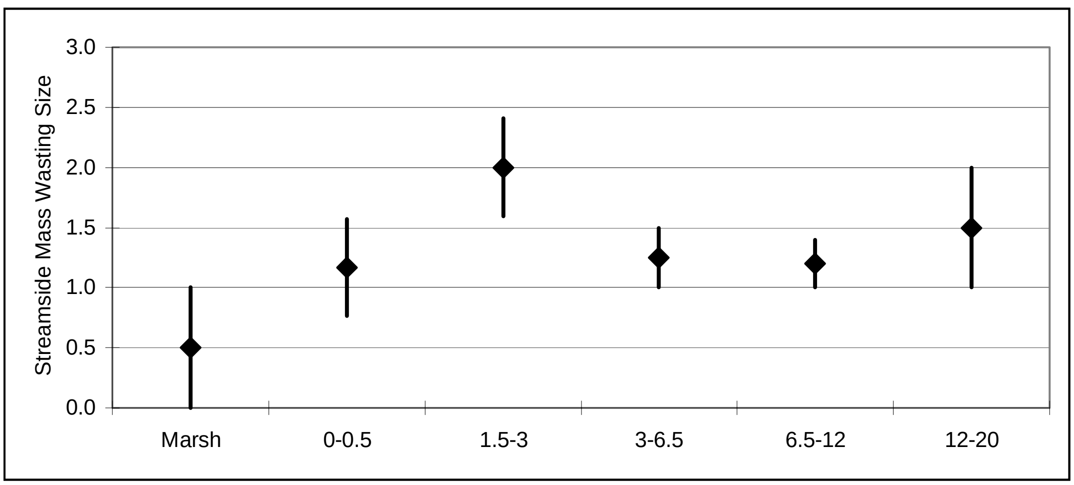


Figure 7-18: Size of streamside mass wasting (SSMW) features in stream channels as a function of channel slope class. A value of 1 indicates the scale of SSMW features are < 5x bank height, a value of 2 indicates that SSMW features are 5-10x bank height. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

Floodplain continuity, a measure of evenly distributed or discontinuous overbank floodplain areas, is displayed in Figure 7-19. Unsurprisingly, the marsh reaches have continuous floodplain. Discontinuous floodplain is found in the 0-0.5% and 1.5-3% slope classes. Above 3% slope, floodplains become less common. The low floodplain continuity in the 3-6.5% slope class correlates with the high bedrock abundance in this channel slope class,

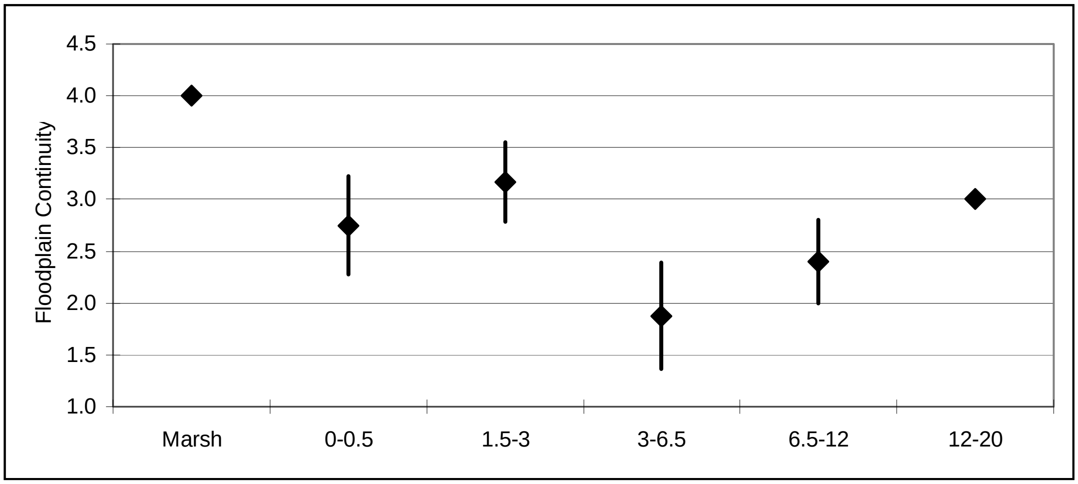


Figure 7-19: Floodplain continuity in stream channels as a function of channel slope class. A value of 4 indicates continuous floodplain in the reach, a value of 3 indicates discontinuous floodplain in the reach, and a value of 2 indicates terraces with no evidence of recent overbank flow. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

tending to confirm its canyon character. The ratio of the floodplain (or terrace) height to bankfull depth provides another measure of relative flood hazard (Figure 7-20). The marsh reaches are notable in that there is relatively little vertical separation between the bankfull elevation and the floodplain elevation. This is consistent with Figures 7-4, 7-5 and 7-19, all of which indicate relatively high flood hazards in the area represented by the marsh reaches.

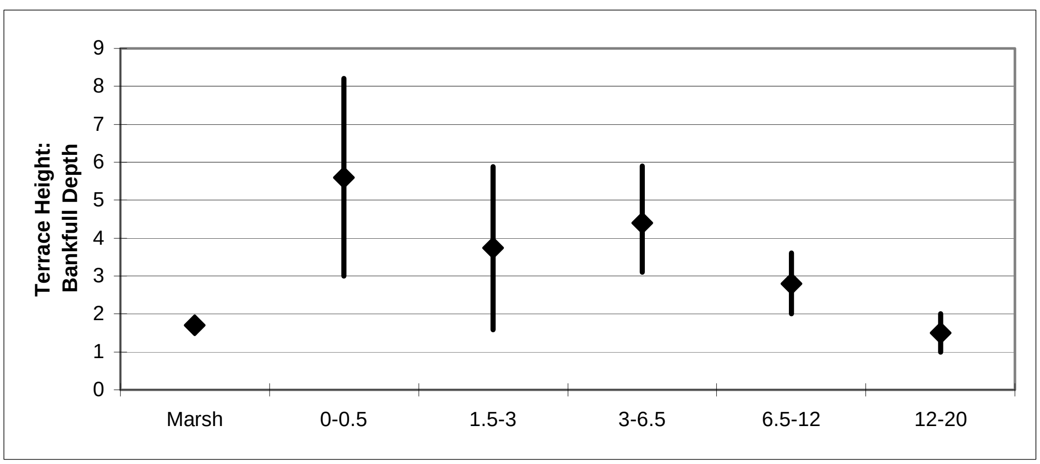


Figure 7-20. Ratio of terrace height to “bankfull” depth in stream channels as a function of channel slope class. This ratio quantifies the relative vertical distance between water elevation at “bankfull” (i.e. field estimated 2-yr recurrence interval flow) and the lowest floodplain surface (often classified in the field as a terrace). High values indicate deep channel entrenchment; low values indicate that the floodplain elevation is low relative to bankfull elevation, suggesting relatively high flooding potential. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

LWD abundance, discussed at some length above, is relatively evenly distributed across channel slope classes, with some indication of declining abundance in steeper slope classes (Figure 7-21). This is generally consistent with drainage area relationships observed earlier (Figure 7-9).

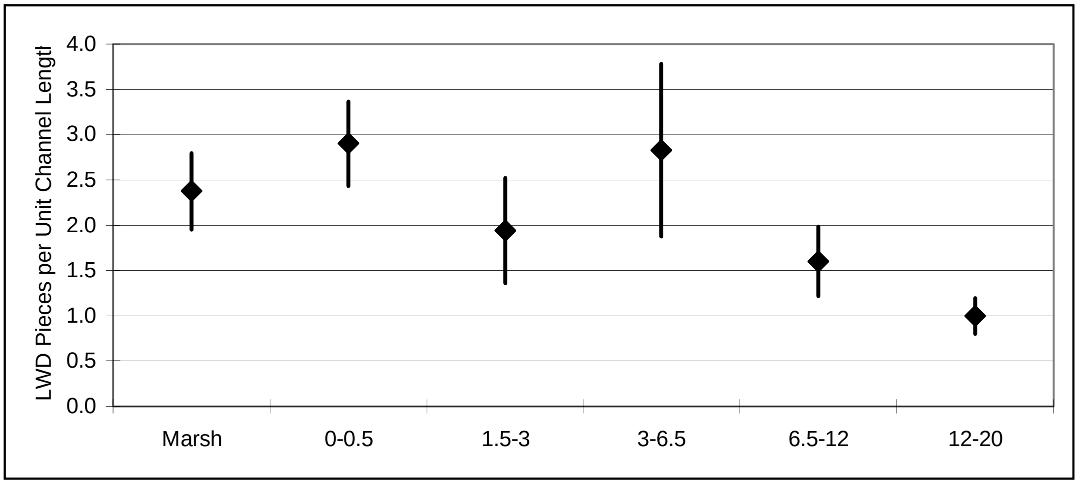


Figure 7-21: LWD per unit channel length (bankfull-width units) as a function of channel slope class. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

Observations pertaining to the decay class of LWD can be used to characterize the age distribution of LWD and to draw general inferences regarding LWD recruitment processes and rates. In addition, when live wood in the bankfull channel is incorporated in LWD surveys, the relative contribution of riparian zone trees to channel processes can be inferred. This is important because live trees also contribute functions generally ascribed to LWD: increased flow resistance, potential pool scouring, and morphological complexity, all of which may be beneficial for fish habitat. Figure 7-22 shows the total number of LWD, including live trees > 1 ft diameter present within the bankfull channel as well as the proportion of deciduous trees and coniferous trees. Live trees > 1 ft diameter are equivalent to 35% of LWD, providing a substantial increment of wood function.

The distribution by channel slope class of live coniferous trees in the bankfull channel (Figure 7-23) and live deciduous trees in the bankfull channel (Figure 7-24) shows the low proportion of live conifers, and the high proportion of deciduous trees, particularly in the lowest gradient channels. These data indicate that live deciduous trees are a significant component of the fluvial system in channels in the Pescadero-Butano watershed. Live trees in the bankfull channel are potentially an important component of flow resistance that influences flood hazards.

Excluding live trees, 91% of LWD is “sound,” 6% is “fresh,” and 3% is “decayed.” For comparison, in the Garcia River watershed, decayed pieces accounted for 23% of the total, sound pieces represented 69%, and fresh pieces represented 7%. The small proportion of

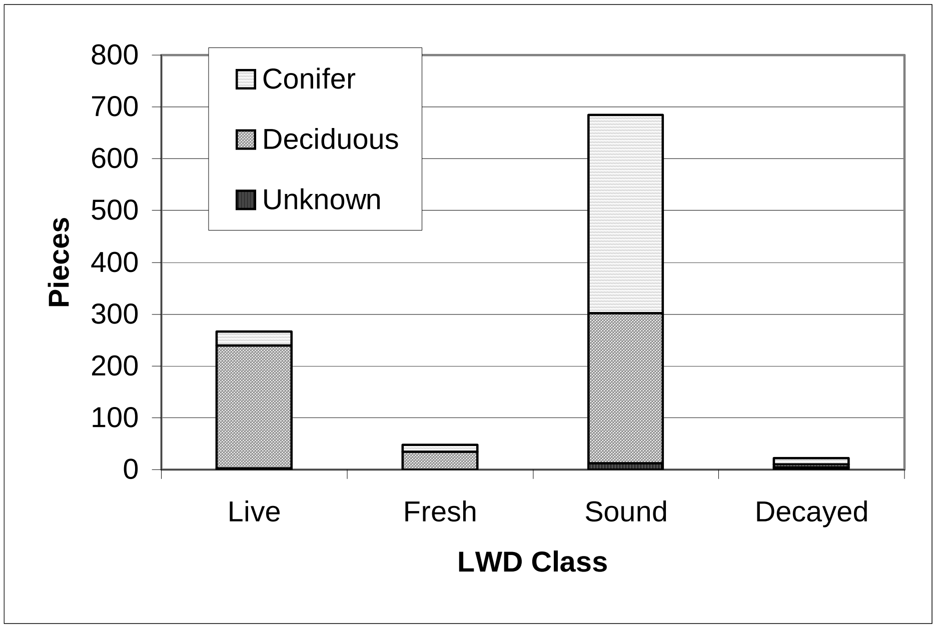


Figure 7-22: Total LWD pieces in each decay class and proportions contributed by coniferous and deciduous trees. The “unknown” type category is negligible. Note the high proportion of live trees that are deciduous.

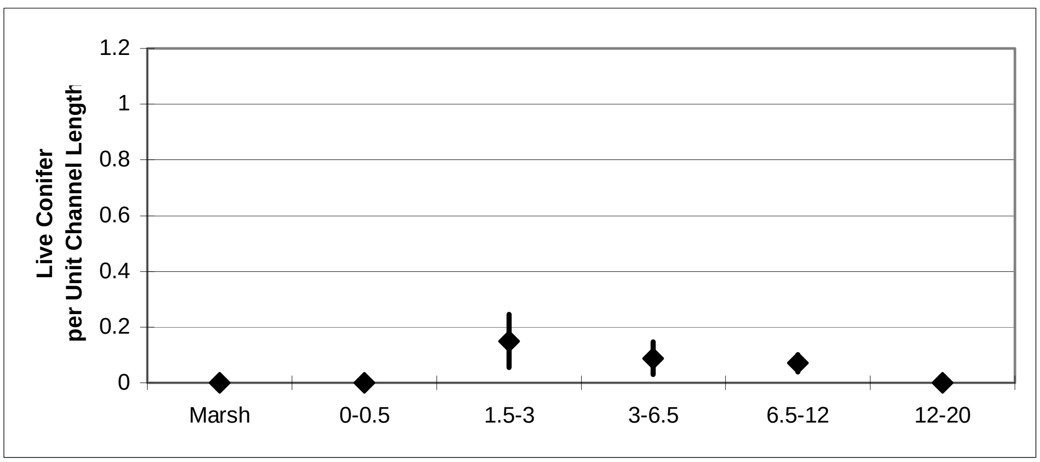


Figure 7-23: Live conifer per unit channel length (bankfull width units) as a function of channel slope class. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

decayed pieces in the Pescadero-Butano watershed suggests one or more of the following: that a period of reduced LWD recruitment occurred several decades ago; that removal of LWD from channels was common decades ago; or that recent floods (e.g. 1998) selectively removed decayed LWD from the channel network. In watersheds where LWD recruitment processes have remained relatively stable over relatively long periods, a higher proportion of decayed LWD might be expected to be present.

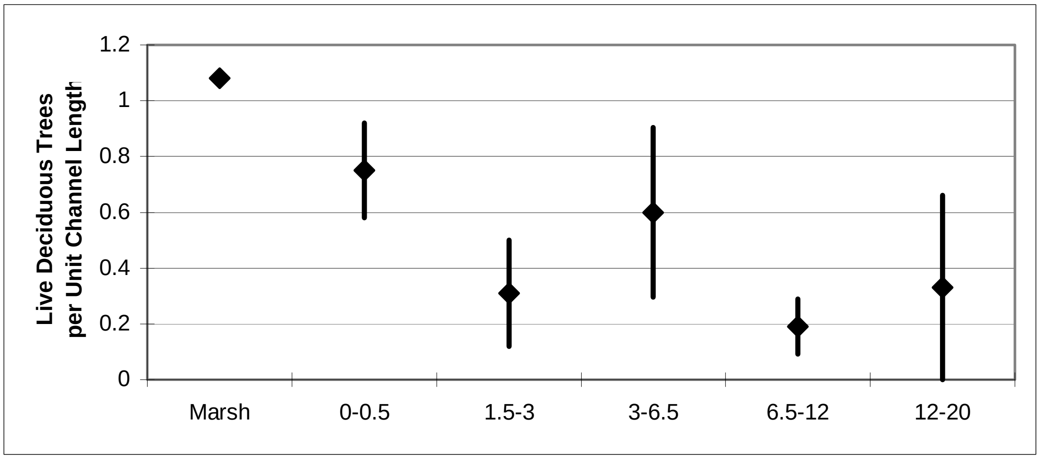


Figure 7-24: Live deciduous trees per unit channel length (bankfull width units) as a function of channel slope class. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

The decay class "fresh" represents LWD that was recruited to the channel over the past year. These data thus approximate a short term LWD recruitment rate. Given 48 pieces of fresh LWD distributed over 4.1 km of surveyed channel, the mean recruitment rate is about 1.2 pieces per 100 m of channel per year for LWD > 1 ft diameter. For comparison, the mean recruitment rate for LWD > 1 ft diameter was about 0.5 pieces per 100 m in the Garcia watershed. When the Pescadero-Butano data are adjusted to consider only sample reaches of comparable bankfull width to the Garcia reaches, recruitment is about 0.9 pieces per 100 m, nearly double that found in the Garcia. Closer inspection of the Pescadero-Butano data revealed that over half the conifer recruitment occurred in reaches PES 180 and PES 190 in Portola Redwoods State Park. This suggests that the relatively mature forest stands in the park generate a high proportion of LWD recruited to channels. The relative absence of such stands in much of the Garcia River reinforces the supposition. Relatively high recruitment rates of conifer (typically redwood) should be anticipated in the park reaches along Pescadero and Butano Creeks, indicating potential future habitat improvement. As can be seen in Figure 7-25, however, LWD recruitment rates throughout the watershed, viewed as a function of channel slope class and regardless of LWD type, is relatively constant. Much of the recruited LWD is from deciduous trees, which decays much more quickly than coniferous LWD, and hence has greater short term value for habitat.

LONGITUDINAL SEDIMENT SIZE DISTRIBUTION

One additional style of data interpretation is presented in Figures 7-26 and 7-27. The first figure displays sediment size distributions at sample reaches in Pescadero Creek from the marsh to the headwaters; the second displays sediment size distributions in Butano Creek from the marsh upstream to the headwaters.

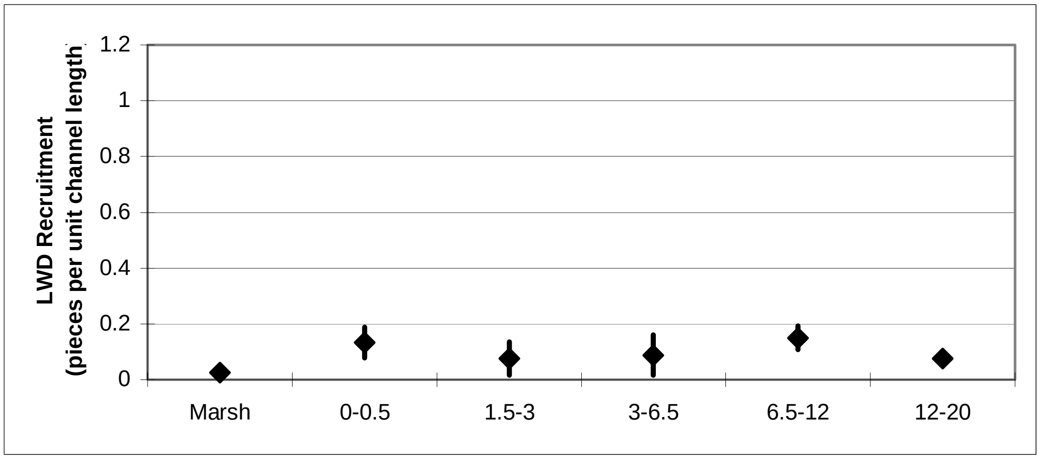


Figure 7-25: LWD recruitment per unit channel length (bankfull width units) as a function of channel slope class. Recruitment is determined as a function of counts of “fresh” LWD in channel surveys. The diamond indicates the mean value; the line represents the range of one standard error around the mean.

