

Lagunitas Creek Watershed Fine Sediment Reduction and Habitat Enhancement Plan



Lagunitas Creek in the Tocaloma Reach

Staff Report

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Cover Photo: Lagunitas Creek in the Tocaloma Reach located near Point Reyes Station, California. Photo by: Stillwater Sciences, Inc.

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- *The Lagunitas Creek Limiting Factors Analysis* (Stillwater Sciences, 2008)
- *The Lagunitas Creek Sediment Budget* (Stillwater Sciences, 2010)
- *The Lagunitas Creek Streambed Monitoring Report: 1995-2007* (Balance Hydrologics, 2010)
- *Linkages Between Sediment Delivery and Streambed conditions in the Lagunitas Creek Watershed, Marin County, California* (Cover, 2012)

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CHAPTER 1: INTRODUCTION

Key Points

- Section 303(d) of the Clean Water Act requires states to compile a list of “impaired” water bodies that do not meet water quality standards.
- In 1990, the Water Board listed Lagunitas Creek as impaired by sedimentation. In addition staff also concludes that habitat complexity and connectivity are impaired in Lagunitas Creek. Both impairments are addressed by this project.
- This report contains Water Board staff analyses and findings pertaining to sediment and habitat impairment in the Lagunitas Creek watershed.

This Staff Report provides the scientific basis for a proposed Basin Plan amendment that will be considered by the California Regional Water Quality Control Board, San Francisco Bay Region (Water Board) to restore water quality objectives for sediment and habitat condition that are intended to help facilitate recovery of listed populations of coho salmon and steelhead in the Lagunitas Creek watershed.

The Basin Plan is the Water Board’s master planning document. It specifies designated beneficial uses of water (e.g., water supply, recreation, fish habitat, etc.), water quality objectives (parameters that can be evaluated to determine whether beneficial uses are supported), and implementation plans and policies to achieve water quality standards. The Basin Plan amendment to address sediment and habitat impairments in Lagunitas Creek will establish numeric targets for sediment and habitat complexity, a maximum sediment load (i.e., a TMDL), and also an implementation plan to achieve these standards.

1.1 Background

The Water Board regulates surface and groundwater quality throughout the Bay Area. By law, the Water Board is required to develop, adopt, and implement a Basin Plan for the San Francisco Bay Region. The Basin Plan specifies and describes:

- Designated beneficial uses of water
- Water quality objectives, which are parameters that can be evaluated to determine whether the designated beneficial uses are protected
- Implementation plans and policies to protect water quality

Designated beneficial uses of water for Lagunitas Creek include the following:

- Water supply (agricultural and municipal)
- Freshwater replenishment
- Contact and non-contact recreation (fishing, swimming, boating, etc.)
- Fish migration and spawning
- Cold and warm freshwater habitats
- Wildlife habitat
- Preservation of rare and endangered species

Beneficial uses adversely affected by excess sediment in Lagunitas Creek are recreation (i.e., fishing), cold freshwater habitat, fish spawning, and preservation of rare and endangered species. As designated in the federal Clean Water Act, the Water Board (acting in coordination with the State Board) has several water pollution control responsibilities, including establishment of ambient water quality standards. Ambient water quality standards include beneficial use protection and water quality objectives (described above), and an antidegradation policy. The antidegradation policy requires that where water quality is better than needed to protect beneficial uses, that such superior water quality be maintained. Furthermore, Section 303(d) of the Clean Water Act also requires biennial assessments to determine whether ambient water quality standards are being achieved in individual water bodies throughout the United States.

In 1990, based on evidence of widespread erosion and concern regarding adverse impacts to fish habitat, the Water Board listed Lagunitas Creek as impaired by sedimentation under Section 303(d) of the Clean Water Act. As a result, the Water Board is required to prepare a TMDL, which involves development of a pollutant budget and a control plan to restore the health of a polluted water body. Key components include:

- Problem statement
- (Pollutant) Source analysis
- Numeric targets (e.g., specification of water quality parameter[s] that can be measured to evaluate attainment of water quality standards)
- Linkage analysis (between pollutant sources and numeric targets)
- Pollutant load allocations
- Implementation plan (to attain and maintain water quality standards)
- Monitoring plan (to evaluate progress in achieving pollutant allocations and numeric targets)

In addition to water quality impairments caused by pollutants including sediment, waters also can be impaired by forms of pollution, which under the Clean Water Act are defined as human-caused alterations of the biotic, chemical and/or physical integrity of a water body (e.g., habitat destruction). Although the Clean Water Act specifies a TMDL as a remedy to address impairment caused by a pollutant, it does not specify a TMDL as a remedy to address impairments caused by forms of pollution (see National Academy of Sciences, 2001; pp. 9-11).

In the case of Lagunitas Creek, we find that it is impaired by sediment, which is a pollutant, and also impaired by degraded habitat complexity and connectivity –a form of pollution - which results in non-attainment of the Basin Plan’s water quality objective for Population and Community Ecology. Historical and/or ongoing channel incision degrades habitat complexity and connectivity, and it is widespread along Lagunitas Creek and its tributaries. Channel incision reduces the frequency of gravel bars and pools, side channels and alcoves, and results in disconnection of the channel from its floodplain. These changes degrade the quality and quantity of habitat for federally listed populations of coho salmon, steelhead, and California freshwater shrimp. Channel incision results from a suite of management actions that have reduced the size and number of large fallen trees in channels throughout the watershed. Along Lagunitas Creek, dam construction also has contributed to incision, by causing a large reduction in coarse sediment (gravel) supply to downstream reaches. Channel incision is a controllable water quality factor, and although this problem is not amenable to a TMDL, we propose numeric targets and habitat rehabilitation actions using a combination of regulatory tools under the Porter Cologne Water Quality Act to address sedimentation, which will inherently address the problem of channel incision. The staff report presents the problems of sedimentation and channel incision, describes causes and sources, sets measurable values for target parameters related to achievement of narrative water quality objectives, and defines a course of action to restore water quality and habitat conditions.