Regarding Pescadero Creek, there appears to be a significant change in size distributions between PES 100 (the USGS gage site) and PES 140 (near the waste treatment plant at the County Park). This may correspond to the significant widening of the valley of Pescadero Creek not far above the USGS gage site. The absence of a confined canyon probably reduces the local supply of cobbles and boulders from mass wasting, and could also correlate with a geologic formation contact in the same area. There might also be a corresponding decline in stream gradient, however, our channel slope data are not sufficiently extensive to determine this.

With respect to Butano Creek, Figure 7-27 shows that Butano Creek tends to contain a finer sediment size distribution compared to Pescadero Creek. It is unclear whether this may indicate higher sediment supply, or lower transport capacity, or both. In our opinion, however, we believe that Butano Creek, particularly in its northerly flowing reaches, has relatively low transport capacity compared to Pescadero Creek. The channel is narrower, there is abundant dense riparian vegetation, and the slope is generally low. In addition, this reach follows a fault zone, which could function as a long-term factor maintaining a reduced channel slope. The finer grain sizes may also be the product of bedrock geology in a large proportion of Butano Creek that does not produce gravel size material as it weathers. The shale and mudstone common in the Butano Creek watershed are inherently weak and friable, typically weathering rapidly to sand and silt sized particles.

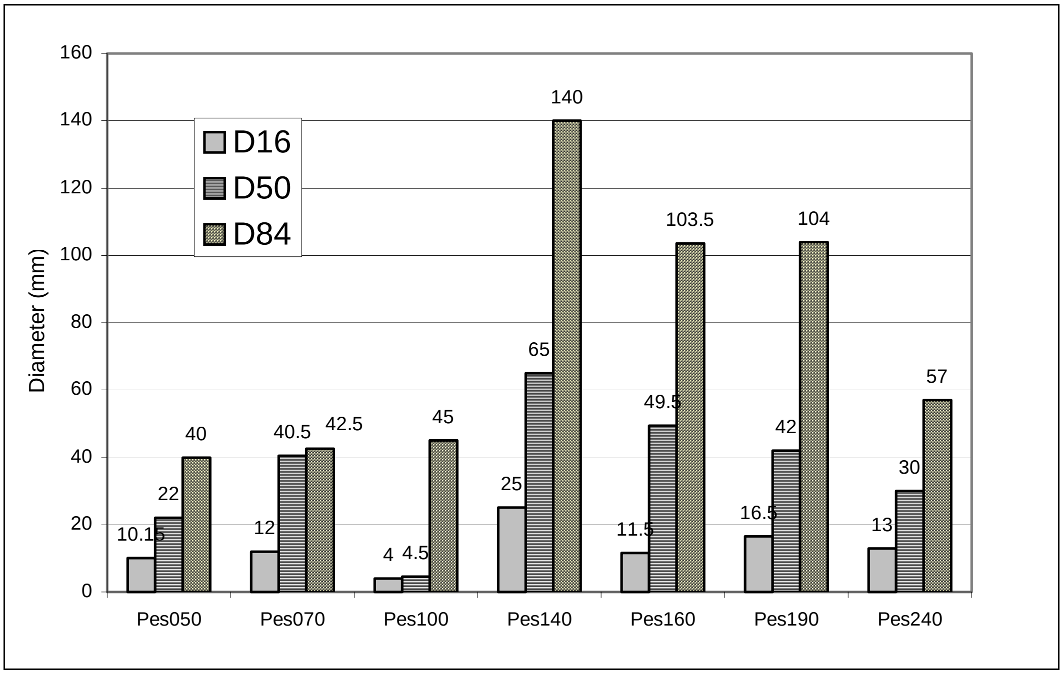


Figure 7-26: Diameters of D16, D50 and D84 for sample reaches ascending Pescadero Creek (from left to right).

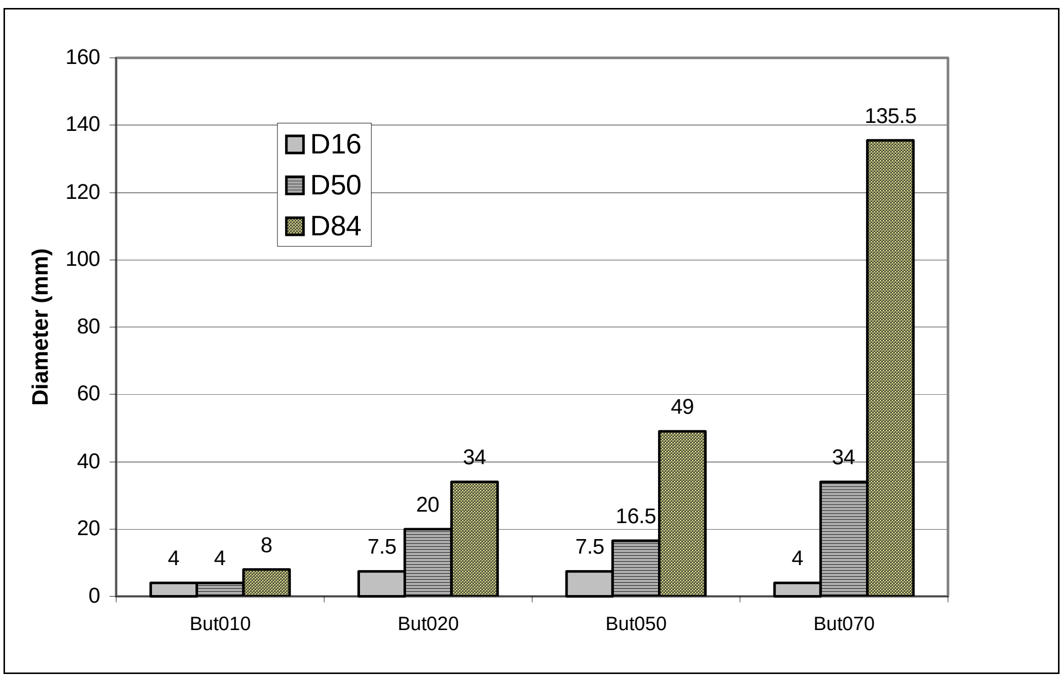


Figure 7-27: Diameters of D16, D50 and D84 for sample reaches ascending Butano Creek (from left to right).

CONCLUSION

This survey of channel conditions in the Pescadero-Butano watershed obtained data from 23 sample reaches that were stratified into six channel slope classes. Data were also analyzed as a function of drainage area. Quantitative surveys of channel geomorphology at the watershed scale help to identify broad patterns and distinctions between channel classes; however, the natural variability of stream channels frequently makes it impractical to utilize statistical inference and formal hypothesis testing to draw conclusions, as was the case in this study. The sample data and sample statistics do provide a basis upon which a more ambitious effort to stratify and quantify distinct channel types could be taken, should that be warranted in the future. The sample data have been presented graphically in plots as a function of drainage area to display the data distributions and in box and whisker plots as a function of channel slope class to display trends. These data have been used to develop a few general inferences regarding stream channels, fluvial geomorphology, and factors influencing fish habitat described below.

Sediment storage metrics (Figure 7-8) indicate that there may be substantial variation in sediment supply entering the system through smaller drainage basins (< 10 km^2), but in the larger streams, the cumulative inflow from smaller basins creates a relatively uniform and abundant supply of sediment stored in stream channels. This is manifested by a relatively consistent distribution of gravel bars in channels with drainage areas > 10 km^2. A surprisingly consistent sediment size distribution is found throughout the Pescadero Creek channel network, extending even into the steeper headwater channels with small drainage areas where coarser sediment size distributions might be expected. Hence, even in relatively small channels high in the watershed, sediment sizes on the bed are frequently suitable for spawning. Given the relatively low channel slopes well within the range utilized by steelhead in even the steepest reaches (Figure 7-12), it appears that migration barriers may be the primary factor limiting the extent of available steelhead habitat. In contrast, Butano Creek bed material consists of both very coarse material and very fine material, with a lower proportion of gravel between the extremes. Unlike Pescadero Creek's watershed, where a relatively large variety of bedrock types are found, the Butano basin contains primarily fine-grained sedimentary rocks that tend to weather to fine gravel, sand and silt sizes, and produce relatively little coarse gravel. Hence, there is some reason to believe that spawning habitat may be more limited in Butano Creek compared to Pescadero Creek.

LWD is believed to be less abundant than prior to European settlement, logging activities, and stream management that included LWD removal over the past century. LWD abundance varies significantly from reach to reach, as is typical in forested watersheds. Mean LWD abundance as a function of channel slope class is, however, relatively consistent throughout the channel network (Figure 7-21). LWD abundance is comparable to that found in another northern California coastal watershed (the Garcia River) from which comparable data are available, providing evidence that LWD loading in the Pescadero-Butano watershed may be typical of current conditions in the region. LWD *recruitment* rates, however, appear to be substantially higher than observed in comparable reaches of the Garcia River, and relatively mature stands of conifers in public parks adjacent to stream channels in the Pescadero-Butano watershed are likely to provide significant LWD inputs that would be expected to improve pool habitat (cover and depth) over the coming decades. Live trees growing within the bankfull channel contribute a significant proportion of LWD function, and, although dominated by deciduous species, provide a source of LWD available over the short-term.

Channel and floodplain morphology in the lower reaches of Pescadero and Butano Creeks, or the ‘marsh’ reaches, are influenced by tidal processes. The marsh reaches exhibit distinctive morphological characteristics compared to the rest of the watershed, including greater channel width, higher entrenchment ratios, and lower ratios of bankfull depth to floodplain height. Moreover, these channel reaches exhibit finer sediment size distributions, suggesting relatively more frequent episodes of overbank flooding and deposition compared to other parts of the watershed. Although our field measurements did not detect a significant change in channel slope, periods of high tide that coincide with flood flows, as well as the typical summer and fall sandbar formation at the mouth of Pescadero Creek and the consequent lagoon formation, would be expected to reduce the water surface slope and therefore the energy gradient of the stream in this area. This creates a strongly depositional environment, which is a normal feature of an alluvial river as it approaches a fixed base level such as the sea. The growth of dense riparian vegetation along channel banks would tend to enhance this effect.

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CHAPTER 8

FISHERIES HABITAT ASSESSMENT

METHODOLOGY

The primary purpose of the fish habitat task of the Pescadero-Butano Watershed Assessment was to categorize the *entire* watershed into reaches or sub-basins that may warrant more detailed restoration or management actions in the future. This categorization was to be based on existing overall fish habitat conditions. This leads directly to the question of the best methodology for such a categorization. The Habitat Inventory Methods specified in the *California Salmonid Stream Habitat Restoration Manual* (Flosi *et al.*, 1998) were initially proposed for use in the Pescadero-Butano Watershed Assessment project, and they are a valuable tool for assessing salmonid habitat conditions and identifying limiting factors that may be reducing overall salmonid habitat availability in a given reach. However, the survey methods are fairly detailed and time consuming.

As such, it was our opinion that the project would be better served if the habitat assessment was conducted using a less detailed but watershed-wide approach. Thus, we used existing biotic and abiotic data and augmented it with our own field assessments in an attempt to achieve watershed-wide coverage. Our primary source of existing data was the Regional Water Quality Control Board's (RWQCB) Surface Water Ambient Monitoring Program (SWAMP), conducted at 22 sites within the Pescadero-Butano watershed in April 2002. The surveys followed the California Stream Bioassessment Protocol (CSBP) (CDFG, 1999), which have been developed for watershed assessments in particular; they use standardized Physical Habitat Assessment forms to score a total of ten distinct habitat parameters, as well as standardized benthic macroinvertebrate (BMI) collections and analyses to rate the overall biotic "health" of a given stream reach.

In addition to the SWAMP data, the results of several habitat inventories and fish surveys conducted by the California Department of Fish and Game (CDFG, 1995) in 1995 were reviewed. While these reports present an overall picture of large Pescadero Creek mainstem reaches and several tributaries, individual habitat parameter data are not presented in a site-specific manner and thus do not allow for direct site comparisons. Therefore, the information presented in the CDFG reports was qualitatively incorporated into the overall assessment.

A total of 23 sites distributed throughout the watershed were surveyed for the Pescadero-Butano Watershed Assessment. In most cases (14 sites), data from existing SWAMP sites were augmented with field surveys of pool habitat parameters and ambient water quality. In addition, seven new, non-SWAMP sites were established and at these locations the same type of data as for the SWAMP effort (i.e., CSBP habitat and invertebrate assessments) were collected in addition to pool and water quality data. However, one of those new sites (Evans Creek, PES320) was dry during the summer 2003 survey period and was therefore only assessed qualitatively. Furthermore, two sites were established in the vicinity of previous SWAMP sampling locations. At these sites, we collected site-specific CSBP habitat data, as well as pool and water quality data, but used the existing biotic condition data generated during the 2002 SWAMP effort. Table 8-1 summarizes by sampling site the various existing and new data sources used in this assessment. Sampling site locations are shown in Map 2-3 in Chapter 2.

TABLE 8-1
FISHERIES HABITAT DATA SOURCES BY SAMPLING SITE

	Existing Data (SWAMP, Spring 2002)		New Data (ESA, Summer, 2003)				
Site ID	CSBP Habitat	CSBP Biotic	CSBP Habitat	CSBP Biotic	Pool Habitat	Water Quality	Water Temp.
PES050	√	√			√	√	
PES070	√	√			√	√	√
PES100	√	√			√	√	√
PES120	√	√			√	√	
PES140	√	√			√	√	
PES160	√	√			√	√	√
PES170	√	√			√	√	√
PES180	√	√			√	√	√
PES190	√	√			√	√	√
PES205		√*	√		√	√	√
PES210	√	√			√	√	
PES215			√	√	√	√	√
PES235		√**	√		√	√	√
PES240	√	√			√	√	
PES320			DRY	DRY	DRY	DRY	DRY
PES350			√	√	√	√	
PES360			√	√	√	√	
PES370			√	√	√	√	
PES380			√	√	√	√	
BUT010	√	√			√	√	
BUT030	√	√			√	√	
BUT050	√	√			√	√	√
BUT070			√	√	√	√	

Notes: * CSBP biotic condition data derived from SWAMP site PES200
** CSBP biotic condition data derived from SWAMP site PES230

SITE SELECTION

Although a primary goal of the assessment was to determine habitat quality for salmonids, survey locations were not confined only to streams and sub-basins known to support anadromous species. All too often, the reason for steelhead or coho absence from a given reach is the presence of downstream barriers such as culverts or dams that block salmonids from accessing otherwise suitable habitat. Such manmade impediments to fish passage are often times relatively easy and cheap to remedy. Thus, the goal of the assessment was to provide a watershed-wide picture of current habitat conditions.

Site selection began with a review of the Regional Water Quality Control Board's SWAMP sites. These were found to be relatively well distributed throughout the watershed, and were particularly representative of low gradient reaches of streams presumed to support anadromous salmonids. These included several stations on the mainstem of Pescadero Creek, as well as stations in the lower reaches of most of the major tributaries to Pescadero Creek. Five stations were located in the Butano watershed, four on the mainstem, and one on Little Butano Creek. In all, there were 22 sites that were included in the 2002 SWAMP program.

We eliminated from our site selection several of the SWAMP sites that were in close proximity to one another on the mainstem channels, as well as several sites for which we were unable to obtain access permission. We augmented existing SWAMP sites with several new sampling locations, primarily in tributaries that had not been assessed previously, or that had only one SWAMP site in their lower course. These included three stations in the upper Peters Creek watershed, a second station on Oil Creek, and stations on Little Boulder Creek and Trestle Creek. Although currently largely non-anadromous due to manmade migration barriers (road crossings), these latter two are among the approximately 20 small streams that drain the north side of Butano Ridge and were included in the assessment to represent conditions in that part of the drainage. Furthermore, two sites in the Butano Creek watershed, BUT050 (Little Butano Creek in Butano State Park) and BUT070 (Butano Creek above the Falls), were assumed to be above permanent limits of anadromy (i.e., above natural waterfalls), but are known to support resident rainbow trout populations that may serve as population or genetic reservoirs for anadromous steelhead populations.

The locations of sampling sites used in this assessment are shown in Map 2-3 in Chapter 2.

FIELD METHODS

All field surveys were conducted between August 21 and September 24, 2003. The previous SWAMP assessments in the watershed had been conducted April 9 through April 12, 2002. As discussed above, the surveys for habitat quality and biotic condition were conducted according to the California Stream Bioassessment Protocol (CSBP) (CDFG, 1999). The assessments of pool habitat conditions followed methods outlined in the *California Salmonid Stream Habitat Restoration Manual* (Flosi et al, 1998), and water quality measurements were collected according to standard practices and manufacturer's instructions for the use of testing equipment. All surveys were conducted within the same stream reach that was used for the geomorphologic assessments described in Chapter 7. Survey reach lengths were typically equal to 20 bankfull widths or the length of stream containing five distinct pool habitats. Each type of assessment is described in further detail below.

PHYSICAL HABITAT QUALITY

The habitat assessment portion of the CSBP consists of ascribing a value of 0-20 to each of ten habitat parameters: epifaunal substrate/available cover, embeddedness, velocity/depth regimes, sediment deposition, channel flow status, channel alteration, frequency of riffles or bends, bank stability, vegetative protection, and riparian vegetative zone width. Data from individual parameter scores are then combined using a standardized habitat conditions rating system, resulting in a single numeric rating (0-200) that can be compared to other streams and other reaches. High total scores are indicative of relatively unimpaired habitat conditions, while low scores are typically indicative of degraded conditions. Thus, the physical habitat quality of streams with a total score of 0-49 are classified as *poor*, a score of 50-99 is classified as *marginal*, a score of 100-149 is classified as *suboptimal*, and a score of 150-200 is classified as *optimal* habitat. A detailed description of the CSBP habitat assessment methodologies is presented in the protocol brief entitled *California Stream Bioassessment Procedure* (CDFG, 1999).

The CSBP habitat assessment was developed based on known benthic macroinvertebrate habitat requirements. However, the habitat requirements of those invertebrates known to be intolerant of pollution and degraded channel conditions are similar to those of salmonids (e.g., low levels of embeddedness, high degree of streambank stability, etc., constitute superior habitat). As such, the CSBP habitat assessment provides a valid, although not all-inclusive, picture of salmonid habitat conditions and limiting factors within the sampling reaches.

BIOTIC CONDITIONS

In addition to standardized habitat assessments, the CSBP also describes the use of benthic macroinvertebrate data in determining the biotic condition, or relative health, of the surveyed stream. Following the methodologies described in the protocol brief (CDFG, 1999), replicate samples of benthic invertebrates were collected from riffles within the survey reach and preserved in ethanol. Samples collected by ESA in 2003 were submitted to BioAssessment Services in Folsom, California, for subsampling, identification, enumeration, and data analysis. The 2002 SWAMP samples were collected, processed, and reported by CDFG's Aquatic Bioassessment Laboratory (ABL) in Rancho Cordova, California. Once identified and enumerated, the benthic macroinvertebrate assemblages' various biological metrics (i.e., taxonomic richness, relative abundances, tolerance measures, and functional feeding groups) are used to describe the invertebrate community present in the sampled stream.

The results of some of the biological metrics are then used to calculate an Index of Biological Integrity (IBI), or relative biotic condition, for each stream. For both the SWAMP and ESA collections, the Russian River Index of Biological Integrity (RRIBI) was used, as it is the only index of its kind that has been developed for northern and central California so far. Although ongoing efforts are aimed at developing other regional indices, the RRIBI was used for the assessment of the 2003 samples because the same index was used by the ABL for the 2002 samples. The RRIBI applies standardized scores to the mean values of six biological metrics and then uses the total score to describe the biotic condition of the sampled stream. A score of 30-24 is indicative of *excellent* biotic conditions, 23-18 of *good* conditions, 17-12 of *fair* conditions, and 11-6 of *poor* conditions. Please refer to Harrington and Born (2000) for a detailed description of invertebrate metrics and their use in determining biotic conditions.

Benthic invertebrate assemblages vary seasonally. Samples collected in the spring typically contain a higher abundance of organisms than summer or fall samples. Furthermore, the relative abundance of sensitive species of the families Ephemeroptera, Plecoptera, and Trichoptera (collectively referred to as EPT) is usually lower in the summer and fall due to the transformation of aquatic larvae into aerial adults during the spring and early summer. As such, biotic samples collected by the ABL in spring 2002 are not directly comparable to those collected by ESA in the summer of 2003. However, due to contractual and logistical time constraints, only the summer sampling period was available to ESA. As such, the results of the 2003 biotic condition assessment are likely to reflect worst-case scenarios while the SWAMP samples probably reflect best-case scenarios. Nevertheless, the results of the two efforts represent the best available information on biotic conditions at the various sampling locations.

POOL HABITAT CONDITIONS

As discussed above, the CSBP habitat assessment protocol is aimed at evaluating overall stream conditions rather than specific aspects of fisheries habitat. An important habitat feature for all salmonids is the presence of relatively deep pools with adequate shelter (cover). Thus, we collected detailed information on pool habitats encountered within survey reaches in order to augment the results of the CSBP assessments. Methods used in the collection of pool habitat data were based on pertinent portions of the CDFG Habitat Inventory Form, as presented in the *California Salmonid Stream Habitat Restoration Manual* (Flosi *et al.*, 1998), and included measurements of the following physical pool parameters: mean length, mean width, mean depth, maximum depth, depth at the pool tail crest, pool tail embeddedness, and pool tail substrate. In addition, notes were made about the relative abundance and quality of available cover such as large woody debris (LWD) and bank undercut.

WATER QUALITY

The following water quality parameters were measured in the field at all sampling stations using a YSI Model 85 multi-purpose probe: Water and air temperature, dissolved oxygen concentration and saturation, and specific conductivity. Furthermore, a Hanna Instruments pHep probe was used to determine water pH and a HACH Company Model 2001P turbidimeter was used to measure turbidity. Streamflows were determined with the use of a Swoffer model 2100 current velocity meter. In addition, HoboTemp® continuous temperature monitors (manufactured by Onset Computer Corp.) were deployed at several of the sampling stations in late July 2003, and retrieved in late October 2003. The temperature traces from the continuous monitors appear in Appendix C.

DATA ANALYSIS

The overall goal of the Pescadero-Butano Watershed Assessment project is to characterize various streams and sub-basins in terms of existing fisheries habitat conditions. In order to allow for the assessment to be used as a tool in future management and restoration decision-making processes, we reduced our findings to three categories: high, moderate, or low priority (see Map 2-3 in Chapter 2). Streams ranked as high priority are those that contain the highest quality fisheries habitat and thus would benefit most from informed management as well as targeted restoration projects based on the results of focused and detailed habitat assessments.

The priority ranking for the 23 sampling sites was based on weighted scores assigned to the results of five of the pool habitat parameters as well as the CSBP habitat score and the RRIBI. The results of the water quality analyses were not directly incorporated into the priority ranking system for several reasons. For one, spot checks of water quality do not provide a true reflection of continuous conditions. With the exception of relatively high water temperatures at a few sites, none of the water quality results were indicative of significant problems that may compromise salmonid habitat quality. While water quality testing provides necessary background information for habitat assessments, the results typically do not allow for site comparisons if all measured parameters are within known preference ranges of the target species. Where we did conduct continuous temperature monitoring of water temperature, the results corroborated our spot observations. The continuous monitoring was conducted for only a portion of the summer season (mid-July through end of October, 2003), when stream temperatures become an issue for salmonids, but the results do provide a comparison of diurnal ranges and maximum temperatures during the period of monitoring, both of which are useful in determining the relative suitability of conditions for salmonids.

The mean values for all pool habitats surveyed in a given reach were used in the scoring system developed for this assessment. The following parameters were used as scoring criteria in the establishment of a priority list:

- *% Pool Habitat* – a measure of the percentage of the total surveyed reach length that is made up of pool habitat. Measures of less than 30% or more than 80% were ascribed a value of “0”, while reaches containing 30-80% pools received a score of “1”.

- *Structural Shelter Rating* – the scoring of pool shelter quality and quantity was based on the system described in the CDFG restoration manual. A score of “0” is given to pools that contain only limited amounts of shelter while a score of “3” is given to pools containing abundant, high quality shelter; scores of “1” or “2” represent intermediate conditions. A detailed description of the structural shelter rating criteria can be found in Flosi *et al.* (1998).

- *Average Pool Depth* – reaches with a mean average pool depth of 11.9 inches or less received a score of “0,” pool depths of 12.0 – 23.9 inches scored “1,” and pool depths equal to or exceeding 24.0 inches scored “2.”

- *Pool Tail Embeddedness* – the mean pool tail embeddedness for each reach was determined by rating individual pools according to Flosi *et al.* (1998). Under this system, relative embeddedness of 0-25% is categorized as 1, 25-50% as 2, 50-75% as 3, 75-100% as 4, and unsuitable spawning habitat (e.g., bedrock substrate) falls into category 5. For the purposes of our assessment, we averaged the numerical values of the individual CDFG category assignments (excluding category 5) to rank the average level of embeddedness within the reach with higher scores indicative of greater embeddedness. To convert the average embeddedness ranking into a priority ranking criteria score, we assigned a score of "0" to reaches with average embeddedness of 3.0-4.0, a score of "1" for embeddedness of 2.0-2.9, and a score of "2" for embeddedness rankings of 1.0-1.9.

- *Predominant Pool Tail Substrate* **–** if the predominant substrate type of pool tails was gravel (0.08-2.5" diameter) and/or small cobble (2.5-5" diameter), the reach received a score of "1;" reaches with dominant substrate sizes of less than 0.08" or more than 5" received a score of "0."

- *CSBP Habitat Score* **–** as described above, the CSBP habitat assessment protocol results in the ranking of streams into optimal, suboptimal, marginal, and poor habitat quality. For the purposes of incorporating the CSBP habitat scores into the priority list ranking for this assessment, a habitat ranking of poor (0-49) was assigned a score of "0," marginal habitat (50-99) received a score of "1," suboptimal habitat (100-149) scored "2," and optimal habitat (150-200) scored "3."

- *RRIBI Biotic Condition* **–** similar to the CSBP habitat score, the RRIBI designations of excellent, good, fair, and poor were converted into numerical scores of "0" for poor conditions, "1" for fair conditions, "2" for good conditions, and "3" for excellent conditions.

In order to create a priority list, the scores for the seven assessment parameters were added to derive a total score of 0-15. Streams with a total score of 0-5 were categorized as "low" priority, those scoring 6-10 were classified as "moderate" priority, and those sites scoring 11-15 were ranked as "high" priority. Within each category, the actual scores for each site (Table 8-6) can be used to further prioritize streams for management and restoration. For example, a "moderate" priority site with a total score of 10 may warrant more attention than a "moderate" priority site with a score of 6. Please refer to Table 8-6 for a description of the various scoring weights applied to each parameter.

FISH HABITAT ASSESSMENT RESULTS

PHYSICAL HABITAT QUALITY

The habitat assessment results (Table 8-2) show that a total of 15 sites contain *optimal* habitat and 6 contain *suboptimal* habitat. Only one surveyed site, Butano Creek downstream of the Pescadero Road crossing, currently contains overall *marginal* habitat. Optimal habitats are generally concentrated on the main stem sites of Pescadero Creek upstream of Loma Mar and in the upper watershed tributaries such as Tarwater, Peters, Slate, and Oil creeks. Suboptimal habitats are more common in the lower reaches of Pescadero Creek as well as in most areas of the Butano Creek watershed. The only surveyed Pescadero tributary exhibiting *suboptimal* habitat was Waterman Creek. Within the Butano Creek watershed, however, only Little Butano Creek appears to provide *optimal* aquatic habitat.

TABLE 8-2
RESULTS OF THE PHYSICAL HABITAT SCORING

Station ID	Survey Date	1. Epifaunal Substrate	2. Embeddedness	3. Velocity/Depth Regimes	4. Sediment Deposition	5. Channel Flow Status	6. Channel Alteration	7. Frequency of Riffles	8. Bank Stability[1]	9. Vegetative Protection[1]	10. Riparian Veg. Zone Width[1]	TOTAL SCORE	Habitat Quality Rating
PES050	9-Apr-02	9	12	17	5	17	17	10	4	14	10	**115**	**Suboptimal**
PES070	10-Apr-02	15	14	17	13	18	17	16	13	14	9	**146**	**Suboptimal**
PES100[2]	10-Apr-02	8	12	17	8	17	16	4	12	12	18	**124**	**Suboptimal**
PES120	10-Apr-02	18	10	19	12	18	18	18	10	15	12	**150**	**Optimal**
PES140	9-Apr-02	14	15	17	12	20	18	14	18	14	20	**162**	**Optimal**
PES160	10-Apr-02	15	13	14	14	20	20	18	13	15	20	**162**	**Optimal**
PES170	10-Apr-02	16	13	14	12	20	20	18	17	17	20	**167**	**Optimal**
PES180	10-Apr-02	14	14	10	17	20	20	18	11	13	20	**157**	**Optimal**
PES190	10-Apr-02	17	14	17	14	20	20	15	14	12	20	**163**	**Optimal**
PES205	22-Aug-03	13	18	14	11	18	20	18	15	17	20	**164**	**Optimal**
PES210	4-Sep-03	18	13	17	13	20	20	18	18	15	20	**172**	**Optimal**
PES215	4-Sep-03	11	20	15	10	19	20	12	18	20	20	**165**	**Optimal**
PES235	4-Sep-03	15	6	15	5	20	15	17	16	20	20	**149**	**Suboptimal**
PES240	9-Apr-02	14	12	14	12	20	20	18	8	12	20	**150**	**Optimal**
PES350	24-Sep-03	18	18	15	18	19	20	20	12	14	19	**173**	**Optimal**
PES360	24-Sep-03	16	17	15	16	18	16	18	8	11	16	**151**	**Optimal**
PES370	11-Sep-03	14	16	10	15	18	20	20	13	10	20	**156**	**Optimal**
PES380	5-Sep-03	13	19	15	18	20	20	17	19	16	20	**177**	**Optimal**
BUT010	9-Apr-02	3	1	9	1	18	16	10	8	16	16	**98**	**Marginal**
BUT030	9-Apr-02	12	8	16	5	18	18	18	13	14	15	**137**	**Suboptimal**
BUT050	9-Apr-02	17	16	15	13	19	17	18	13	15	19	**162**	**Optimal**
BUT070	23-Sep-03	9	1	15	2	19	20	11	9	10	16	**112**	**Suboptimal**
AVERAGE		**14**	**13**	**15**	**11**	**19**	**19**	**16**	**13**	**14**	**18**	**151**	

Notes: 1. Individual scores from left and right streambanks are combined
2. Scores reflect ESA 2003 assessemnt conducted upstream of bridge

Although the individual habitat parameters identified as *poor* or *marginal* are generally scattered across the watershed (Table 8-2), some trends are evident. Embeddedness, sediment deposition, and lack of epifaunal substrate tend to be the predominant problems in the lower Pescadero Creek watershed and the entire Butano Creek watershed. In the upper Pescadero Creek watershed, however, habitat parameters such as bank stability and vegetative protection receive low scores. These observations support the argument that the sources of the watershed's sediment load typically lie in the upper watershed while the effects of fine sediments are most evident in the lower, depositional reaches. Averaging the individual parameter scores across the area helps to identify overall limiting factors that are prevalent in the watershed. As shown in Table 8-2, Sediment deposition, embeddedness, bank stability, vegetative protection, and epifaunal substrate availability and quality appear to be the primary factors negatively affecting habitat quality throughout the watershed. Cross-watershed averages for habitat parameters such as channel flow status, channel alterations, riparian zone width, and riffle frequency, on the other hand, are typically high, suggesting relatively high channel integrity as well as adequate spawning habitat quantities (although the quality may be reduced by elevated levels of embeddedness).

The following table summarizes the results of the physical habitat assessment. Dark-shaded cells denote *poor* conditions (parameter score of 0-5) and light-shaded cells denote *marginal* conditions (parameter score of 6-10 or total score of 50-99).

BIOTIC CONDITIONS

The results of the biotic conditions assessment (Table 8-3), based on the benthic macroinvertebrate community metrics such as taxonomic richness and diversity, support the description of the overall habitat conditions discussed above. *Poor* to *good* biotic conditions are generally found in the lower Pescadero Creek watershed and all sampled sites within the Butano Creek watershed while *excellent* conditions are prevalent in the mid to upper reaches of Pescadero Creek and its tributaries.

When comparing habitat condition ratings to biotic condition ratings, it is important to keep in mind the unfortunate differences in rating nomenclature. For example, several sites received a score of “good” for biotic conditions and “suboptimal” for habitat conditions. Based on the definitions of the two terms, these results appear to contradict each other. However, both are the second-highest score for their respective rating systems, thus indicating a general agreement between biotic and habitat conditions. Nevertheless, both the 2002 SWAMP surveys and the 2003 ESA surveys did result in some apparent contradictions between habitat and biotic conditions. For example, some high-gradient tributary reaches, such as Upper Peters Creek (PES360) and Trestle Creek (PES370) sampled in 2003, had “optimal” (highest ranking) habitat conditions but only “fair” (third ranking) biotic conditions. The Water Lane site on Pescadero Creek (PES050), sampled in 2002, had “suboptimal” (second ranking) habitat conditions but “poor” (lowest ranking) biotic conditions. The reason for these apparent contradictions is that not all habitat assessment parameters are directly related to invertebrate habitat conditions. It is not uncommon for a reach with generally stable, undisturbed channel and riparian conditions, and thus a high habitat rating, to lack substrate in the size-class (i.e., gravel and small cobble) preferred by sensitive benthic organisms, resulting in a low biotic rating.

POOL HABITAT CONDITIONS

Results of the pool habitat condition assessment are summarized in Table 8-4. Pool habitat appears to be fairly abundant throughout the watershed with the notable exceptions of two Pescadero Creek mainstem sites (PES070 and PES240), Trestle Creek (PES370), and lower Butano Creek (BUT010). However the average mean pool depth exceeded 18 inches at only four of the 22 sampling locations, all of which are located on the mainstem of Pescadero Creek.

TABLE 8-3
RESULTS OF THE BIOTIC CONDITION SCORING

Station ID	Taxonomic Richness		Dominant Taxon (%)		EPT Taxa		Sensitive EPT Index (%)		Shannon Diversity		Tolerance Value		Total RRIBI Score	Biotic Condition
	Metric Value	RRIBI Score	Metric Value	RRIBI Score	Metric Value	RRIBI Score	Metric Value	RRIBI Score	Metric Value	RRIBI Score	Metric Value	RRIBI Score		
PES-050	27	3	53	1	15	3	6	1	1.8	1	6.4	1	**10**	**Poor**
PES-070	28	3	30	3	17	3	17	3	2.4	3	4.6	3	**18**	**Good**
PES-100	31	3	25	3	20	5	47	3	2.6	3	2.9	5	**22**	**Good**
PES-120	34	3	18	3	20	5	50	3	2.7	3	3.1	3	**20**	**Good**
PES-140	30	3	34	3	20	5	67	5	2.5	3	2.0	5	**24**	**Excellent**
PES-160	38	5	16	3	21	5	53	3	3.1	5	2.6	5	**26**	**Excellent**
PES-170	33	3	30	3	16	3	35	3	2.7	3	3.0	5	**20**	**Good**
PES-180	40	5	16	3	20	5	39	3	3.1	5	3.3	3	**24**	**Excellent**
PES-190	36	5	30	3	20	5	47	3	2.8	3	2.9	5	**24**	**Excellent**
PES-205*	42	5	15	3	20	5	29	3	3.2	5	3.2	3	**24**	**Excellent**
PES-210	40	5	18	3	20	5	21	3	3.1	5	4.0	3	**24**	**Excellent**
PES-215	35	3	22	3	12	3	22	3	2.7	3	3.5	3	**18**	**Good**
PES-235**	32	3	26	3	13	3	40	3	2.4	3	3.4	3	**18**	**Good**
PES-240	40	5	13	5	22	5	44	3	3.1	5	3.0	5	**28**	**Excellent**
PES-350	38	5	15	3	15	3	28	3	3.0	5	3.4	3	**22**	**Good**
PES-360	33	3	21	3	11	1	22	3	2.8	3	3.7	3	**16**	**Fair**
PES-370	29	3	28	3	9	1	14	1	2.4	3	4.9	1	**12**	**Fair**
PES-380	30	3	15	3	12	3	28	3	2.9	3	3.6	3	**18**	**Good**
BUT-010	10	1	57	1	3	1	3	1	1.3	1	5.3	1	**6**	**Poor**
BUT-030	29	3	16	3	16	3	44	3	2.8	3	3.3	3	**18**	**Good**
BUT-050	37	5	19	3	21	5	34	3	2.9	3	3.3	3	**22**	**Good**
BUT-070	31	3	29	3	14	3	26	3	2.5	3	3.5	3	**18**	**Good**

Notes: * CSBP biotic condition data derived from SWAMP site PES200;
** CSBP biotic condition data derived from SWAMP site PES230;
EPT = members of the invertebrate families Ephemeroptera, Plecoptera, and Trichoptera. The relative abundance of these taxa are indicative of high quality habitat and water quality conditions.

Similarly, maximum pool depths equaled or exceeded 36 inches at only six sites, including four mainstem sites and two tributaries (Tarwater and Oil creeks).

Furthermore, although pools were fairly abundant, few contained significant cover features such as large woody debris or undercut banks. In fact, only three sites, Slate, Oil, and Little Butano Creeks, received the highest possible structural shelter rating of "3" based on the rating system presented in the CDFG restoration manual (Flosi *et al.*, 1998). LWD throughout the watershed tends to be rare and "clumpy," that is to say LWD tends to accumulate in infrequent but large log jams in the surveyed reaches. This may be explained by the shape of the stream channels – LWD, especially smaller pieces, tends not to stay in place in the typically deeply entrenched U-shaped or V-shaped channels found in the Pescadero-Butano watershed, but rather is easily mobilized and transported downstream in floods, until it reaches a sticking point, such as an existing log jam. It is likely that, prior to the large-scale mechanized logging that began around 1930, large redwoods lined stream channels throughout much of the upper watershed, providing long-lasting LWD that is not easily mobilized. (See also the discussion of LWD in Chapter 7.)