1.2 Document Organization

Those sections of the staff report that follow include the following information:

Chapter 2. Problem Statement. This section describes the relationships between the identified pollutant (sediment) and pollution (habitat degradation) problems, applicable water quality objectives and beneficial uses, and current water quality conditions in Lagunitas Creek and its tributaries. The problem statement also describes factors limiting populations of coho salmon and steelhead in the Lagunitas Creek watershed.

Chapter 3. Sediment Source Analysis. In this section, we summarize the approach, methods, and results of the sediment source analysis

Chapter 4. Water Quality Objectives and Numeric Targets. Here, we present the rationale to support proposed water quality parameters and numeric targets, and their relation to attainment of applicable water quality standards.

Chapter 5. Linkage Analysis, TMDL, and Allocations. In this chapter, we describe hypothesized linkages between sediment loads and habitat conditions, and therefore, the rationale for establishing the assimilative capacity for sediment in Lagunitas Creek. We also present the TMDL and allocations - the amount of sediment allocated to each source category, the margin of safety to account for uncertainty in estimating loads and assimilative capacity (and which includes an allowance for future growth).

Chapter 6. Implementation Plan. Here, we outline actions needed to attain water quality standards for sediment and to protect and/or enhance other stream habitat conditions.

Chapter 7. Regulatory Analysis. This section contains legally required analyses of potential environmental impacts and costs that may be associated with the adoption of the proposed Basin Plan amendment.

CHAPTER 2: PROBLEM STATEMENT

Key Points

- Loss of habitat (formerly) upstream of dams, and channel simplification and floodplain disconnection in the remaining habitat are primary causes for decline of salmonid runs.
- The amount of fine sediment in the streambed is elevated above natural background and contributing to the decline of coho salmon and steelhead populations.
- Channel incision is a primary sediment source and it also causes habitat simplification and floodplain disconnection, and as such, is a key factor in the decline of salmonids.

2.1 Summary

The TMDL problem statement describes the relationship between the identified pollutant (sediment), applicable water quality standards, and current water quality conditions in the Lagunitas Creek. Water quality standards are composed of three parts:

- A statement of designated uses for a specified body of water (beneficial uses)
- One or more water quality parameters that can be evaluated to determine whether beneficial uses are protected (water quality objectives)
- An antidegradation policy, which requires that where water quality is better than needed to protect beneficial uses, those superior water quality conditions must be maintained

Water quality objectives for sediment and aquatic life, and relevant beneficial uses for Lagunitas Creek are listed in Table 2.1. We conclude that narrative water quality objectives for sediment and settleable material are not met because the percentage of fine sediment in the streambed¹ is elevated substantially above natural background and the bed is more mobile, contributing to salmonid population declines.

Elevated fine sediment deposition and higher bed mobility in Lagunitas Creek and its tributaries result not just from sediment supply increases, but also from fundamental alteration of channel sediment transport and storage processes. The largest human-caused sediment source is channel incision. Channel incision also alters sediment transport and storage processes and obliterates the basic physical habitat structure of the channel, expressed by a

¹ When we refer to fine sediment in the streambed, we are referring primarily to sand ($< 2\text{mm}$) and lesser amounts of fine or very fine gravel ($2\text{ mm} \leq D \leq 8\text{ mm}$). These grain sizes constitute the bed material suspended load that is transported either as bedload during smaller runoff events (that are greater the threshold for bed material transport), and/or as suspended load during larger runoff events.

substantial reduction in the frequency and area of gravels bars, riffles, and side channels, and disconnection of the channel from its floodplain. Channel incision is a controllable water quality factor that results in non-attainment of the narrative water quality objective for population and community ecology (Table 2.1). Reductions in large woody debris loading also substantially alter sediment transport and storage. In summary, our reasoning regarding sediment and habitat impairment is as follows:

- 1) In the Lagunitas Creek watershed, about half of the potential habitat for steelhead and coho salmon is no longer accessible or has been lost as a result of dam construction² (Spence et al., 2008, pp. 68-69, 91-92, and 94). In the remaining habitat, downstream of the dams, changes in sediment delivery, transport, and storage and habitat simplification also have contributed to the decline of the salmonid runs.
- 2) Total sediment supply is at least two-times the natural background rate, and also richer in percent sand and finer sediment (Stillwater Sciences, 2010, pp. 3-4). As sediment supply increases or becomes finer, the streambed may respond by becoming finer and more mobile (Dietrich et al., 1989; Buffington and Montgomery, 1999a).
- 3) Lagunitas Creek and its tributaries have a greatly diminished capacity to sort, store, and meter sediment because of floodplain disconnection³ and a significant reduction in large woody debris loading. Floodplain disconnection results from channel incision, which also increases sediment transport capacity. Under natural conditions, floodplains along San Geronimo and Lagunitas creeks may have stored half-or-more of the sediment delivered from upstream reaches, as documented in nearby Redwood Creek (Stillwater Sciences, 2004, pp. 5-6, 18, and 36-37). Also, in channels draining old-growth redwoods, debris jams can store several decades or more of potential bedload supply (Keller et al., 1995, pp. P23-P26). Both of these natural sediment storage reservoirs have been compromised.
- 4) As documented in other local watersheds (Stillwater Sciences, 2004, pp. 21-22 and Figure 7; Figure 3.1), we hypothesize that prior to European-American settlement, some tributaries to Lower Lagunitas, Nicasio, and San Geronimo creeks (where these main channels traversed broad valleys) were naturally disconnected; further reducing sediment supply to fish-bearing channel reaches under natural conditions⁴.

² The two largest reservoirs, Kent Lake, and Nicasio Reservoir were constructed in 1954 and 1961 respectively. In 1982, the storage capacity of Kent reservoir was doubled to 32,000 acre-feet.

³ Former floodplains have been converted to terraces as the bed of the channel has lowered by incision. The incised channel now conveys all of the runoff even during very large floods (Recurrence interval ≥ 25 years). As a result, the terraces are not regularly flooded, and thus no longer function as significant sediment deposition sites.

⁴To facilitate development on the floodplain, naturally disconnected channels would have been ditched and connected to downstream reaches.

- 5) High flows and sediment pulses in Lagunitas Creek are not synchronized when a dry period of years precedes a large storm event. This is because San Geronimo Creek is the primary sediment source to the State Park Reach of Lagunitas Creek, and almost all of the rest of the watershed drains into large water supply reservoirs (e.g., Kent Lake). Therefore, when a large storm follows a dry period of years the reservoirs do not spill, causing peak flow to be attenuated along the mainstem of Lagunitas Creek, and sedimentation events to last longer here, as appears to have occurred following the New Year's Eve 2005 storm (compare Balance Hydrologics, 2010, Figure 7, to Figures 2.5a and b, this report).
- 6) Elevated rates of streambed mobility are inferred in small tributaries to Lagunitas and/or San Geronimo creeks. Cover (2012) evaluated linkages between sediment supply and streambed conditions in a number of small tributaries to San Geronimo and Lagunitas creeks including Woodacre, Arroyo, Larsen, Devils Gulch, and Cheda, all of which provide spawning and rearing habitat for coho salmon and steelhead. In the study reaches, bed mobility was strongly correlated to sediment supply and inferred to be high/very high ($\tau^* = 0.08$ to 0.10) in reaches with medium sediment supply, and very high/extreme ($\tau^* = 0.16$ to 0.18) in channel reaches with high sediment supply. Values of 0.03 -to- 0.06 for τ^* of are typical in gravel-bedded channels, where sediment supply and transport capacity are balanced.
- 7) Rates of streambed mobility and reach-average values for streambed scour are strongly correlated (Haschenberger, 1999; Bigelow, 2005; May et al., 2009; Shellberg et al., 2010). Streambed scour at spawning redds can be a significant source of mortality during incubation for coho salmon (McNeil, 1966; Montgomery et al., 1996; Shellberg, 2010). High rates of streambed mobility also have been linked to persistent reductions in the biomass of benthic macro-invertebrates (Matthaei and Townsend, 2000) suggesting there also could be the potential for reduced growth of juvenile salmonids in all freshwater life stages as a result of elevated rates of bed mobility.
- 8) In Lagunitas Creek, early life stage mortality for coho salmon, from egg fertilization through summer rearing, is very high in all years – from 94-to-99 percent⁵ - and may be linked to increases in sediment supply. In some years, early life stage mortality limits smolt production. For example, in five-of-sixteen years of record, the juvenile population at the end of the dry season was less than the estimated winter carrying capacity for juveniles (6000 to 7000)⁶ limiting smolt production in those years.

⁵ Values were estimated from juvenile population and redd count data collected by the Marin Municipal Water District, and compiled for comparison (Napolitano, 2012a). We compared coho salmon redd counts in the preceding wet season to juvenile population sampling at/near the end of the dry season, and assumed that the average number of eggs deposited in each redd was 2500. Percent survival = (juvenile population estimate) ÷ (# of redds x 2500 eggs/redd) x 100.

⁶As hypothesized by Stillwater Sciences (2008) and supported by the results of four additional years of smolt trapping (Ettlinger and Andrew, 2011).

Mechanisms have not been established, but based on strong correlation between the magnitude of winter peaks and spring runoff events (Stillwater Sciences, 2008, pp. 42-44); it is plausible the mechanism(s) may include: redd scour; entombment; and/or involuntary entrainment (from a paucity of velocity refuges). Scour and entombment are both influenced, in part, by sediment supply. Involuntary entrainment could be diminished through enhanced large woody debris loading and floodplain connection, both of which are needed to achieve sediment water quality objectives.

- 9) For steelhead, smolt production may be limited at least in part, by interstitial spaces in cobble-boulder substrate patches, which provide an important component of winter rearing habitat (Bustard and Narver, 1975; Stillwater Sciences, 2008, p. 57 and p. 63). Density and suitability of these interstitial spaces can be degraded by increases in the supply of sand and gravel delivered to the channel (see for example, Cover et al., 2008).
- 10) Also, results from studies conducted elsewhere in the California Coast Range suggest that elevated levels of fine sediment deposition can have significant adverse effects on juvenile growth and survival during the summer rearing period (Suttle et al., 2004; Harvey et al., 2009).

Table 2.1: Water Quality Objectives and Sediment-Related Beneficial Use Categories		
Beneficial Use Categories	Water Quality Objectives	
Cold Freshwater Habitat Fish Migration	Turbidity	Increase from background <10% where natural turbidity is >50 NTU*
Preservation of Rare and Endangered Species	Sediment	Should not cause a nuisance or adversely affect beneficial uses
Fish Spawning Warm Freshwater Habitat	Settleable Material	Should not cause a nuisance or adversely affect beneficial uses
Wildlife Habitat Recreation	Suspended Material	Should not cause a nuisance or adversely affect beneficial uses
Cold Freshwater Habitat Fish Migration Preservation of Rare and Endangered Species Fish Spawning	Population and Community Ecology	The health and life history characteristics of aquatic organisms in water affected by controllable water quality factors shall not differ significantly from those for the same waters on areas unaffected by controllable water quality factors
Note: Bold text indicates water quality objective is not being attained. *NTU Nephelometric Turbidity Unit		

2.2 Detailed Problem Statement

Salmonid Populations in decline

Lagunitas Creek, from its headwaters on Mount Tamalpais to its mouth in Tomales Bay is the largest watershed in Marin County (Figure 2.1). It provides critical habitat for coho salmon, steelhead trout, and California freshwater shrimp, all of which are listed under the federal Endangered Species Act.