TABLE 8-4
POOL HABITAT CONDITIONS

Station ID	Stream Name	Station Name	Survey Date	Time	Streamflow (cfs)	Reach Length (ft.)	% Pool Habitat	Structural Shalter Rating	Ave. Pool Length (ft)	Ave. Pool Width (ft)	Ave Pool Depth (in.)	Max. Pool Depth (in.)	Ave. Pool Tail Depth (in.)	Ave. Pool Tail Embeddedness	Predom. Tail Substrate
PES050	Pescadero	Water Lane	8-Sep-03	14:15	5.83	665	51	0	112.6	24.7	12.7	24.0	2.8	2.3	Gr
PES070	Pescadero	Cloverdale Road	21-Aug-03	16:00	4.60	1312	5	1	66.5	18.5	23.5	34.0	16.5	4.0	Gr
PES100	Pescadero	USGS Gage	8-Sep-03	11:45	3.96	338	40	1	135.0	NA	20.0	47.0	6.0	2.0	LC/SC
PES120	Pescadero	Loma Mar	9-Sep-03	12:00	3.50	560	67	2	75.5	15.8	15.6	46.0	6.7	1.2	Bo
PES140	Pescadero	Wurr Road	9-Sep-03	10:30	2.62	553	55	1	60.3	14.4	9.6	27.0	5.5	1.4	Br
PES160	Pescadero	Towne Fire Road	21-Aug-03	9:35	4.19	1312	13	1	83.7	24.6	25.3	51.0	8.8	1.5	Br
PES170	Tarwater	Tarwater Cr.	11-Sep-03	14:10	0.10	426	32	2	45.3	8.3	16.3	48.0	1.3	1.3	Gr
PES180	Peters	Lower Peters Cr.	22-Aug-03	13:20	1.42	656	44	1	57.2	12.1	15.2	32.0	2.9	2.4	Gr
PES190	Pescadero	Portola SP	22-Aug-03	15:20	2.33	681	75	1	102.2	20.6	19.6	40.0	5.1	2.3	SC
PES205	Slate	Lower Slate Cr.	22-Aug-03	10:15	0.26	485	27	3	26.2	9.0	13.4	24.0	4.5	1.0	Gr
PES210	Oil	Lower Oil Cr.	5-Sep-03	10:00	0.65	328	63	3	41.1	8.9	12.0	36.0	4.2	1.0	SC/Gr
PES215	Oil	Upper Oil Cr.	4-Sep-03	15:20	1.38	377	52	1	39.0	8.9	10.6	22.0	2.7	1.0	Bo
PES235	Waterman	Above Bridge	4-Sep-03	10:45	0.20	191	69	2	26.4	6.1	7.4	21.0	1.9	3.2	Gr
PES240	Pescadero	Headwaters	5-Sep-03	14:15	0.13	164	7	1	11.0	4.0	8.0	24.0	2.0	2.0	Gr
PES320	Evans	Portola SP Road	11-Sep-03	13:00	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
PES350	Lambert	Lambert Cr.	24-Sep-03	12:00	0.39	151	42	1	12.6	5.0	12.0	18.0	2.6	1.0	Gr
PES360	Peters	Upper Peters Cr.	24-Sep-03	13:45	0.17	136	49	1	13.2	6.1	9.0	20.0	1.8	1.5	Br
PES370	Trestle	Old Haul Road	11-Sep-03	10:50	0.13	162	6	1	10.0	6.0	4.0	7.0	1.0	3.0	SC
PES380	Little Boulder	Saw Mill Road	5-Sep-03	12:00	0.13	263	15	2	13.5	4.5	13.3	28.0	2.7	1.0	Bo
BUT010	Butano	Lower Butano	8-Sep-03	13:30	1.93	832	2	2	15.0	7.5	5.0	13.0	3.0	4.0	Si
BUT030	Butano	Girl Scout Camp	23-Sep-03	9:20	1.13	523	67	2	87.0	12.9	14.5	18.0	3.4	3.8	SC
BUT050	Little Butano	Little Butano	8-Sep-03	10:15	0.35	356	49	3	44.0	7.6	11.3	24.0	2.1	1.3	Gr
BUT070	Butano	Upper Butano	23-Sep-03	11:50	0.50	477	53	1	50.8	8.5	13.6	32.0	4.0	1.0	Bo

Also, some sampling sites were located in the vicinity of bridges and LWD may periodically be removed from the channel in these areas to protect such structures. However, even sites with no nearby roads or bridges often contained only minor amounts of LWD.

As discussed above under *Physical Habitat Quality*, embeddedness of pool tail crests tends to be higher in the lower-most reaches of both Pescadero Creek and Butano Creek, while sites in the upper watersheds typically contained smaller amounts of fine sediment. Pool tail crests and riffles containing gravel and small cobble sized substrate with low levels of embeddedness are important habitat requirements for spawning salmonids. Mainstem Pescadero Creek sites in particular contained extensive areas with adequate spawning gravels with fair to moderate levels of embeddedness. Habitat inventories conducted in 1995 by CDFG on Pescadero Creek between the USGS gage (PES100) and Wurr Road (PES140) noted considerable amounts of spawning gravels, some of which contained evidence of recent spawning redds (CDFG, 1995). It appears that reduction in fine sediment delivery to the lower reaches of Pescadero Creek would greatly enhance the quality of the fairly abundant spawning areas in that watershed.

WATER QUALITY

The results of the spot-check water quality measurements are summarized in Table 8-5 and the results of the continuous water temperature loggers are presented in Appendix C.

TABLE 8-5
WATER QUALITY

Station ID	Stream Name	Station Name	Survey Date	Time	Air Temperature (°C)	Water Temperature (°C)	Specific Conductivity (µs)	Dissolved Oxygen Concentration (mg/l)	Dissolved Oxygen Saturation (%)	pH	Turbidity (NTU)	Streamflow (cfs)
PES050	Pescadero	Water Lane	8-Sep-03	14:15	17.6	19.1	770	7.79	84.4	8.2	3.50	5.83
PES070	Pescadero	Cloverdale Road	21-Aug-03	16:00	23.2	20.8	730	7.69	86.2	7.9	5.28	4.60
PES100	Pescadero	USGS Gage	8-Sep-03	11:45	17.7	17.0	764	9.11	94.5	8.4	2.78	3.96
PES120	Pescadero	Loma Mar	9-Sep-03	12:00	19.4	15.9	726	9.12	92.5	8.5	1.92	3.50
PES140	Pescadero	Wurr Road	9-Sep-03	10:30	17.6	15.4	707	9.01	90.3	8.7	2.39	2.62
PES160	Pescadero	Towne Fire Road	21-Aug-03	9:35	19.0	17.3	679	9.32	97.3	8.2	2.40	4.19
PES170	Tarwater	Tarwater Cr.	11-Sep-03	14:10	21.5	14.8	1472	6.83	67.7	8.1	1.41	0.10
PES180	Peters	Lower Peters Cr.	22-Aug-03	13:20	19.4	16.9	787	9.13	94.6	8.3	1.74	1.42
PES190	Pescadero	Portola SP	22-Aug-03	15:20	19.6	17.9	635	8.56	90.4	8.2	2.42	2.33
PES205	Slate	Lower Slate Cr.	22-Aug-03	10:15	17.8	15.4	703	9.13	91.4	8.3	1.44	0.26
PES210	Oil	Lower Oil Cr.	5-Sep-03	10:00	14.0	13.4	609	9.22	88.3	8.6	1.35	0.65
PES215	Oil	Upper Oil Cr.	4-Sep-03	15:20	21.8	16.5	602	8.38	85.8	8.5	2.73	1.38
PES235	Waterman	Above Bridge	4-Sep-03	10:45	17.5	15.4	778	7.97	79.8	8.4	3.62	0.20
PES240	Pescadero	Headwaters	5-Sep-03	14:15	19.0	15.1	748	8.26	82.2	8.2	1.24	0.13
PES320	Evans	Portola SP Road	11-Sep-03	13:00	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
PES350	Lambert	Lambert Cr.	24-Sep-03	12:00	18.4	15.0	512	8.91	88.5	8.5	2.94	0.39
PES360	Peters	Upper Peters Cr.	24-Sep-03	13:45	17.1	15.6	529	8.68	87.2	8.4	1.91	0.17
PES370	Trestle	Old Haul Road	11-Sep-03	10:50	19.2	13.8	362	9.03	87.4	8.4	1.35	0.13
PES380	Little Boulder	Saw Mill Road	5-Sep-03	12:00	16.2	13.9	554	8.98	87.0	8.4	3.42	0.13
BUT010	Butano	Lower Butano	8-Sep-03	13:30	17.8	18.8	385	9.36	100.6	8.6	6.29	1.93
BUT030	Butano	Girl Scout Camp	23-Sep-03	9:20	19.6	15.3	429	7.85	78.4	7.6	10.90	1.13
BUT050	Little Butano	Little Butano	8-Sep-03	10:15	16.7	14.3	329	9.09	88.8	8.2	3.26	0.35
BUT070	Butano	Upper Butano	23-Sep-03	11:50	18.6	14.1	421	8.87	86.3	8.2	3.75	0.50

None of the water quality results are indicative of adverse conditions for salmonids or other aquatic organisms. A dissolved oxygen concentration of 5 milligrams per liter (mg/l) is generally considered to be the lower end of the tolerance range of Pacific salmonids. All measured dissolved oxygen levels were above 6.8 mg/l and most were within the 8 to 9 mg/l range. As would be expected, water temperatures during the late summer and early fall of 2003 were highest in the lower watershed where wide channels reduce the amount of shading offered by riparian vegetation. Afternoon spot-check water temperatures at PES050 and PES070 exceeded the generally accepted upper salmonids tolerance limit of 18°C (the lethal limit is 24°C), but most other temperature readings suggested adequate conditions for salmonids.

The HoboTemp® continuous temperature monitor traces (Appendix C) also indicate generally suitable water temperatures for salmonids throughout the watershed (though the monitor placed in mainstem Butano Creek (station BUT020) was disturbed and did not produce a useable record). Little Butano Creek and the upper Pescadero Creek tributaries exhibited the lowest temperatures, but Pescadero Creek itself has suitable temperatures. There is a downstream trend toward warmer temperatures in Pescadero Creek, with a noticeable jump in temperature between Memorial Park (PES160) and the USGS gauging station (PES100). Downstream from the gauging station, however, temperatures are again cooler as the stream nears the town of Pescadero (PES70). The warming at the USGS gauge is presumably due to a widening of the stream after it emerges from its canyon, and relatively less shade provided both by topography and by riparian vegetation. Further downstream, temperatures may cool due to increased shading from thicker vegetation and from cooler air temperatures nearer the coast.

Turbidity levels were highest in the lower Pescadero Creek watershed, some tributaries (Waterman, Lambert, and Little Boulder creeks) and the four Butano watershed sites. Although these measurements may be indicative of some of the sources of ongoing erosion, all observed turbidity values were far below levels considered adverse to salmonid health. Rainy season water quality testing would further illuminate differences in water quality between watershed areas.

OVERALL PRIORITY RATING

The overall goal of the Pescadero-Butano Watershed Assessment is to establish a priority list of streams or sub-basins that currently provide high quality salmonid habitat and thus warrant special attention with regards to protecting the existing resources. An inherent limitation of habitat assessments based on selected representative sites rather than surveys of entire drainages is the uncertainty involved in extrapolating the results to areas not surveyed. However, a detailed, watershed-wide inventory of existing habitat conditions was beyond the scope of this assessment. Thus, assumptions and inferences had to be made to allow for a meaningful prioritization of sub-basins based on surveyed conditions. Site-specific results were assumed to be representative of conditions throughout those portions of a drainage that fell within similar gradient classes, similar geology, and similar land-uses. Although this approach clearly does not account for site-specific influences, such as the potential presence of a massive land-slide downstream of a sampling site, channel-forming factors such as hydrology, gradient, geology, and land use typically affect extensive areas of a given stream, and overall habitat conditions such as the lack of deep pools or the presence of high quality spawning gravels can typically be found for considerable distances above and below the actual sampling site. As discussed previously, this assessment is not intended to provide the final word on the habitat conditions of every reach within the watershed or a detailed inventory of all sites in need of restoration. Rather, this document is intended to provide a preliminary, watershed-wide estimation of fisheries conditions and should be used to identify sub-basins that should receive further assessments of site-specific habitat conditions, limiting factors, and restoration needs.

Although it is a common misconception that only degraded habitats require restoration while high quality habitat areas do not, we believe that the highest value-cost effect can usually be gained by developing restoration plans that address specific limiting factors in otherwise high quality habitat. As such, a sampling site identified as a *High* priority location in Table 8-6 and Map 2-3 should not only receive special conservation attention but should also be further evaluated, using detailed assessment methodologies such as those described in the CDFG restoration manual, for potential ways of improving habitat values for all life-stages of salmonids. Conversely, a site that receives a *Low* priority rating would require such extensive restoration efforts that it would be unwise to spend limited resources on such areas.

High priority sites are generally located in the mid- to upper Pescadero Creek watershed. Tributaries such as Tarwater, Peters, Slate, Oil, and Lambert creeks in particular provide high quality salmonid habitat and thus require special attention in regards to conservation and restoration. As already discussed in the description of CSBP habitat values, the lower Pescadero Creek watershed and Butano Creek generally score low in all parameters that were considered in this assessment and thus may not warrant as much attention as other sites. As discussed above, however, the CDFG stream inventories conducted in the mid-1990's noted several spawning redds in the low gradient reaches of Pescadero Creek. Although it is not apparent in our scoring system, the low gradient reaches do contain the highest amount of spawning-size gravel reaches found anywhere in the watershed. Future efforts to reduce sediment input in the upper watershed would likely have beneficial effects on spawning habitat in the lower reaches.

CONCLUSIONS

Assessments of physical habitat quality, biotic conditions, pool habitat quality, and water quality in the Pescadero-Butano watershed revealed the following overall fisheries habitat conditions currently present in the watershed: (1) Accessible salmonid habitat is fairly abundant throughout the watershed, (2) salmonid habitat quality is higher in the mid and upper Pescadero Creek watershed and lower in the Butano Creek watershed as well as the low gradient reaches of Pescadero Creek, (3) pool habitat is fairly abundant but of limited depth and suboptimal cover, (4) water quality throughout both watersheds is generally adequate for salmonids and other aquatic organisms.

The primary limiting factors with regards to salmonid habitat, based on the sampled reaches, are generally shallow pool depths, limited amounts and frequency of large woody debris, and relatively high levels of fine sediments. These limiting factors are likely to be of greater significance to coho salmon than steelhead. Coho in particular require deep pools with low water velocities and adequate cover for survival and growth while steelhead are more adapted to occupying and foraging in the faster and shallower areas of stream channels (e.g., Bisson *et al.*, 1988a; Bisson *et al.* 1988b; Kruzic *et al.*, 2001). Thus, current habitat conditions in the watershed favor steelhead over coho salmon.

TABLE 8-6
PRIORITY RATINGS

Station ID	Stream Name	Station Name	% Pool Habitat	Structural Shelter Rating	Ave Pool Depth (in.)	Pool Tail Embeddedness	Predom. Tail Substrate	CSBP Habitat Score	RRIBI Biotic Condition	**Total Score**	Priority Rating
PES050	Pescadero	Water Lane	1	0	1	1	1	2	0	**6**	Moderate
PES070	Pescadero	Cloverdale Rd	0	1	1	0	1	2	2	**7**	Moderate
PES100	Pescadero	USGS Gage	1	1	1	1	1	2	2	**9**	Moderate
PES120	Pescadero	Loma Mar	1	2	1	2	0	3	2	**11**	High
PES140	Pescadero	Wurr Road	1	1	0	2	0	3	3	**10**	Moderate
PES160	Pescadero	Towne Fire Rd	0	1	2	2	0	3	3	**11**	High
PES170	Tarwater	Tarwater Cr.	1	2	1	2	1	3	2	**12**	High
PES180	Peters	Lower Peters	1	1	1	1	1	3	3	**11**	High
PES190	Pescadero	Portola SP	1	1	1	1	1	3	3	**11**	High
PES205	Slate	Lower Slate	0	3	1	2	1	3	3	**13**	High
PES210	Oil	Lower Oil	1	3	1	2	1	3	3	**14**	High
PES215	Oil	Upper Oil	1	1	0	2	0	3	2	**9**	Moderate
PES235	Waterman	US Bridge	1	2	0	0	1	2	2	**8**	Moderate
PES240	Pescadero	Headwaters	0	1	0	1	1	3	3	**9**	Moderate
PES350	Lambert	Lambert Cr.	1	1	1	2	1	3	2	**11**	High
PES360	Peters	Upper Peters	1	1	0	2	0	3	1	**8**	Moderate
PES370	Trestle	Old Haul Road	0	1	0	0	1	3	1	**6**	Moderate
PES380	Little Boulder	Saw Mill Road	0	2	1	2	0	3	2	**10**	Moderate
BUT010	Butano	Lower Butano	0	2	0	0	0	1	0	**3**	Low
BUT030	Butano	Girl Scout	1	2	1	0	1	2	2	**9**	Moderate
BUT050	Little Butano	Little Butano	1	3	0	2	1	3	2	**12**	High
BUT070	Butano	Upper Butano	1	1	1	2	0	2	2	**9**	Moderate

% Pool Habitat (0-1): 30% - 80% = 1, <30% or >80% = 0
Structural Shelter Rating (0-3): 0-3, see CDFG Restoration Manual
Ave Pool Depth (0-2): 0-11.9" = 0, 12.0-23.9" = 1, 24.0"+ = 2
Embeddedness (0-2): 1.0-1.9 = 2, 2.0-2.9 = 1, 3.0-4.0 = 0
Tail Substrate (0-1): Gravel and/or small cobble = 1, all others = 0
CSBP Habitat Score (0-3): 0-49 = 0, 50-99 = 1, 100-149 = 2, 150-200 = 3
RRIBI Biotic Condition Index (0-3): poor = 0, fair = 1, good = 2, excellent = 3

It is likely that these limiting factors are the legacy of large-scale mechanized logging that began around 1930. In general, pool frequency, pool depth, and LWD frequency are not sensitive to disturbance over the short-term (with the exception of direct channel modifications). There is a long lag-time between activities on the landscape and the response in the channel, both in response to detrimental effects of management and to restoration actions. Stream channels where large wood has been removed and where adjacent riparian forests have been harvested will require decades (or centuries) to return to natural loading rates (Bauer and Ralph, 2001). Current land use practices in the watershed appear to be significantly less detrimental to aquatic habitats than past uses, but the recovery of the stream system may continue for the foreseeable future. In the meantime, the limited quantities of LWD currently found in the system should be preserved and the removal of wood or log jams from the channel should be discouraged, unless they propose a threat to life, property, or infrastructure. Carefully designed and targeted restoration efforts, based on detailed future assessments within sub-basins identified as *high* priority and aimed at reducing sediment input and increasing LWD recruitment would be expected to improve overall salmonid habitat conditions in the long run.

With the notable exception of a few (less than 5) juvenile coho salmon observed in Peters Creek in 1999, the species has not been observed in the Pescadero-Butano watershed over the past decade (NMFS, 2001). Five coho salmon were trapped in an outmigrant study conducted by Pescadero High School students in 1994, who reported that these were the first coho seen in the creek since 1984 (Zatkin et al, 2002). However, approximately 17,000 hatchery-raised coho smolts were released in Pescadero Creek in late March/early April of 2003 in an attempt to repopulate this watershed (Hayes, pers. comm.). Fishermen report that some of these coho, marked by adipose fin clips, apparently returned to the watershed after only one year of ocean residency when the sand bar opened in December 2003. The creation of high quality pool habitat through the placement of anchored log structures would likely increase the success rate of these efforts.