There has been a precipitous decline in the abundance of coho salmon and steelhead in the Lagunitas Creek watershed during the historical period. Although historical data are limited, based on our review, we conclude that coho salmon and steelhead runs once numbered in the several thousands (Chatham, 1990⁷, p. xiii; Moyle, 2002, pp. 250-251), compared to more recent spawning runs in the tens to hundreds (MMWD, 2013).

⁷ Lagunitas Creek in the late nineteenth century was referred to as “Paper Mill Creek”, a name that continued to be used by some longtime residents.



Figure 2.1: Lagunitas Creek watershed in western Marin County, California. The TMDL project area (outlined in yellow) includes the entire land area and all channels draining into and including Lagunitas Creek, below Kent Lake and Nicasio Reservoir, downstream to the confluence of Lagunitas Creek with Olema Creek.

Up until the late 1960s, Lagunitas Creek was a popular destination for sport fisherman hoping to catch steelhead and coho salmon (Figure 2.2). In 1996, Lagunitas Creek’s salmon and steelhead populations were listed under the Endangered Species Act indicative of an extremely rapid and significant decline.



Figure 2.2: Fisherwoman on Lagunitas Creek in 1922. Photo is provided courtesy of Anne T. Kent California Room, Marin County Free Library. “In the 1900s special trains would bring anglers from the San Francisco Bay Area to fish for juvenile and adult steelhead and salmon (Smith, 1986, p. 1).”

Annual surveys conducted since 1996, provide a basis for assessment of the current status of coho salmon populations in the watershed (Figure 2.3). During the 1996 through 2005 period, the coho salmon run in the Lagunitas Creek watershed was stable or increasing, varying from approximately 200 to 1000 adult spawners (peaking in the winter of 2004-05) and averaging 500. Beginning in the winter of 2007-08, a period of very poor ocean conditions and following the very large and damaging New Year’s Eve 2005 storm, coho salmon runs plummeted in Lagunitas Creek and most locations throughout the State. Consequently in the winters of 2008-09, 2009-10, and 2010-11, the Lagunitas Creek coho salmon run was much smaller, varying from approximately 50 spawners (in the winter of 2008-09) to 160 spawners (in 2010-11). All three brood years⁸ declined by 50-to-80 percent, as compared to the previous generation. The winter of 2011-12 was the first since 2005-06, in which the number of adult spawners increased (260 this winter) as compared to the same brood year in the previous generation (52 spawners in 2008-09), likely in response to much better ocean conditions (Ettlinger, personal communication, 2012).

⁸ All female coho salmon return to spawn when they are approximately three years old. As such, populations are comprised of three brood years, in which all the young salmon hatched in a given year are the progeny of the female salmon hatched three years earlier. As a result, ocean and/or freshwater conditions that have a significant influence on population size in a given year also may influence population size, of the subsequent generation, three years later.

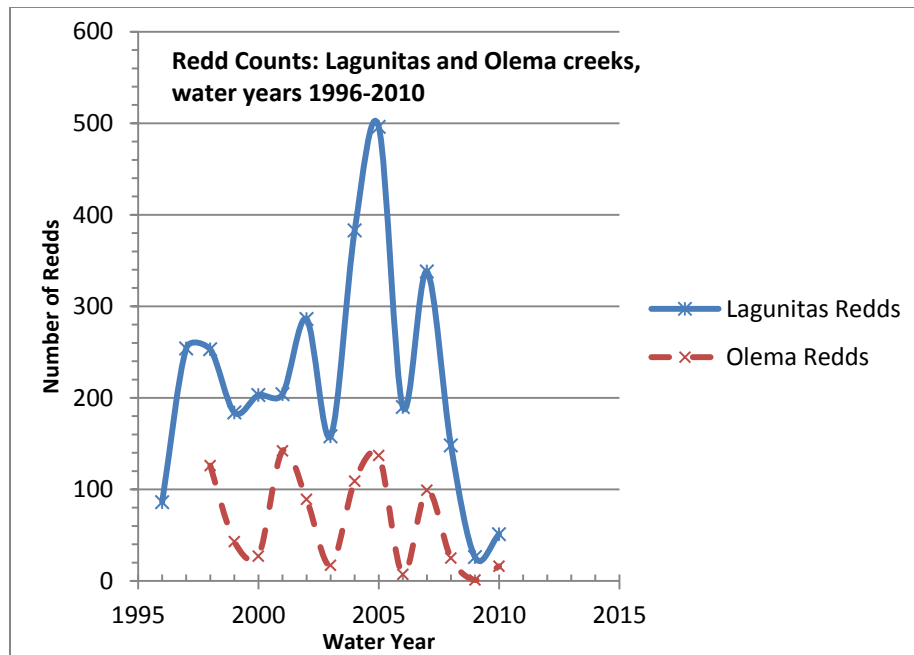


Figure 2.3: Number of coho salmon spawning sites (redds) detected during winter surveys. We multiply redds by two to estimate run size. Lagunitas counts include all major tributaries, except Olema, which also is surveyed and shown above. Although run size varies greatly between years, populations were stable or increasing in Lagunitas until 2008, when the run plummeted and has yet to fully recover. The Olema Creek data illustrate the vulnerability of a very small population. The brood year returning to spawn in 2003, 2006, and 2009 was very small to begin with (17 redds in 2003), and two generations later in 2009, a period that included a large and damaging storm and very poor ocean conditions, only 1 coho salmon redd was detected. Data sources: MMWD, SPAWN, and USNPS.

Although significantly reduced, the Lagunitas Creek watershed coho salmon population, nevertheless appears to be the largest remaining population south of Mendocino County, and constitutes approximately 10 percent of the total population in California.

Linkages to Freshwater Habitat Conditions

In the Lagunitas Creek watershed, about half of the potential habitat for steelhead and coho salmon is no longer accessible or has been lost as a result of dam construction (Spence et al., 2008, pp. 68-69, 91-92, and 94). In the remaining habitat, changes in sediment delivery, transport, and storage and habitat simplification also have contributed to the decline of the salmonid runs. Also, in the Lagunitas Creek watershed, there has been a two-fold or greater increase in the amount of sediment supplied to channels, and an increase in the percentage that is sand or finer in grain-size (Stillwater Sciences, 2010, pp. 3-4; also, see Source Analysis, Chapter 3). Channel incision, or the down-cutting of the channel into its bed is the primary source of the increase in sediment supply (Stillwater Sciences, 2010), and also a primary agent of

channel habitat simplification, and disconnection of the channel from its floodplain⁹ (Figure 2.4). At present, San Geronimo Creek and its tributaries, and Lagunitas Creek along most of its length, are deeply incised, in most locations by 6-feet-or-more (see Study Area Description, Appendix I). Although the causes and timing of incision have not been the focus of previous studies, based on review of its disturbance history (including intensive grazing, logging of the redwood forest, dam construction on Lagunitas Creek, and gravel mining), and comparison to nearby watersheds that experienced similar disturbances and consequent incision, we hypothesize that prior to European-American settlement, the valley flat adjacent to Lagunitas and San Geronimo creeks functioned as a floodplain, and as a result of land-use related disturbances, the channels have incised¹⁰. In Appendix I (Study Area Description), we present a detailed physical description of channel and watershed attributes, to provide additional background regarding the relationships between channel form and processes.

Studies have been conducted in the Lagunitas Creek watershed to examine potential linkages between freshwater habitat conditions (including sedimentation) and salmonid population dynamics. In the early 1980s: a) anomalously high rates of streambed scour, related at least in part to a high concentration of sand and fine gravel in the streambed, were documented in Lagunitas Creek and its tributaries, and inferred to be a primary control on coho salmon production (Bratovich and Kelley, 1988, pp. 84 and 88-92); and b) a strong negative correlation was noted between substrate embeddedness (e.g., the extent to which cobbles and boulders in the streambed are buried by finer sediment) and juvenile steelhead density, suggesting embeddedness could exert a significant influence on steelhead production (Kelly and Dettman, 1980, pp. 15-18).

More recently, in 2008, a salmonid limiting factors analysis was completed that characterizes contemporary habitat conditions and inferred influences on salmonid smolt production (Stillwater Sciences, 2008). Based on this work, it appears that Steelhead smolt production, in many years, may be limited in part by the winter refuge capacity provided in channels within cobble-boulder substrate. The frequency of openings in the spaces between the cobbles and

⁹ Also there are fewer large fallen trees in channels as a result of nineteenth century logging, intensive removal of debris from channels, and as a consequence of channel incision (e.g., incised channels are narrow and deep and as a result many fallen trees remain perched above the channel). The lack of large fallen trees in channels is a problem for fish because large trees force pools and bars to form, cause sediment to be sorted into discrete patches (that vary in grain size), and create side channels, islands, and floodplains.

¹⁰ In all of the Marin County watersheds where channel incision has been studied, scientists have concluded it was initiated following European-American settlement and is linked to land-use related disturbances including: Novato Creek (Collins, 1998); Walker Creek (Haible, 1980); and Redwood Creek (Stillwater Sciences, 2004). Based on the results of C₁₄ dating of charcoal deposits in gravels at the base of the valley fills, deposition of the valley fill is inferred to have started along Walker Creek about 5,000 years ago and was continuous until about the 1850s when an episode of incision began. Similarly in Redwood Creek, valley deposition began about 3,500 years ago (also as inferred by dating of charcoal deposits) and deposition was continuous up until about the 1850, when a period of incision began.

boulders may in turn be diminished by increases in the amount of gravel and/or sand supplied to the channel. Steelhead and coho size for a given life stage, and hence fitness/survival rate also is influenced by food supply and energy expenditure both of which may be adversely impacted by increases in substrate embeddedness, and/or bed mobility (Harvey et al., 2009; Suttle et al., 2004; Matthaei and Townsend, 2000).

In most years, the amount of complex in-channel habitat (primarily debris jams) that is available in channel reaches that are connected to floodplains (these two habitat types act in concert to provide winter refuge habitat), appears to limit coho salmon rearing capacity during the wet season to 6,000 to 7,000 juveniles. Therefore, another way that increases in sand and/or gravel supply may degrade salmonid habitat is by resultant increases in sedimentation in/around debris jams, which if not otherwise filled with gravel and sand, could provide additional winter refuge habitat.

In about one-in-three years, mortality during incubation and/or early juvenile life stages appears to be very high causing the juvenile population at the end of the dry season to be significantly below wet season carrying capacity (survival from spawning to the end of the dry season is often below 2%). The most likely agents for very high rates of early life stage mortality in these years is one or more of the following: a) high rates of redd scour during large flood events (recurrence interval > 5 years); b) entombment of coho salmon in the gravel prior to emergence as a result of excessive amounts of sand deposition (creating a hard cap that the young fish cannot penetrate); c) involuntary entrainment of young fish during high spring runoff events as a result of a paucity of low velocity refuge habitat within the stream channel (e.g., lack of woody debris jams with good shelter); and d) redd superimposition (primarily by steelhead disturbing the streambed during subsequent spawning in the same locations selected earlier in the wet season by coho salmon). Redd scour and entombment both are made worse, at least in part, by increases in total sediment supply and/or the percentage in the sand size range. All four factors to some degree reflect deficiencies in channel habitat structure, floodplain connection, and sediment sorting and metering. All of these deficiencies could be addressed at least in part if there were more large fallen trees in the channel, and greater connection between the channel and floodplain along at least part of its length.