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CHAPTER 9
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The Assessment, including the scope of work, the Quality Assurance Project Plan, and this assessment report, have been overseen by a Technical Advisory Committee (TAC), who have guided the study and reviewed draft documents. The TAC has been in existence for several years, and its membership has changed over this time. The list below includes all of those individuals who have served on the TAC, and that have provided advise and guidance on project planning and/or implementation.

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Chapter 4 –Analysis of Gauging Record: Dennis Jackson

Chapter 5 –Re-survey of Bridge Cross Sections: Dennis Jackson

Chapter 6 –Sediment Source Analysis: Danny Hagans, John Green

Chapter 7 –Current Channel Conditions: Matt O'Connor

Chapter 8 – Fisheries Habitat Assessment: Mike Podlech

APPENDIX A

SEDIMENT SOURCE ANALYSIS DATA FORMS AND EXPLANATIONS

Field dataform used in Pescadero sediment source investigation.

Watershed Name:______________________ **Sub Drainage Basin:______________ Sample Cell ID No. -Dom. Geol. - Plot #:_______________________**

Analyst and Date Mapped:______________________ **Page: _____ of ______.**

Unique ID #	Site #	Air Photo #	Feature Type	Source Loc.	Slope Loc.	Eros. Dimens. (ft)			Sed. Del. (%)	Stream	Activity	Age	Land Use Link		Geomorp Assoc.		Geol Unit		Veg Clas	Slope in %	GPS # (Y/N)	EPE
						L	W	D					Pri.	Sec.	Pri.	Sec.	Map	Field				

Explanation for Pescadero Creek Sediment Source Inventory Field Form August, 2003

While conducting the past erosion field inventory of each randomly selected sample plot, the type of sediment source or channel response reach observed (e.g. shallow or deep-seated landslide, debris torrent, stream crossing failure, gully or incised stream channel) is noted and mapped on either mylar overlays on the 9" x 9" aerial photographs or on enlarged topographic maps (scale is 1 inch = 217 feet). These features will later be transferred onto the base maps (1:24000 scale) which have already been labeled by air photo center and planning watershed name.

A unique number is assigned to each feature to distinguish it from all other features. This identification system provides an identifier for each feature that can be correlated between maps, the database and text. For each identification number all the appropriate questions on the data form (database) are answered. Each plot will include a plot summary of field observations. Each plot must have dashed line identifying the track line of the surveyors path of assessment throughout the 41 acre plot.

Plots were deleted and re-selected with erosional features greater than 5,000 yds^3. When a site is on the plot boundary, if 50% of feature is within the plot the total eroded volume is included.

For complex erosional features, use multiple rows on the dataform to facilitate rapid determinations of past erosion and sediment delivery.

Start a new dataform for each sample plot. For each feature, the following information is collected in the field. Use abbreviations to define fields.

Header

*** Watershed name**
*** Largest sub-drainage basin name (not collected for the Pescadero survey)**

*** Sample Cell ID Number, Plot #, and dominant geology**

*** Analyst name and date**

*** Page:**

Data Fields

1. Unique ID#

2. Field Feature or erosional site identification number

3. **Aerial photo number and year of photography**

4. **Feature Type** (choose one of the following)
    A. Shallow debris landslide (DL) – Must include a hillslope component above the immediate stream banks.
    B. Large deep-seated landslide (LPD) – Volume must be greater than 5,000 yds^3
    C. Small deep-seated landslide (SSD) – Volume must be less than 5,000 yds^3
    D. Debris flow source area (DF)
    E. Debris flow track (TT) – Debris torrent channel bottom and degraded side slopes will have two volumes of erosion ; a) Degraded torrent track channel area x total length, b) Degraded sideslope volume x total length
    F. Bank Erosion (BE) – Applies to channel incision and channel migration Associated with streamside (SS) hillslope location or floodplain or terrace (FP) hillslope location
    G. Channel Incision (CI) – Applies to only incised channel bottoms. Associated with stream channel (ST) hillslope location.
    H. Gully (GU)
    I. Surface Erosion (SE)
    J. Spring (SP)

5. **Source Location** (choose one of the following)
    A. Road or Skid Trail Bed (RB or SB)
    B. Road Ditch (RD)
    C. Road or Skid Trail Cutbank (RC or SC)
    D. Road or Skid Trail Fillslope (RF or SF)
    E. Road or Skid Trail Stream crossing (RXING or SXING)
    F. Hillslope (non road or skid trail) (NR)

6. **Hillslope Location-** Location on a topo map in relation to 4th – 6th order stream channels. (choose one of the following)
    A. Upper (US)
    B. Middle (MS)
    C. Lower (LS)
    D. Streamside hillslope (SS)
    E. Floodplain or Terrace (FP)
    F. Stream (ST)

7. **Erosion Dimensions**

    Record average **depth, length and width in feet** of the feature as measured in the field. (Break into multiple segments if the feature is very large or complicated).

7. **Sediment Delivery**

    Note if sediment is delivered to a stream, the type of stream and make an rough estimate of percent (%) delivery.
    - No delivery (N)
    - If sediment delivered is **YES**, then estimate the percentage of delivery:

8. **Type of stream** (choose one of the following)
    A. Perennial stream- stream with year round surface flow (PER)
    B. Intermittent stream- annual flow during rainfall/runoff seasons (INT)
    C. Ephemeral stream- surface flow during large rainfall events sometimes more transient than steady state activity (EPH)

9. **Activity Level of erosional feature** (choose one of the following)
    Indicate whether the erosional feature is:
    A. Active (ACT)- no established vegetative cover
    B. Inactive (INAC)- no future erosion
    C. Potentially active (PACT)- must have future erosion

10. **Age of Past Erosion**
    Do your best to estimate the age (by decade) of last major erosional activity at the site. If the erosional feature is active include the time frame (ie 1970-2000). Do not attempt to estimate the age of erosion prior to 1940. If the erosional feature failed prior to 1940 include the time frame (ie pre-1940)

11. **Land Use History**- is the land use association for the time of the erosion, determined at the feature initiation point (list primary and secondary, if any)
    A. Logging Road (LD), Ranch Road (RR), Subdivision Road (SR), County Road (CR), or Caltrans Road (CTR)
    B. Skid trail location (SK)
    C. <15 year old tractor clearcut (TC1)
    D. >15 year old tractor clearcut (TC2)
    E. <15 year old cable clearcut (CC1)
    F. >15 year old cable clearcut (CC2)
    G. <15 year old partial or selection harvest (PT1)
    H. >15 year old partial or selection harvest (PT2)
    I. > 30 year old Advanced second growth (ASG)
    J. Grazing (GZ)
        a. Urban or subdivision activities (US)
        b. Homestead Activities (HA)
    K. No apparent management activities (NO)

12. **Geomorphic Association**- determined at the feature initiation point
    A. Inner gorge slope (i.e. > 65% leading directly to a stream) (IG)
    B. Streamside slope (i.e. < 65% leading directly to a stream) (SS)
    C. Stream channel (ST)
    D. Swale channel (SW)
    E. Headwall area (HD)
    F. Major break-in-slope on hillslope, not inner gorge (BIS)
    G. Plannar hillslope (PL)
    H. Hummocky hillslope (HUM)

13. **Geologic Unit –** primary bedrock or parent material within each erosional feature Record the primary or dominant geologic strata (one of the 4 types) based on;
    1) the map geology (already determined by plot)
    2) the field determined geology (list the rock type if it is discernible at the point of initiation)

14. Vegetation Classification

Record the dominant vegetation type at the feature initiation point.

A. Conifer forest (CF)- pure stands of conifers
B. Mixed conifer (MC)- indicates mixed conifer and hardwood trees
C. Oak woodland (OW)- dominate hardwood forest
D. Grassland (GL)

15 Slope Gradient

Record the slope of the land in percent

Debris Landslide Sites (DL)- record the slope gradient of the failure plane.
Bank Erosion (BE)- record the slope gradient of the failure plane.
Channel Incision (CI)- record the stream gradient.

13. GPS

Mark each site-enter the plot number and site number (ex. Plot #- Site #). Record the GPS error in feet (EPE).

PWA AIR PHOTO INTERPRETATION FORM

Watershed Name:_______________________ **Sub-basin:_____________________________**

Analyst and Date Mapped:_________________________ **Photo Year:_______** **Photo Scale:_______________**

PWA Air Photo Interpretation Sediment Source Inventory Form

GIS unique ID #	Feature ID #	Air Photo #	Feature Type	Feature Certainty	Photo Year	Feature Size (1/50s of inch)		Sed. Delivery % to nearest stream	Delivery Certainty	Aspect	Stream Class & Type	Land Use History	Geo-morph. Assoc.	Horiz. curv.	Activity	Initial % Veg. Cover	Final % Veg. Cover (2000)	Slope (%)	Comments
						L	W												

Explanation for Pescadero Creek Air Photo Interpretation

Sediment Source Inventory Form
August, 2003

The air photo interpretation data form is used for each California watershed unit. On each data form, the name and date of the mapper are indicated, as well as the larger watershed name. While conducting aerial photo interpretation, it is important for mappers to have already defined the 1) Calif. watershed unit boundaries and 2) locate the centers of the aerial photographs on the base maps in order to know which watershed unit a particular sediment source should be assigned to. Consequently, it is likely that more than one data form will be used at the same time.

While examining the aerial photographs, the type of sediment source or channel response reach observed (e.g. shallow or deep-seated landslide, debris torrent, stream crossing failure, gully or enlarged stream channel) is noted and mapped on mylar overlays on the 9” x 9” aerial photographs. These features are then transferred onto the base maps (1:24000 scale) which have already been labeled by air photo center and planning watershed name.

A unique number is assigned to each feature to distinguish it from all other features. This identification system provides an identifier for each feature that can be correlated between maps, the database and text. For each identification number all the appropriate questions on the data form (database) are answered. The majority of the questions require using an appropriate abbreviation or code to answer the question. The purpose is to provide for rapid entry of the answers into a computer database and for rapid data analysis. For each feature, as much as possible of the following information is compiled:

Fill in the following header information for each data sheet:

*** Watershed name**

*** Largest sub-watershed or drainage basin name**

*** Mapper’s name and date**

*** Photo year and scale**

The following columns require data from the air photo analysis and interpretation:

***GIS unique ID# (identification number) -** a unique number assigned by the GIS software to each digitize point

*** Feature ID # -** a unique number assigned to each mapped feature.

*** Aerial photo number -** indicate the photo flight line and frame number.

*** Feature Type and certainty of interpretation**

Feature Type
- Shallow debris landslide (DL)
- Large deep-seated landslide (LPD)
- Small deep-seated landslide (SSD)
- Debris torrent source area (DT)
- Debris torrent track (TT)
- Bank erosion (BE)
- Enlarged Channel (EC)
- Stream Crossing (XI)
- Gully (GU)

Feature Certainty
- Definite (D)
- Probable (P)
- Questionable (Q)

*** Photo year -** Year of the photo used, in which new or newly enlarged feature first was observed

*** Feature size -** Record average **length and width** of the feature as measured from the air photos, in 50th of an inch. Use an engineer's scale and measure average dimensions. If feature is a reactivated landslide, measure only the enlarged area of the slide.

* **Sediment delivery percent -** Note if sediment is or appears to have been delivered to a stream, make an rough estimate of percent (%) delivery, based on site characteristics.

- No delivery (N)
- If sediment delivered is **YES**, then estimate the amount:
  - **<25** percent (<25)... assigned average delivery of 13%
  - **<50** percent (25-50)... assigned average delivery of 38%
  - **<75** percent (50-75)... assigned average delivery of 63%
  - **<100** percent (75-100)... assigned average delivery of 88%

*** Delivery certainty –**

- Definite (D)
- Probable (P)
- Questionable (Q)

*** Aspect -** Record general orientation of the landslide (i.e. direction of movement).

- North (N)
- Northwest (NW)
- West (W)
- Southwest (SW)
- South (S)
- Southeast (SE)
- East (E)
- Northeast (NE)

*** Stream type -** Type of stream or drainage area of the nearest watercourse, based on the following estimated size classes:
- Perennial stream - greater than 300 acres (PER)
- Intermittent stream - 40 to 300 acres (INT)
- Ephemeral stream - less than 40 acres (EPH)

*** Land use history at feature initiation point -** based on air photo interpretation or historic logging information, classify the current land use "status" at the point of failure (upper-most point on landslide):

- Road location (RD)
- Skid trail location (SK)
- <15 year old tractor clearcut (TC1)
- >15 year old tractor clearcut (TC2)
- <15 year old cable clearcut (CC1)
- >15 year old cable clearcut (CC2)
- Partial or selection harvest (PC1 or PC2)
- Advanced second growth, i.e. greater than 30 years since last apparent landuse (ASG)
- Grazing/farming (F/A)
- Urban development (UD)
- No apparent management activities (NO)

*** Geomorphic association at feature initiation point -** identify the geomorphic site characteristics at the failure site (upper-most point on landslides)

- Inner gorge slope (IG) (>65% continuous to stream)
- Stream side (SS) (<65% continuous to stream)
- Stream channel (ST)
- Swale channel (SW)
- Headwall area (HD)
- Major break-in-slope on hillslope, not inner gorge (BIS)
- Plannar hillslope (PL)
- Hummocky hillslope (HUM)

*** Horizontal curvature -** Record the horizontal curvature of the hillslope at the feature initiation point.
- Planar (P)
- Convergent (C)
- Divergent (D)

*** Activity -** If the feature appears on an earlier photo set, does it show change from the earlier to the later photo?

*** Initial % vegetation cover -** Record the percentage canopy cover at the feature initiation point.

*** Final % vegetation cover -** Record the percentage canopy at the feature initiation point on the 2000 aerial photo set.

*** Slope -** When transferring the feature to the base map, measure the hillslope gradient (in percent) for all landslides and gullies. Use a scaling template to collect the data from the best available topographic maps.

*** Comments -** Use this space and an additional row if you want to discuss the feature/process any further.

APPENDIX B

CHANNEL GEOMORPHOLOGY DATA

This appendix contains the following:

1. Site Field Data (3 pages)
2. Large Woody Debris Field Data Summary (1 page)
3. Gravel Bar Field Data Summary (1 page)
4. Sediment size data (1 page)

APPENDIX B-1: SITE FIELD DATA (SHEET 1 OF 3)

Site number	River	Site	Ob-servers	Date	total reach length (m)	Geology @ Site	W'shed Geology Consistent w/ Site?	Drainage Area (km^2)	map slope class (%)	field channel slope (%)	SPI	Unit SPI	FPW @ 2bfd	BF width-active (m)
But010	Butano	Pescadero State Beach	BR/SB/BC	8/27/2003	170	Q	N	52.1	0	0.4	2.7	0.3	50	8.5
But020	Butano	Pescadero State Beach	BR/AR	10/7/2003	135	Q	N	47.3	0-0.5	0.5	2.8	0.5	8	5.5
But050	Little Butano	Butano SP	BR/SB	8/27/2003	130	SHMS	Y	6.6	1.5-3	1.2	6.2	1.0	13	6.5
But070	Butano	Big Tree property	BR/AR	10/7/2003	180	SS	Y	5.6	6.5-12	2.9	37.7	2.9	15	13
Pes050	Pescadero	Pescadero State Beach	BR/SB	8/27/2003	280	Q	N	206.3	0	0.4	5.3	0.4	75	15
Pes070	Pescadero	Cloverdale Rd	BR/MP	8/21/2003	400	Q	N	138.1	0-0.5	0.1	3.1	0.2	22	17
Pes100	Pescadero	USGS gauge	BR/MO	8/20/2003	320	SHMS	N	118.7	0-0.5	0.3	10.6	0.7	35	16
Pes140	Pescadero	WTP	BR/SB	8/26/2003	320	SHMS	N	106.7	0-0.5	1.4	35.8	2.2	30.5	16
Pes160	Pescadero	Portola SP	BR/MP	8/21/2003	400	SS	N	92.4	0-0.5	0.5	19.5	1.0	25	19.5
Pes170	Tarwater	Portola SP	BR/SB	8/26/2003	160	SS	Y	4.7	3-6.5	1.0	6.8	1.1	11	6.5
Pes180	Peters	Portola SP	BR/SB	8/22/2003	200	SS	N	25.5	1.5-3	0.2	3.9	0.3	10	15
Pes190	Pescadero	Portola SP	BR/SB	8/22/2003	260	SS	N	49.6	0-0.5	0.5	8.0	0.6	18	14.5
Pes200	Slate		BR/SB	8/22/2003	150	SS	Y	7.8	3-6.5	3.3	18.5	2.6	9.5	7
Pes210	Lower oil	Big Tree property	BR/SB	9/5/2003	100	SS	Y	12.4	1.5-3	1.0	6.0	1.2	10	5
Pes215	upper oil	Big Tree property	BR/JK	9/4/2003	115	ML	Y	8.6	6.5-12	1.6	14.4	1.9	9.7	7.5
Pes230	Waterman	Big Tree property	BR/JK	9/4/2003	200	ML	N	4.9	3-6.5	2.5	19.5	3.3	10	6
Pes240	Pescadero	Big Tree property	BR/SB	9/5/2003	50	SS	N	3.4	6.5-12	1.2	1.8	0.6	4.5	3
Pes320	Evans	Portola SP	BR/SB	8/26/2003	80	SS	Y	2.6	3-6.5	2.5	14.0	3.5	10.5	4
Pes340	Upper Peters	OSD	BR/AR	10/8/2003	100	ML	Y	0.7	1.5-3	2.0	5.7	1.4	12	4.1
Pes350	Lambert	OSD	BR/AR	10/8/2003	100	ML	Y	4.6	12-20	4.6	16.1	3.2	8	5
Pes360	Peters	OSD	BR/AR	10/8/2003	100	ML	Y	4.8	6.5-12	7.2	43.2	7.2	7.5	6
Pes370	Trestle	State Park	BR/AR	10/7/2003	50	SS	Y	1.0	12-20	2.1	2.1	0.8	5	2.5
Pes380	Little Boulder	Big Tree property	BR/SB	9/5/2003	80	ML	Y	2.7	6.5-12	2.4	6.7	1.7	6.5	4

APPENDIX B-1: SITE FIELD DATA (SHEET 2 OF 3)