Lagunitas Creek is one of only a handful of locations in California, where long-term monitoring of substrate conditions has occurred. Annual surveys to characterize streambed grain size distributions, embeddedness, and sediment storage occurred in the early 1980s and each of the years between 1995 and 2007 (the most recent year for which data have been reported) (Balance Hydrologics, 2010). Results of long-term monitoring allow us to characterize sedimentation levels through time (Figures 2.5a and 2.5b). Although substrate conditions apparently improved during the early and late 1990s, both of these periods were dominated by wet years that did not include a large and damaging storm event (e.g., large sediment input). Then, following the large and damaging New Year's Eve 2005 storm/flood, substrate conditions degraded substantially, conditions have not recovered yet. In the most recent years for which

data is available (water years 2005-2007), substrate conditions appeared to be poorer than during the early 1980s.



Photo Credit: Stillwater Sciences, 2008.

Figure 2.4: Incised channel reach of Lagunitas Creek in SP Taylor State Park. Photo credit: Stillwater Sciences, 2008. During storms, the channel flows deep and fast throughout. There are few low velocity refuges, where juvenile fish can rest and hold their position.

Floodplain habitats, including side channels and alcoves, when inundated regularly during the wet season, provide essential habitat for coho salmon, steelhead, and other native fishes. Dam construction, watershed development, and management actions have interacted to cause channel incision/ habitat simplification, and to fundamentally alter channel sediment delivery, transport, and storage. As a result, it is likely that the concentration of sand and very fine gravel in the streambed is elevated above the natural background level, the streambed is much more mobile during high flows, and the quality of spawning and rearing habitat is substantially degraded (Cover, 2012; also, see Chapter 5, Linkage Analysis).

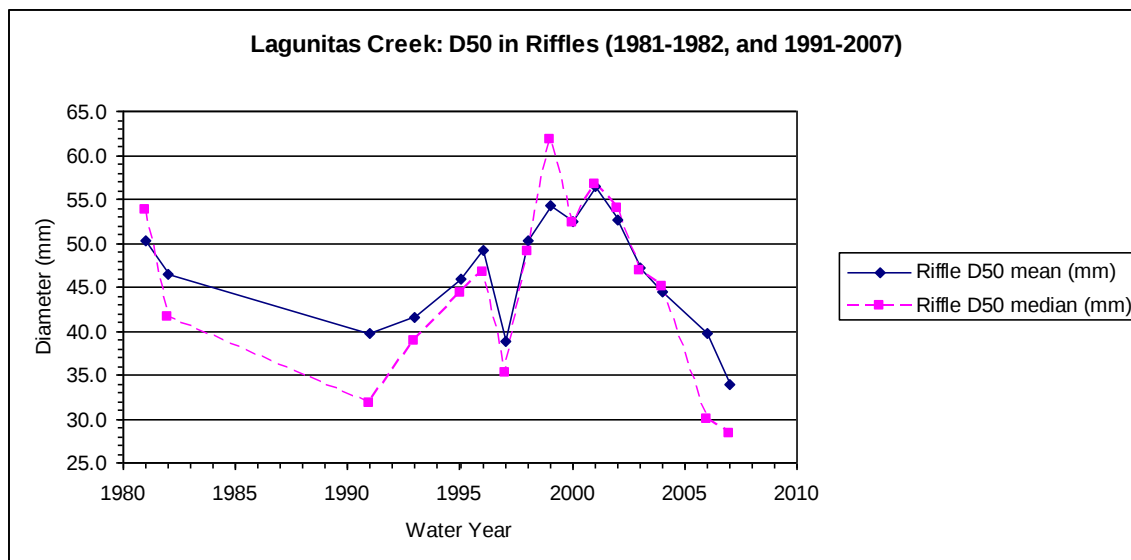


Figure 2.5a Trends through time in streambed grain-size in riffles in Lagunitas Creek. D_{50} is the median particle size for the surface layer of the streambed, which has been measured repeatedly in eight reaches of Lagunitas Creek since the early 1980s. We tabulated D_{50} values for these eight sites to calculate an average and median value for D_{50} in riffle habitats throughout Lagunitas Creek, which is depicted in the graph above. The graph is developed from data reported in Balance Hydrologics (2010).

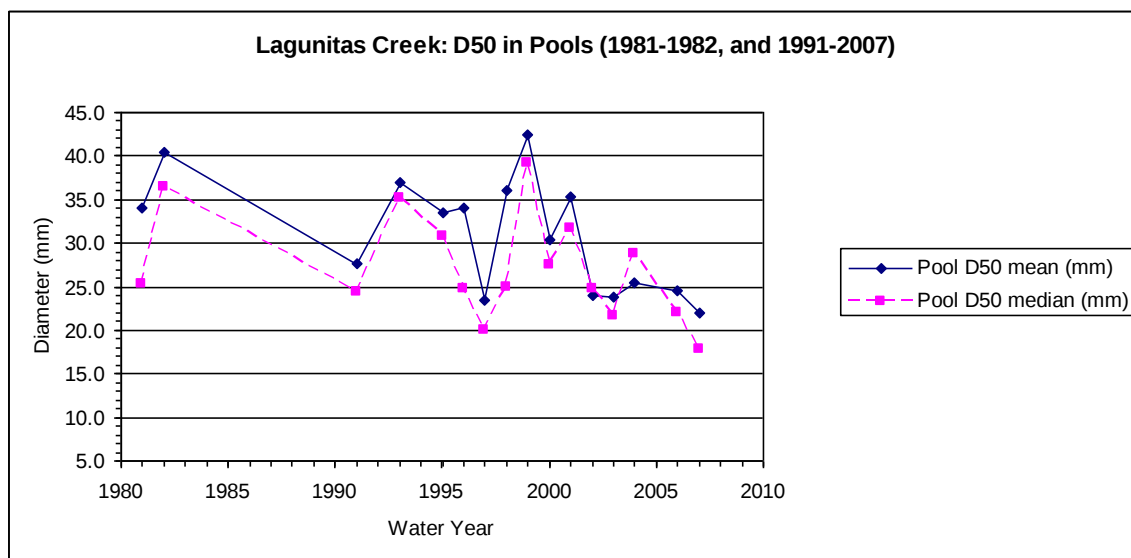


Figure 2.5b Trends through time in streambed grain-size in pools in Lagunitas Creek. Parameters are as defined in Figure 2.5a above, except this graph characterizes conditions in pool habitats.

Additionally, Stillwater Sciences (2010, pp. 3-4) found that total sediment supply to channels is two-or-more times the natural background, and that fine sediment supply is elevated to an even greater degree.

Channel incision and wood loss make Lagunitas Creek and its tributaries particularly sensitive to elevated chronic and episodic sediment inputs. De-synchronization of sediment pulses and high flows in some years in the State Park Reach¹¹, further extends the duration of sedimentation impacts. The resultant cumulative effects of habitat simplification and elevated sediment supply adversely affect growth and survival of juvenile salmonids in all freshwater life stages.

Substantial reduction in wood loading and disconnection of floodplain habitat precludes the elevated sediment supply from being effectively metered or well sorted within the bed (Keller et al., 1995, pp. P23-P26; Buffington and Montgomery, 1999b). Streambed scour likely is more frequent and extensive following episodic sediment pulses (Bratovich and Kelley, 1988, pp. 84 and 88-92; Montgomery et al., 1996), and in-channel and floodplain refuges are rare or non-existent throughout much of the channel network (Stillwater Sciences, 2008, see Figures A-23 and A-25; Stillwater Sciences, 2009, pp. 3-58 and 3-59). Biomass of vulnerable invertebrate prey species is reduced by elevated fine sediment deposition causing lower growth rates and resultant decreases in juvenile survival in all freshwater life stages (Suttle et al., 2004). Refuges from high flow and predation provided by clusters of un-embedded cobbles and boulders have been degraded by elevated sediment supply, reduction in large woody debris loading, and disconnection of floodplains.

Summary

The decline in salmonid populations is linked to loss of habitat upstream of large dams, and downstream of dams due to habitat simplification and floodplain disconnection, and also increases in sediment supply.

¹¹ The State Park Reach begins upstream where San Geronimo Creek joins Lagunitas Creek and continues downstream through SP Taylor State Park (see Figure 2.1). About 60 percent of the land area upstream of Lagunitas Creek at its confluence with Devils Gulch drains into reservoirs, which exert a significant influence on peak flow.

CHAPTER 3: SOURCE ANALYSIS

Key Points

- Total and fine sediment delivery to fish-bearing channels has increased by a factor of two-or-more as compared to natural background.
- Although sediment supply has been substantially increased, channels have incised. Therefore, by definition¹², watershed and channel disturbances have altered transport and storage process to an even greater degree than supply.
- Primary drivers for channel incision are a reduction in large woody debris loading, reduction in coarse sediment supply following construction of Kent Lake and Nicasio Reservoir, and other historical and ongoing land-use activities.
- The net results are much greater level of fine sedimentation and substantial simplification of channel habitat structure.

3.1 Introduction

The adverse impacts of fine sediment deposition and channel incision are described in detail in the problem statement and numeric targets chapters. To establish the sediment TMDL, we identify all significant sediment sources linked to these impacts, we estimate the approximate magnitude of each sediment source, and infer natural or anthropogenic causation, using a rapid sediment budget¹³ developed for the Lagunitas Creek watershed during the 1983 through 2008 period (Stillwater Sciences, 2010). We provide a summary of Stillwater Sciences' analysis and results in this chapter.

Reid and Dunne (1996) define a sediment budget as follows:

“A sediment budget is an accounting of the sources and disposition of sediment as it travels from its point of origin to its eventual exit from a drainage basin.” (p. 3)

The 1983-2008 sediment budget characterizes the response of Lagunitas Creek and its tributaries to: a) enlargement of Peters Dam in 1982¹⁴; b) major sediment supply events in water years 1982,

¹² In order for channel incision - the net lowering of the elevation of the streambed over time - to occur, sediment transport must exceed supply.

¹³ A rapid sediment budget can be performed over a short period of time using forensic analytical techniques to provide approximate estimates of the rates and sizes of sediment delivered to channels, channel sediment transport rates, changes in storage, and discharge to a downstream point of interest. Estimated rates are expected to be within a factor of two of actual values (Reid and Dunne, 1996, pp. 136-137).

¹⁴ The dam was raised by 14 meters in 1982, increasing its storage capacity by approximately 100 percent (from 16,000 to 32,000 ac-ft), and consequently decreasing the magnitude and frequency of downstream flows capable of transporting bedload material in the State Park Reach of the mainstem of Lagunitas Creek.

1983, and 2006; c) a prolonged drought (water years 1987 through 1991); and d) a state mandated sediment control and habitat enhancement program - Water Rights Order 95-17 – (State Board, 1995) that was established to protect fishery resources.

3.2 Historical Reference Model for Channel and Floodplain Habitat Conditions

To understand how anthropogenic disturbances may have altered sediment supply and transport processes, and what actions are needed to restore habitats, we developed a natural channel reference model (Buffington et al., 2009), based on review of research conducted in similar nearby watersheds and a wider body of research.

Prior to Euro-American settlement, we hypothesize that incised channels were uncommon in the Lagunitas Creek watershed. In channel reaches with wide valleys and riparian forests, like much of San Geronimo and Nicasio creeks, and the mainstem of Lagunitas Creek in the Lower Lagunitas Reach, it is likely that some channel reaches were naturally branching or anastomosing (Abbe and Montgomery, 2003; Makaske, 2001; Jerolmack and Mohrig, 2007), and that channels were well connected to adjacent floodplains.