Site number	BF width-vegetated (m)	BF depth (m)	Confine-ment Class	FPW:BFW	Estimated Floodplain Height (m)	Terrace #1 Height (m)	Terrace #2 Height (m)	TH:BFD	Floodplain Continuity	Disturbance	SS mass wasting	SSMS abundance	SSMS size
But010	1	0.8	3	5.9	1.2	1.2	--	1.5	4	N, C	AS	3	1
But020	1	1	1	1.5	4.0	4	--	4.0	4	N	N	0	0
But050	0	0.8	2	2.0	1.7	1.7	3.8	2.1	3,2	L1,R,flume,weir	CM	2	2
But070	2	1	1	1.2	6.0	6	8	6.0	1	L1	SM	1	2
Pes050	3	1	3	5.0	1.8	1.8	8	1.8	4	C	N	0	0
Pes070	6	1.8	1	1.3	3.5	3.5	3.5	1.9	4	F,C	N	0	0
Pes100	4	2.2	2	2.2	5.0	5	--	2.3	3	R, F, C	SM	1	2
Pes140	5	1.6	1	1.9	8.0	8	--	5.0	2	L1, (F)	SM	1	2
Pes160	4	2	1	1.3	4.5	4.5	--	2.3	1	L1	SS	1	1
Pes170	1.5	1.05	1	1.7	8.0	8	--	7.6	1	L1	SS	1	1
Pes180	0	1.3	1	0.7	4.0	4	6	3.1	2.5	C	CL	2	3
Pes190	6	1.1	1	1.2	20	20	--	18.2	2.5	F,C	CM	2	2
Pes200	0	0.8	1	1.4	2.8	2.8	4.5	3.5	2.5	L1	SM	1	2
Pes210	0	1.2	2	2.0	12.0		--	10.0	3	L1,L2,IG	SM	1	2
Pes215	0.5	1.2	1	1.3	2.9	2.9	6	2.4	2	L1,L2,RD	SS	1	1
Pes230	4	1.3	1	1.7	1.6	1.6	2	1.2	3	L1,L2,C,IG,Rd	CS	2	1
Pes240	0	0.5	1	1.5	0.9	0.9	--	1.8	3	L1,C,P,RD	SS	1	1
Pes320	1	1.4	2	2.6	8.0	8.0	--	5.7	1	N	SS	1	1
Pes340	1	0.7	2	2.9	0.7	0.7	2	1.0	4	N (poss skid rd on LB)	CS	2	1
Pes350	0	0.7	1	1.6	1.4	1.4	--	2.0	3	L1, pipes	SS	1	1
Pes360	0	1	1	1.3	1.5	1.5	2.7	1.5	3	L1,Rd	SS	1	1
Pes370	0	0.4	2	2.0	0.4	0.4	--	1.0	3	L1,L2	CM	2	2
Pes380	0	0.7	1	1.6	1.6	1.6	--	2.3	3	L1,IG	CS	2	1

APPENDIX B-1: SITE FIELD DATA (SHEET 3 OF 3)

Site number	Bedrock	Mean D16 (mm)	Mean D50 (mm)	Mean D84 (mm)	Bar Rating	Rough-ness Elements	Channel Morph-ology	Photos	Comments
But010	0	4	4	8	5	V	R	1,2	sand bed channel, beaver dams removed 2001, caused aggradation, banks freshly eroded, zero on RB on willow
But020	1	7.5	20	34	22	V,Bk,B	PR	6,7,8	dirty smelly water, frogs, crayfish, bedrock ledge at TOR, 1 big log jam
But050	0	7.5	16.5	49	10	Bk,V/W	PR	21,22	zero on alder RB, ~ 20m u/s bridge, note weir and flume in reach!!! Much wider/shallower u/s weir
But070	2	4	34	135.5	13	B,R/W,F	PR/SP	2,3,4,5	zero on log at access point, u/s bedrock canyon, deep pools, humbolt bridge, lots of salamander, mostly boulders and sand
Pes050	1	10.15	22	40	14	V,Bk	PR	23,24	zero on downed willow RB, note worked d/s from here
Pes070	0	12	40.5	42.5	13	V, Bk/W	PR	1,2	thick riparian veg, lots of stranded wood, piles of cobbles, slight undercut banks
Pes100	0	4	4.5	45	14	V, Bk/F/W	PR/R	19,20,21	zero pt at USGS staff plate (5-8 ft), BFW at top of reach 12 m, lots of cutoff logs, abundant steelhead fry, alternating long sandy reaches with coarse riffles
Pes140	2	25	65	140	16	V,B/F,R,W	PR	19,20	zero on alder LB, ~ 20m u/s bridge, alternating bedrock,/boulder/sand reaches
Pes160	0	11.5	49.5	103.5	4	V, B/Bk, F	PR	23,24	*slope may be out - check with SWAMP data
Pes170	2	18.5	37	75.5	13	R, W, F/Bk	PR/BR	17,18	zero on redwood sapling LB leaning, u/s of redwood spanner
Pes180	2	24.5	61.5	145	6	B/R/W	fPR	6,7	bank slumps, lots of new wood recruits
Pes190	1	16.5	42	104	12	W, V/B/R/F	PR	14,15	trim lines ~2.5m above bed, veg bars in channel, sediment particles break down easily
Pes200	2	9.5	37.5	81	14	B,V/R	fPR	3,4	SWAMP habitat site slightly u/s
Pes210	2	14.5	46	104	7	W/R/B,F	fPR	8,9	zero at confl w/ dry trib on LB, log jam
Pes215	1	12	25.5	51	5	B,R/W,V	PR/BR	6,7	zero on small tree on LB just u/s 1st trib on LB, upper oil replaces upper waterman, bedrock in lower part of reach, pigs
Pes230	1	13.5	29	51	7	V,W	PR	3,4,5	zero vert tree centre of channel u/s bdge, F&G excavated channel, dam removed, tons of small cut wood (willows) in channel, nearly impossible to walk up!! Some huge log jams but most pieces < 1ft D
Pes240	0	13	30	57	11	W,V	PR	14,15	zero on decid log on RB near confluence, pigs, sluce box and flume in MS just d/s of reach, skid trails
Pes320	3	18.5	49.5	100	10	R, C/W	BR	15,16	narrow bedrock channel with deep pools, zero point on log on RB beside 2nd pool u/s bdge
Pes340	1	11.5	41	100	0	W,B,C,Bk	PR	15,16	dry, zero point just d/s of huge RW log in channel, reach alternates wide and narrow, lots of sand
Pes350	1	13	38.5	96.5	3	B/F,V,W	SP	12,13,14	zero ~ 20m u/s Peters confluence, lots of concrete & steel pipes (broken)
Pes360	1	22	62	230	11	B/W,V,F	SP	9,10	nice pools, ss ls, granite boulders, fish, huge log jam at 40m, zero at access point
Pes370	1	21	49.5	110	19	B/W,F	PR/SP	22-24,1	zero ~20m u/s bridge
Pes380	1	16.25	47	125	22	B,F(sp),V	SP	12,13	zero just u/s bdge LB, landslide scars, old skid roads? Used to be dammed - removed 18 yrs ago

APPENDIX B-2: LARGE WOODY DEBRIS FIELD DATA SUMMARY

	Conifer				Deciduous				Unknown						
Site	**Live**	**Fresh**	**Sound**	**Decayed**	**Live**	**Fresh**	**Sound**	**Decayed**	**Live**	**Fresh**	**Sound**	**Decayed**	**Total**	**Pieces per Unit Length (BFW units)**	**Comments**
But010					21	1	16	1					39	1.95	
But020			2		7	1	17	1					28	1.4	
But050	8	1	20		1			1			1		32	1.6	
But070	2		44		1	1	4						52	2.6	
Pes050			9		22		23	1			1		56	2.8	
Pes070			5		28	7	45				5	3	93	4.65	
Pes100			11		7	2	19	1				1	41	2.05	
Pes140			15		18		23						56	2.8	
Pes160			21		19	1	24		2		5		72	3.6	
Pes170	5		41	1	3		10						60	3	1 jam >22 logs, channel width
Pes180		5	12		1								18	0.9	
Pes190		3	15		11	2	24						55	2.75	
Pes200			4	2	23		4						33	1.65	
Pes210	4		38	7	6		16	1					72	3.6	
Pes215	2		31		7	3	1						44	2.2	
Pes230		1	57		22	5	24						109	5.45	lots of small wood (willows)
Pes240	3		12		1	2	8						26	1.3	
Pes320	2	1	19				2						24	1.2	
Pes340			3		17		13						33	1.65	one huge redwood log
Pes350			3	1	13	1	6						24	1.2	
Pes360		1	7		10	2	10						30	1.5	one huge log jam
Pes370			13			2	1						16	0.8	
Pes380		2	1	1		4							8	0.4	

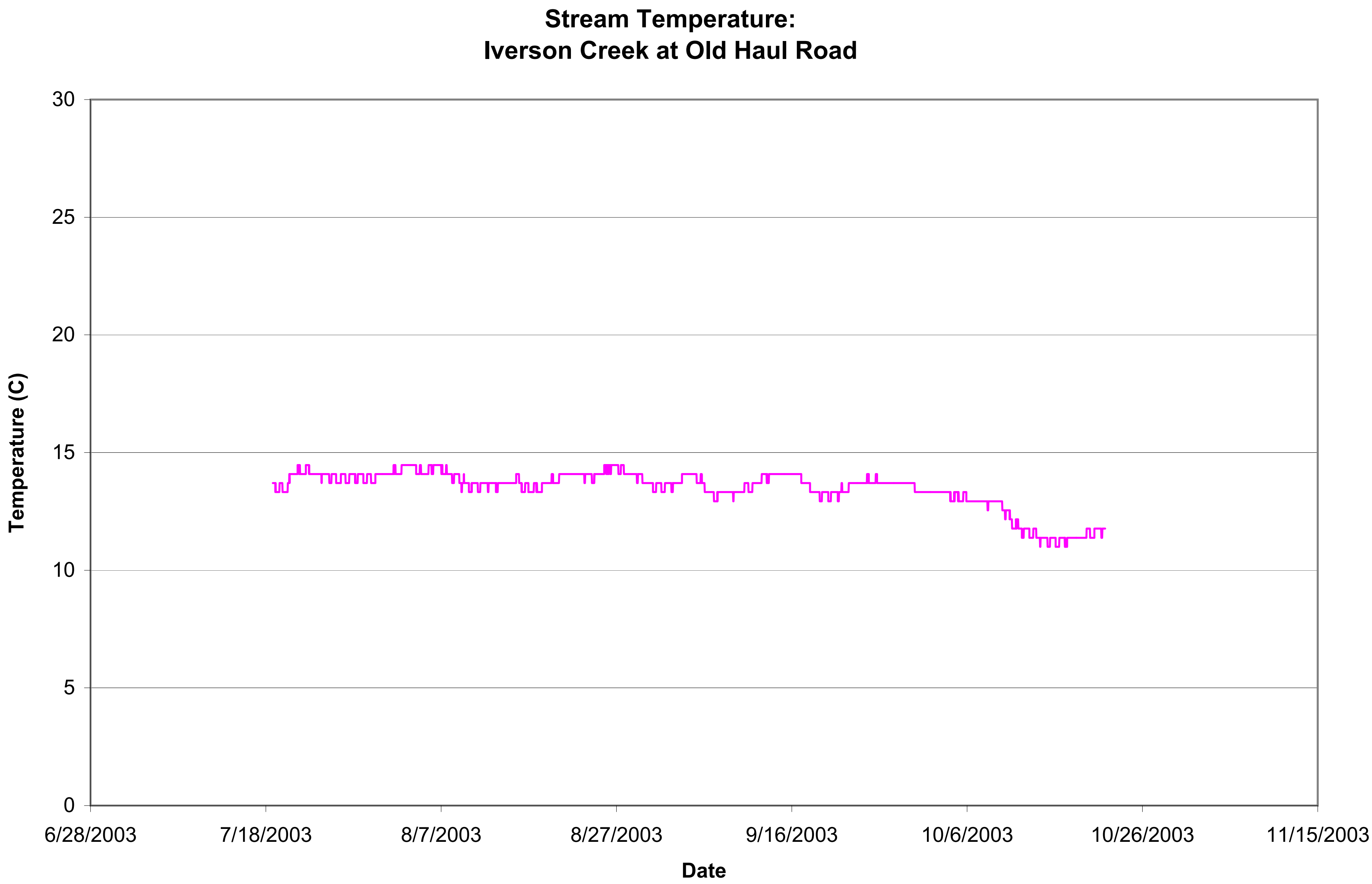
APPENDIX B-3: GRAVEL BAR FIELD DATA SUMMARY

Site	small	med	large	total	RATING	Bar Rating per Unit Length (BFW units)
But010	1	3		4	10	0.5
But020	5	3		8	14	0.7
But050	2	5		7	17	0.85
But070	4			4	4	0.2
Pes050	4	3		7	13	0.65
Pes070	3	1		4	6	0.3
Pes100	3	3		6	12	0.6
Pes140	1	3		4	10	0.5
Pes160	2	2	1	5	13	0.65
Pes170	2	3	1	6	16	0.8
Pes180	1	3		4	10	0.5
Pes190	2	2	1	5	13	0.65
Pes200	1	1		2	4	0.2
Pes210	2	4		6	14	0.7
Pes215	2	1		3	5	0.25
Pes230	7			7	7	0.35
Pes240	0	4	2	6	22	1.1
Pes320	2	3		5	11	0.55
Pes340	4	5		9	19	0.95
Pes350	7	2		9	13	0.65
Pes360	1	7		8	22	1.1
Pes370	3	1	1	5	11	0.55
Pes380	3			3	3	0.15
				Note: rating = 1*S+3*M+5*L		

APPENDIX B-4: PEBBLE COUNT FIELD DATA SUMMARY

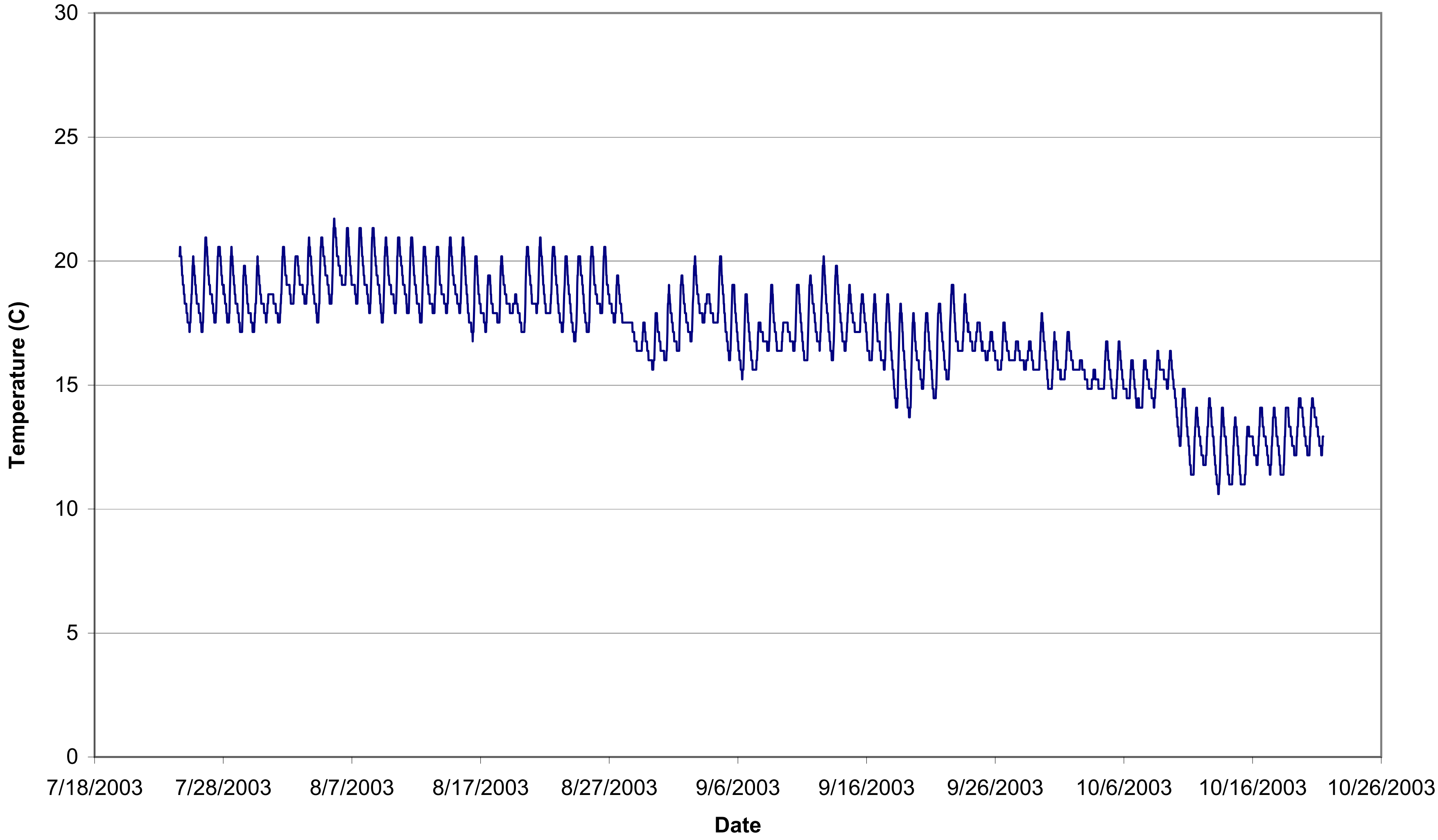
site	D16	D50	D84	sorting
But010xs	<4	<4	8	2.8
But020xs	11	23	38	1.9
But020ds	<4	17	30	
But050xs	11	24	49	2.1
But050ds	<4	9	49	3.5
But070xs	5	64	260	7.2
But070ds	<4	<4	11	
Pes050xs	8.3	19	40	2.2
Pes050ds	12	25	40	1.8
Pes070xs	11	30	50	2.1
Pes070ds	13	51	35	1.6
Pes100xs	4	5	50	3.5
Pes100ds	4	4	40	3.2
Pes140xs	32	78	160	2.2
Pes140ds	18	52	120	2.6
Pes160xs	11	46	105	3.5
Pes160ds	12	53	102	3.3
Pes170xs	14	36	90	2.5
Pes170ds	23	38	61	1.6
Pes180xs	45	100	220	2.2
Pes180ds	4	23	70	4.2
Pes190xs	20	46	128	2.5
Pes190ds	13	38	80	4.5
Pes200xs	13	45	92	2.7
Pes200ds	6	30	70	3.0
Pes210xs	13	56	128	3.1
Pes210ds	16	36	80	2.2
Pes215xs	16	36	58	1.9
Pes215ds	8	15	44	2.3
Pes230xs	16	32	58	1.9
Pes230ds	11	26	44	2.0
Pes240xs	15	36	70	2.2
Pes240ds	11	24	44	2.0
Pes320xs	23	64	120	2.3
Pes320ds	14	35	80	2.4
Pes340xs	17	42	100	2.4
Pes340ds	6	40	100	4.1
Pes350xs	16	52	150	3.1
Pes350ds	10	25	43	2.1
Pes360xs	22	62	230	3.2
Pes360ds	15	39	95	2.5
Pes370xs	30	67	160	2.3
Pes370ds	12	32	60	2.2
Pes380xs	24	64	160	2.6
Pes380ds	8.5	30	90	3.3
Note- xs indicates cross-section location				
ds indicates down-stream bar location				

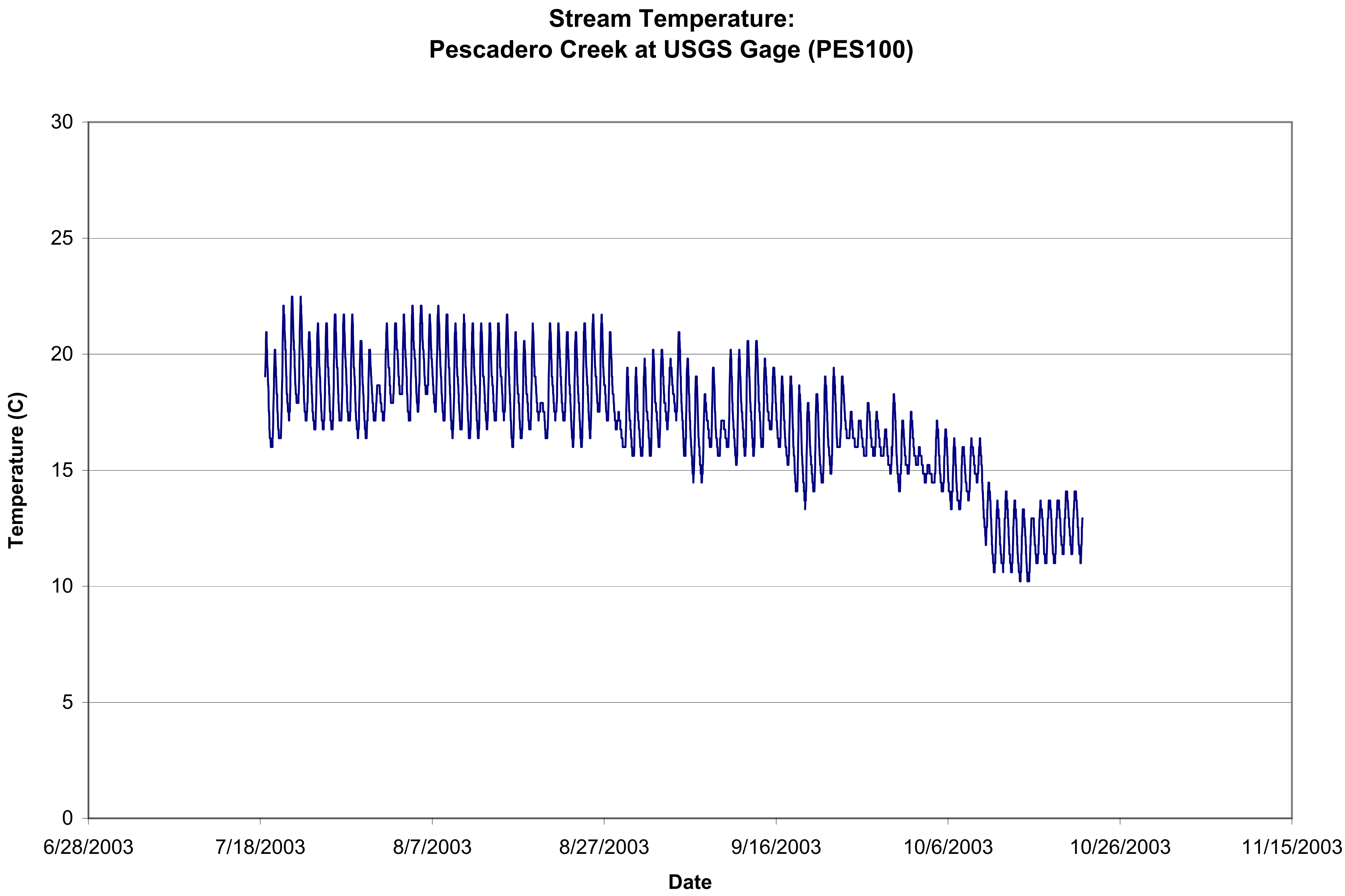
APPENDIX C
STREAM TEMPERATURE DATA



Stream Temperature:
Iverson Creek at Old Haul Road
Temperature (C)
30
25
20
15
10
5
0
6/28/2003
7/18/2003
8/7/2003
8/27/2003
9/16/2003
10/6/2003
10/26/2003
11/15/2003
Date

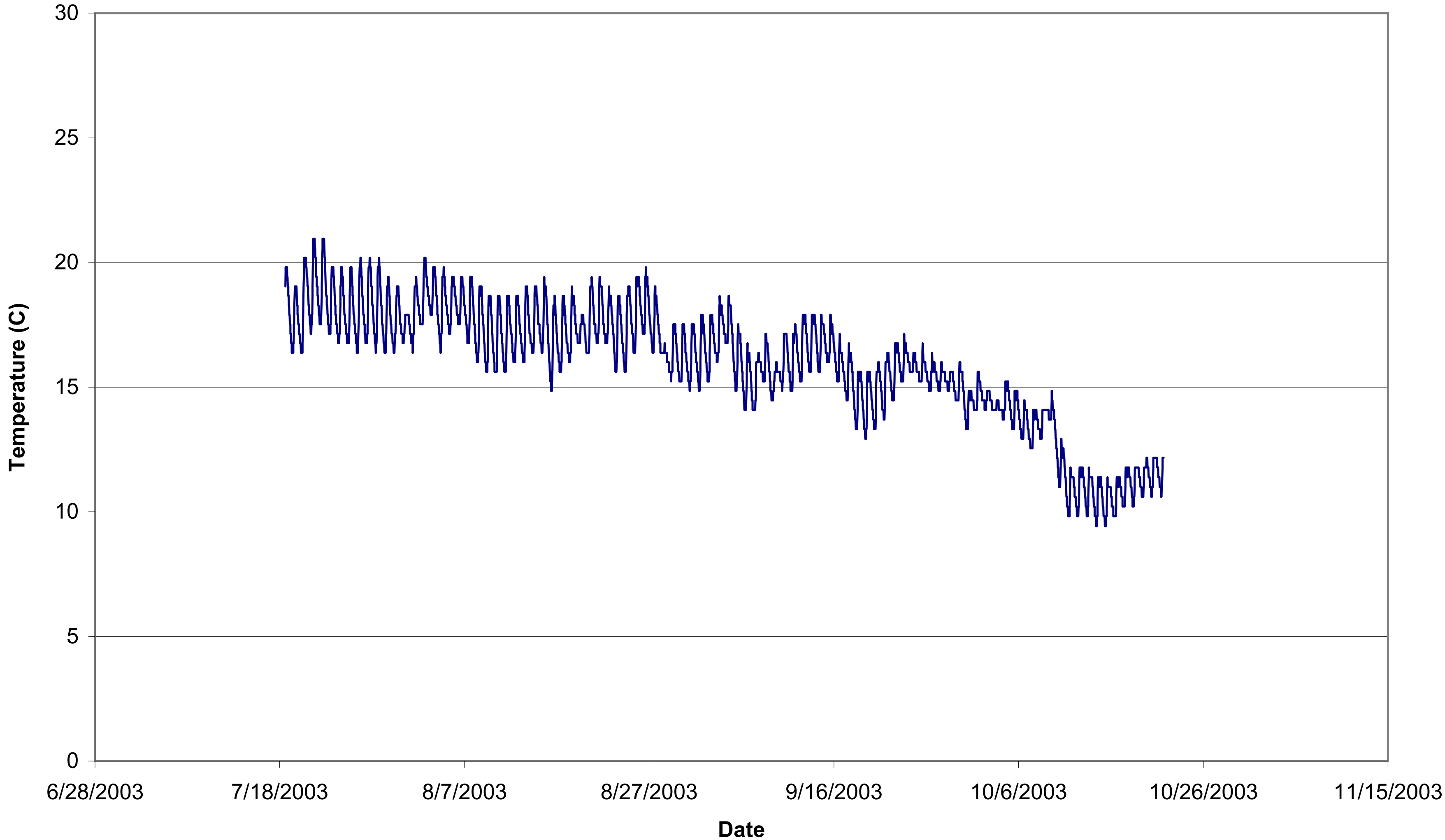
Stream Temperature:
Pescadero Creek Near Confluence with Honsinger Creek (PES070)

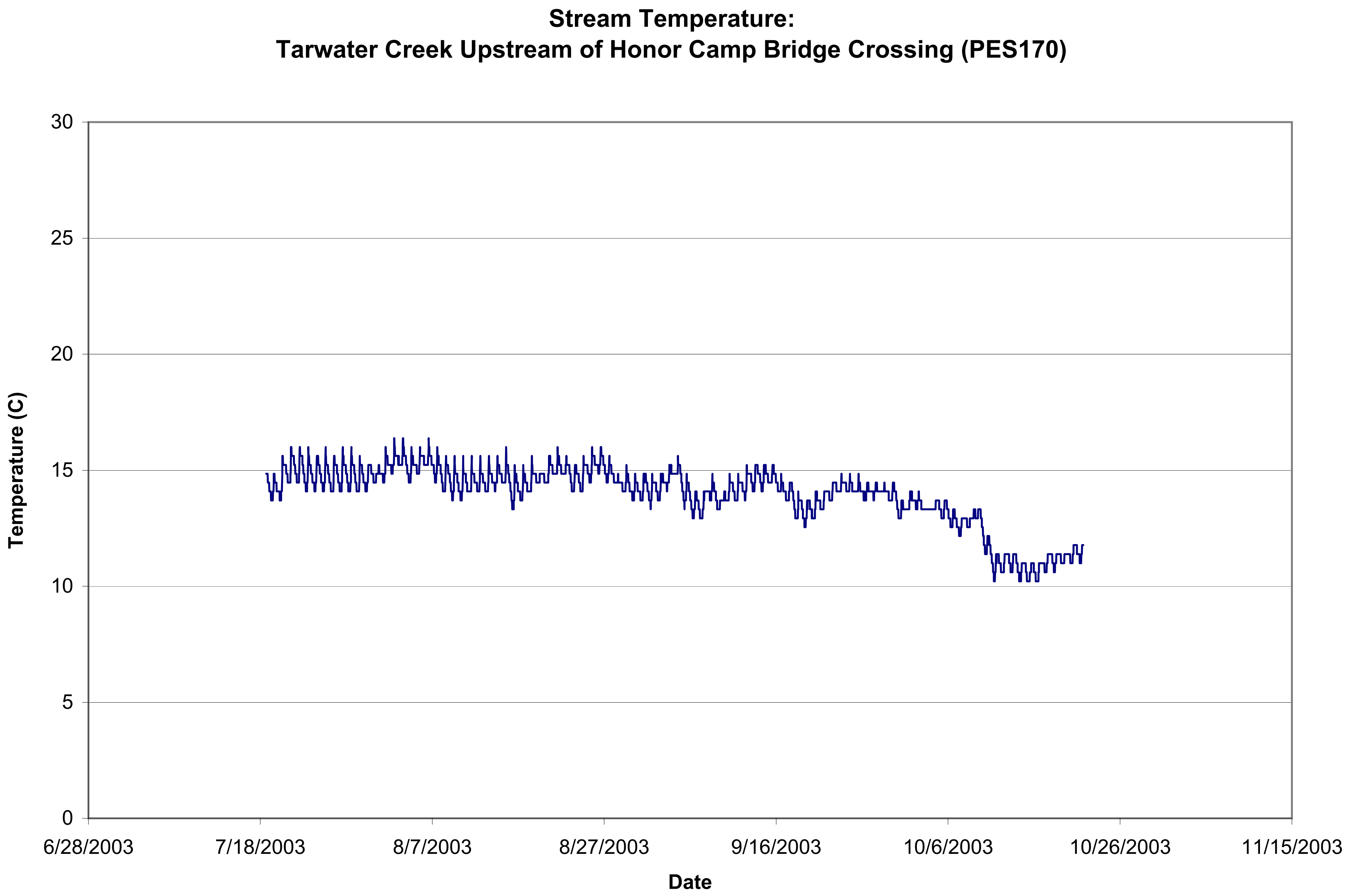




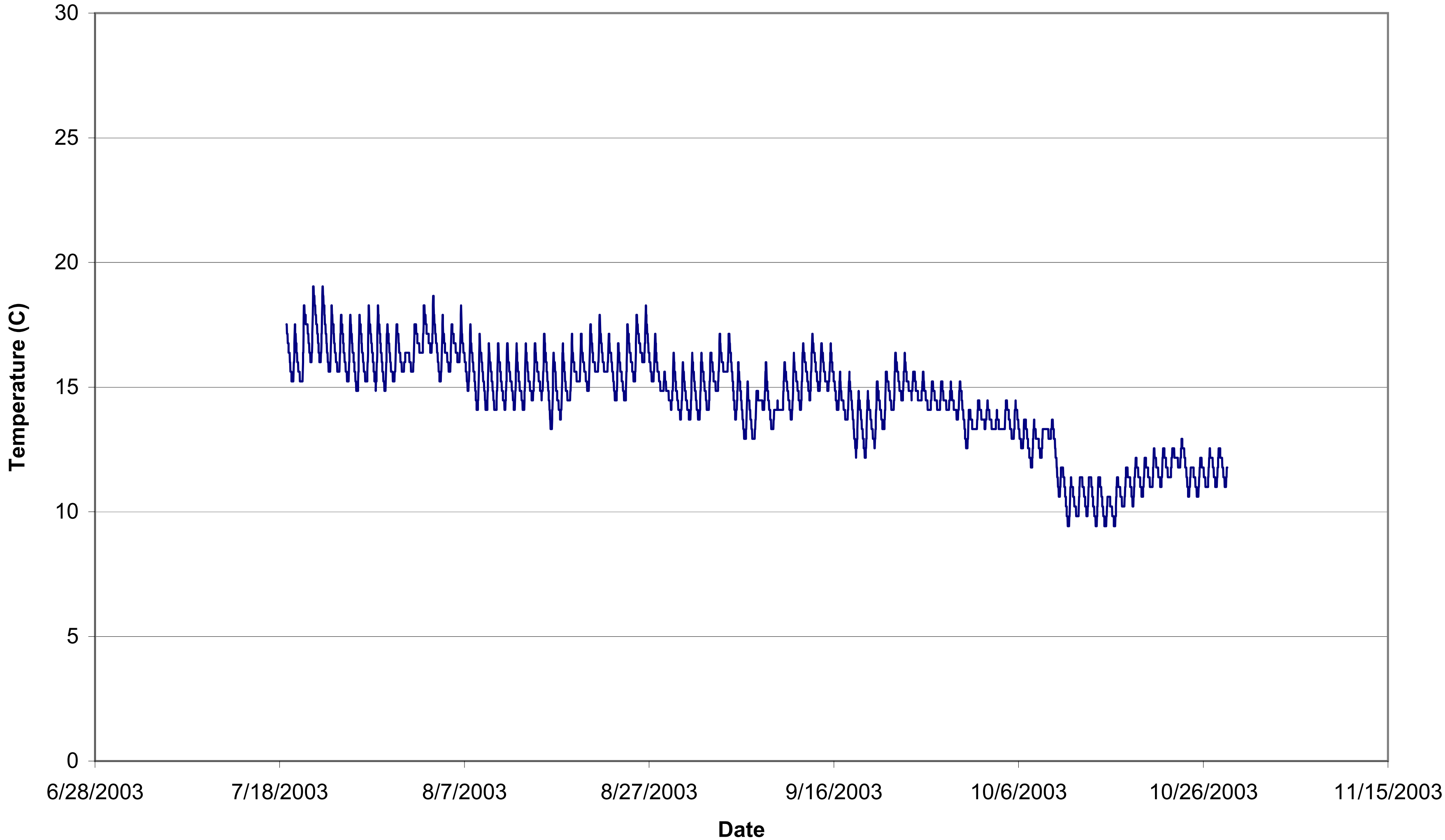
Stream Temperature:
Pescadero Creek at USGS Gage (PES100)
Temperature (C)
30
25
20
15
10
5
0
6/28/2003
7/18/2003
8/7/2003
8/27/2003
9/16/2003
10/6/2003
10/26/2003
11/15/2003
Date

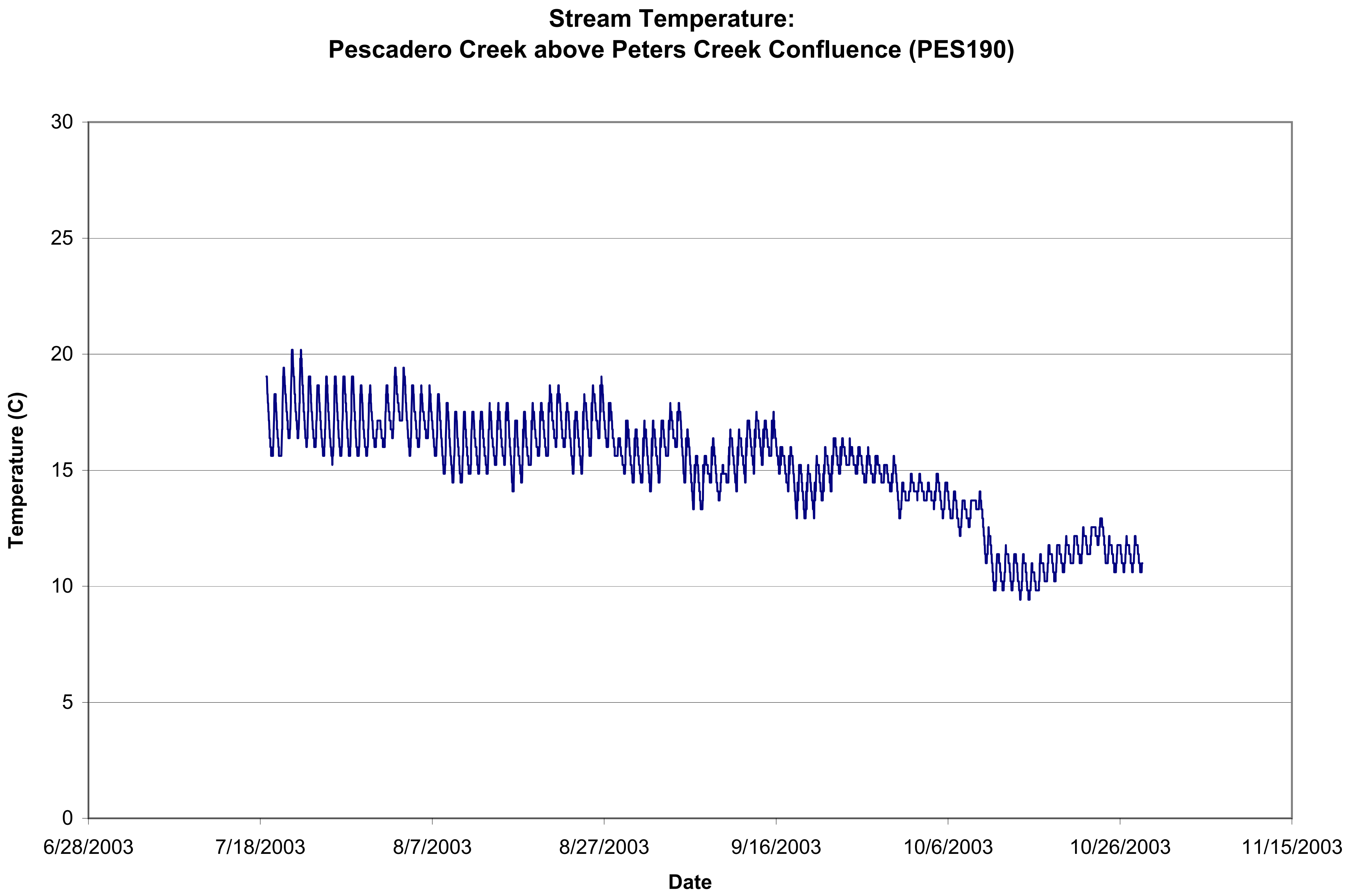
Stream Temperature:
Pescadero Creek at Towne Fire Road (PES160)



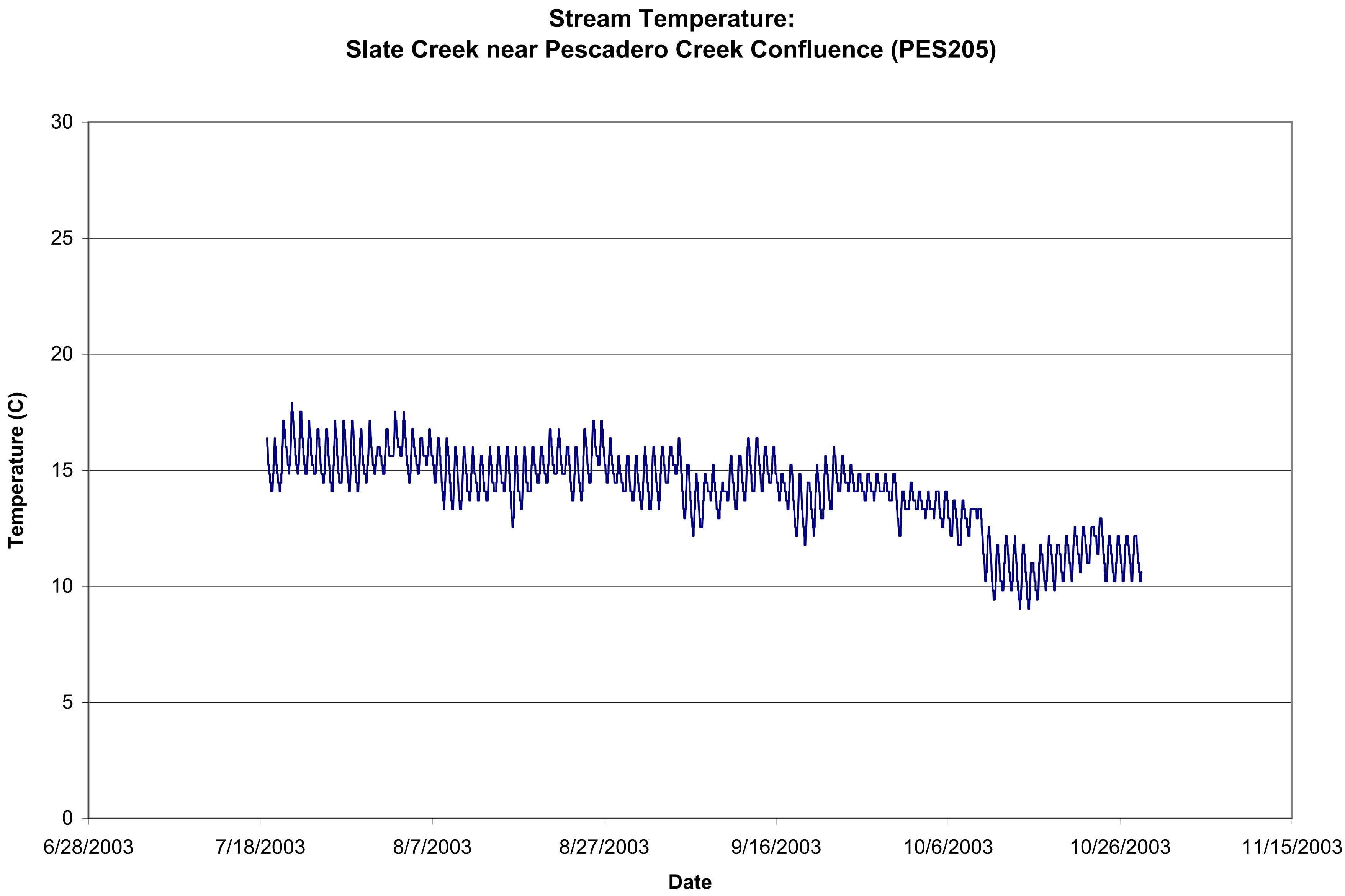

Stream Temperature:
Tarwater Creek Upstream of Honor Camp Bridge Crossing (PES170)
Temperature (C)
30
25
20
15
10
5
0
6/28/2003
7/18/2003
8/7/2003
8/27/2003
9/16/2003
10/6/2003
10/26/2003
11/15/2003
Date

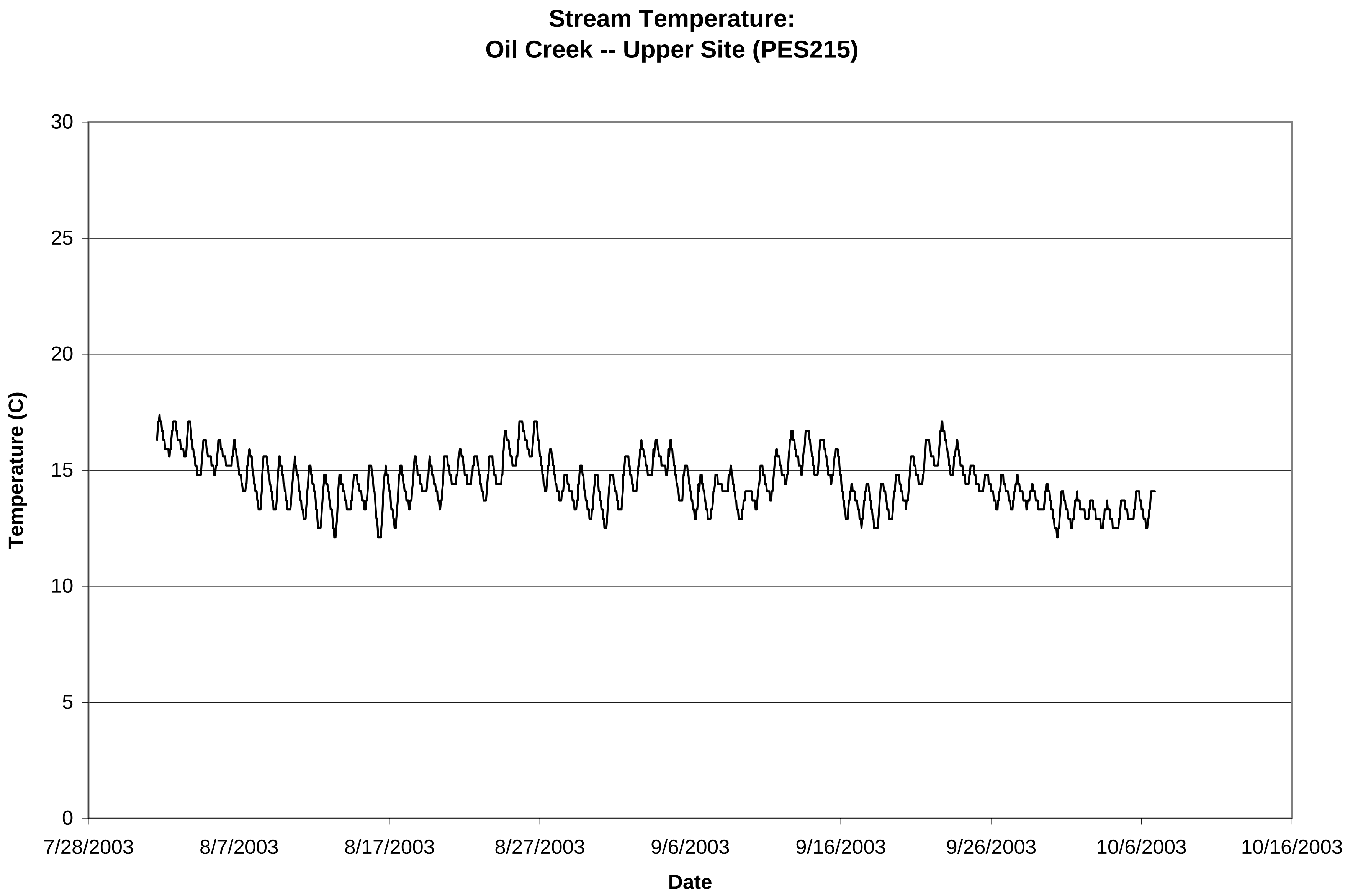
Stream Temperature:
Peters Creek Near Pescadero Creek (PES180)





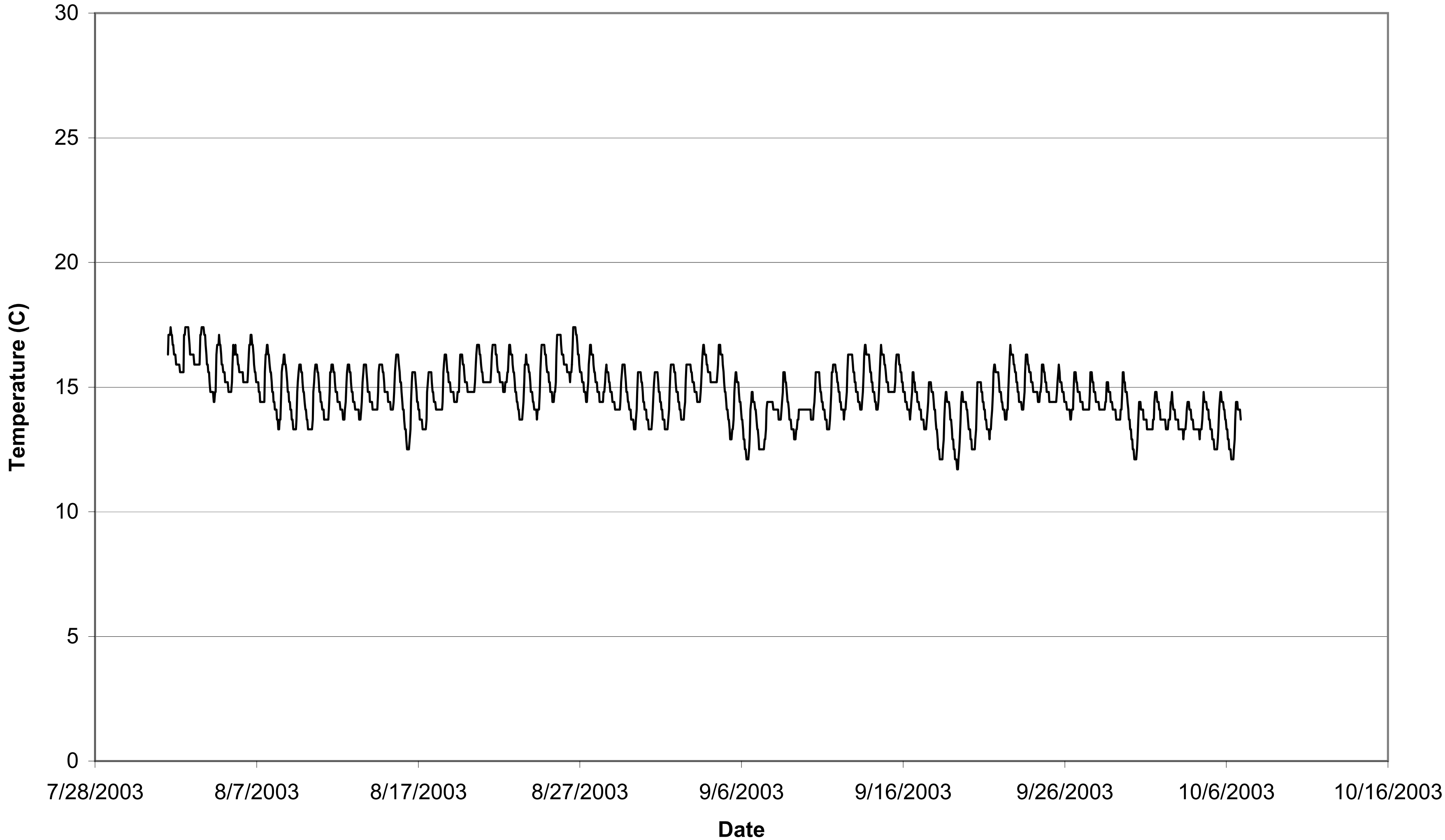
Stream Temperature:
Pescadero Creek above Peters Creek Confluence (PES190)
30
25
20
15
10
5
0
Temperature (C)
6/28/2003
7/18/2003
8/7/2003
8/27/2003
9/16/2003
10/6/2003
10/26/2003
11/15/2003
Date

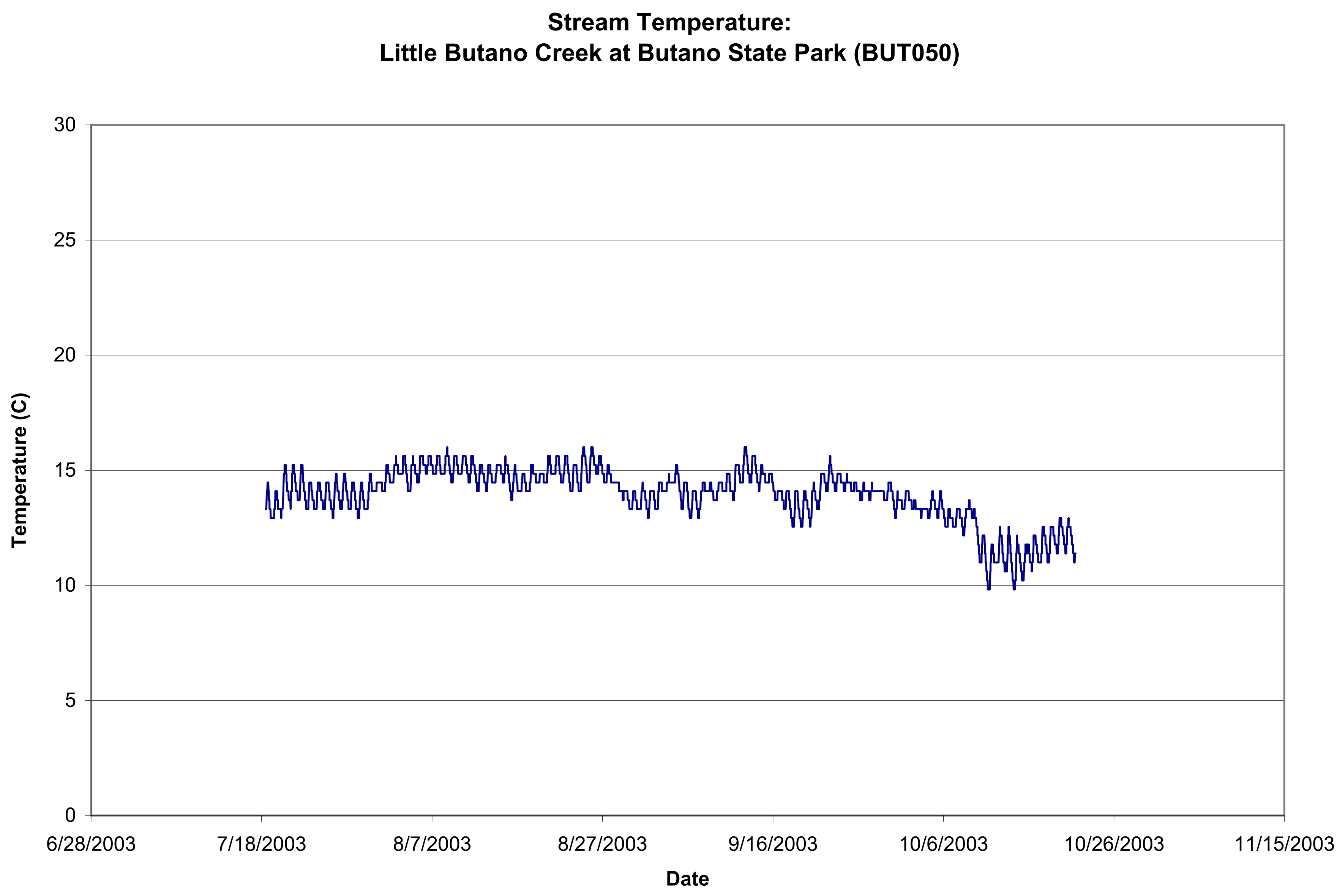

Stream Temperature:
Slate Creek near Pescadero Creek Confluence (PES205)
Temperature (C)
30
25
20
15
10
5
0
6/28/2003
7/18/2003
8/7/2003
8/27/2003
9/16/2003
10/6/2003
10/26/2003
11/15/2003
Date



Stream Temperature:
Oil Creek -- Upper Site (PES215)
30
25
20
15
10
5
0
Temperature (C)
7/28/2003
8/7/2003
8/17/2003
8/27/2003
9/6/2003
9/16/2003
9/26/2003
10/6/2003
10/16/2003
Date

Stream Temperature:
Waterman Creek (PES235)





Stream Temperature:
Little Butano Creek at Butano State Park (BUT050)
Temperature (C)
30
25
20
15
10
5
0
6/28/2003
7/18/2003
8/7/2003
8/27/2003
9/16/2003
10/6/2003
10/26/2003
11/15/2003
Date

APPENDIX D

GIS DATA SOURCES

Map 2-1 The Pescadero-Butano Watershed

Topography: 10-meter digital elevation model (DEM) data from USGS Bay Area Regional Database (BARD). See http://bard.wr.usgs.gov/htmldir/dem_html/dem-pa.html; quads are San Gregorio, La Honda, Mindego Hill, Pigeon Point, Franklin Point and Big Basin.

Streams and shoreline: hydrography digital line graph (DLG) data from USGS BARD. See http://bard.wr.usgs.gov/htmldir/dlg_html/dlg-pa.html and select hydrography layer for each quad. Hydrography was modified in Pescadero Marsh to trace stream centerlines rather than shorelines.

Ownerships: from GIS parcel data provided by San Mateo County Public Works Department.

Place names: located using road maps and local knowledge.

Map 2-2 Hillslope Geomorphic Units and Sediment Yield

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

HGU Geology: For San Mateo County, USGS Open File Report 98-137. See http://wrgis.wr.usgs.gov/open-file/of98-137/. For Santa Cruz County, USGS Open File Report 97-489. See http://wrgis.wr.usgs.gov/open-file/of97-489/.

HGU slope classifications: Were calculated using Topography described in Map 2-1 above.

Map 2-3 Fisheries Habitat Ratings

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Sampling points: San Francisco Bay Regional Water Quality Control Board Surface Water Ambient Monitoring Program (SWAMP), with additional points defined for project purposes by Environmental Science Associates.

Map 2-4 Priority Subbasins

Topography: Same as Map 2-1 above. Basins were derived from DEM topography using GIS software (ArcMap 8.3 and ArcView 3.2a, by Environmental Systems Research Institute, ESRI).

Streams and shoreline: Same as Map 2-1 above.

Map 6-1 Geology of the Pescadero-Butano Watershed

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Geology: Same as HGU Geology, Map 2-2 above.

Map 6-2 Coniferous Forests in the Pescadero-Butano Watershed

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Vegetation: Based on vegetation mapping from the California Fire and Resource Assessment Program; see Coastal Redwood Vegetation section of http://frap.cdf.ca.gov/data/frapgisdata/select.asp. Vegetation polygons were created using a nearest-neighbor analysis to encompass areas that were predominantly classified as Redwood or Douglas Fir.

Map 6-3 Initial Hillslope Geomorphic Units

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Geology: Same as HGU Geology, Map 2-2 above.

HGU slope classifications: Same as Map 2-2 above.

HGU vegetation: Same as vegetation, Map 6-2 above.

Map 6-4 Hillslope Geomorphic Units

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Geology: Same as HGU Geology, Map 2-2 above.

HGU slope classifications: Same as Map 2-2 above.

Map 6-5 40-Acre Sample Plots

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Geology: Same as HGU Geology, Map 2-2 above.

HGU slope classifications: Same as Map 2-2 above.

40-acre grid for region was defined by Environmental Science Associates. Sample plots were selected by Pacific Watershed Associates.

Map 6-6 Erosion Features Mapped from Aerial Photographs, 1956, 1982, 2000

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Erosion features were mapped by Pacific Watershed Associates.

Map 7-1 Channel Geomorphic Units and Sampling Stations

Topography: Same as Map 2-1 above.

Streams and shoreline: Same as Map 2-1 above.

Geology: Same as HGU Geology, Map 2-2 above.

HGU slope classifications: Same as Map 2-2 above.

Sampling Points: Same as Sampling points, Map 2-3 above.

End-to-end gradients of stream reaches were calculated by Environmental Science Associates.