Many of the larger tributaries to San Geronimo, Nicasio, and Lagunitas creeks (all of which traverse wide valleys over at least part of their lengths) likely were naturally disconnected, ending in alluvial fans or in flood basins without reaching the main channel as has been documented in other similar nearby watersheds prior to Euro-American settlement including Redwood Creek (Stillwater Sciences, 2004, pp. 21-22 and Figure 7), and Miller Creek (Figure 3.1). If our model is correct, then much of fine sediment and all of the coarse sediment delivered from naturally disconnected tributaries, would have been stored long-term in the fans and flood basins, and not have been supplied regularly and directly to the mainstem channels.

Large woody debris was the primary agent in shaping complex channel habitats (Abbe and Montgomery, 2003; Collins et al., 2012), and for the formation and maintenance of the branching channel morphology because debris jams would form frequently under natural conditions and block channels, facilitating rapid upstream deposition, overtopping of channel banks, and redirection of flow to form a new channel (channel avulsion) (Harwood and Brown, 1993, Collins and Montgomery, 2002; Sear et al., 2010) (Figure 3.2).

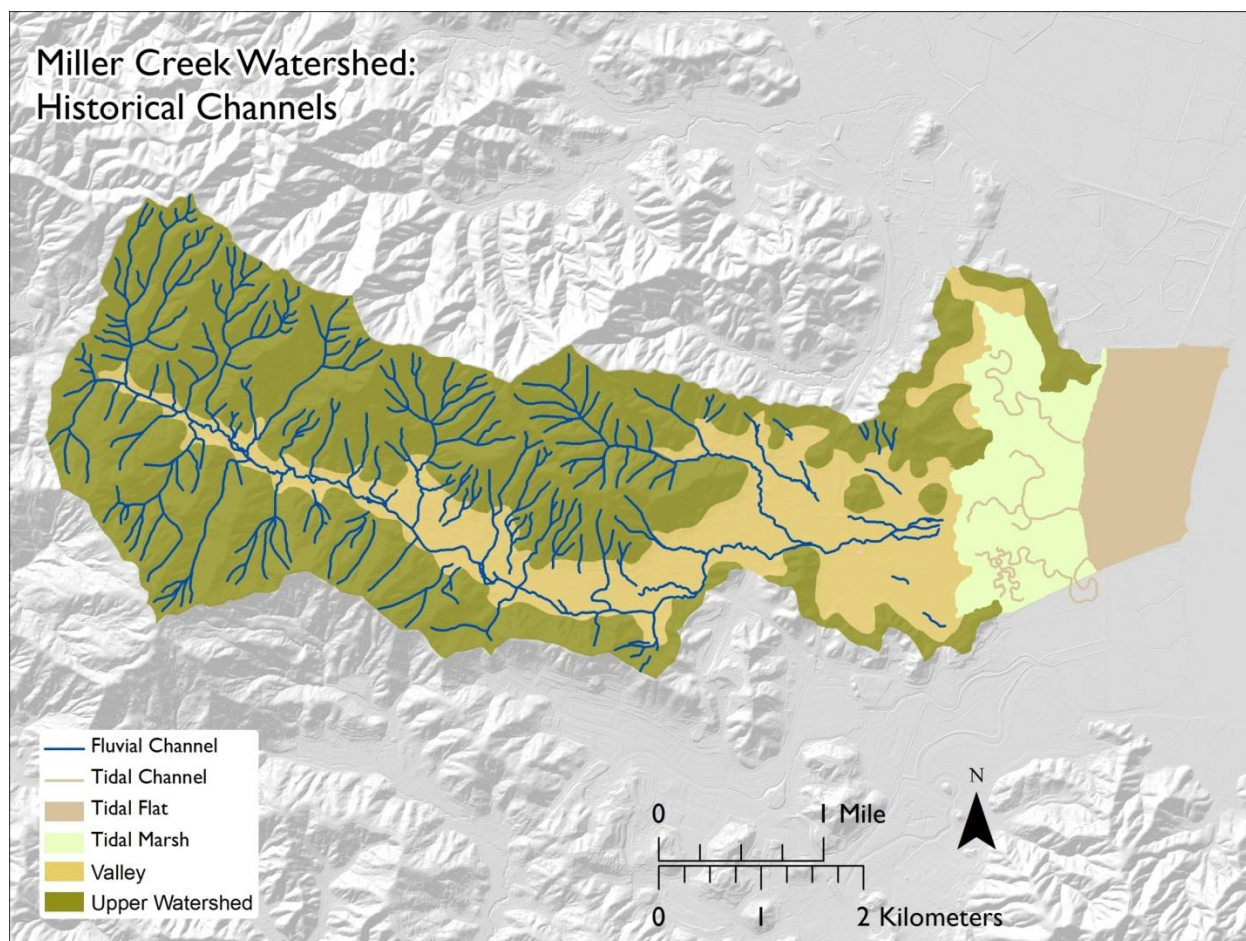


Figure 3.1: Inferred historical channel network for Miller Creek watershed, Marin County, California (San Francisco Estuary Institute, 2008). Prior to Euro-American settlement, many of the Miller Creek tributaries, especially where the valley floor is wide (see center of the figure) were naturally disconnected, ending in alluvial fans. Also, some reaches of Miller Creek appear to have been multi-threaded. Nicasio and San Geronimo creeks, also traverse wide valley floor reaches, their watersheds are similar in size to Miller, and they also are underlain primarily by the *mélange* unit of the Franciscan Assemblage. Therefore, we would expect under natural reference conditions, they also had naturally disconnected tributaries and multi-threaded channel reaches.

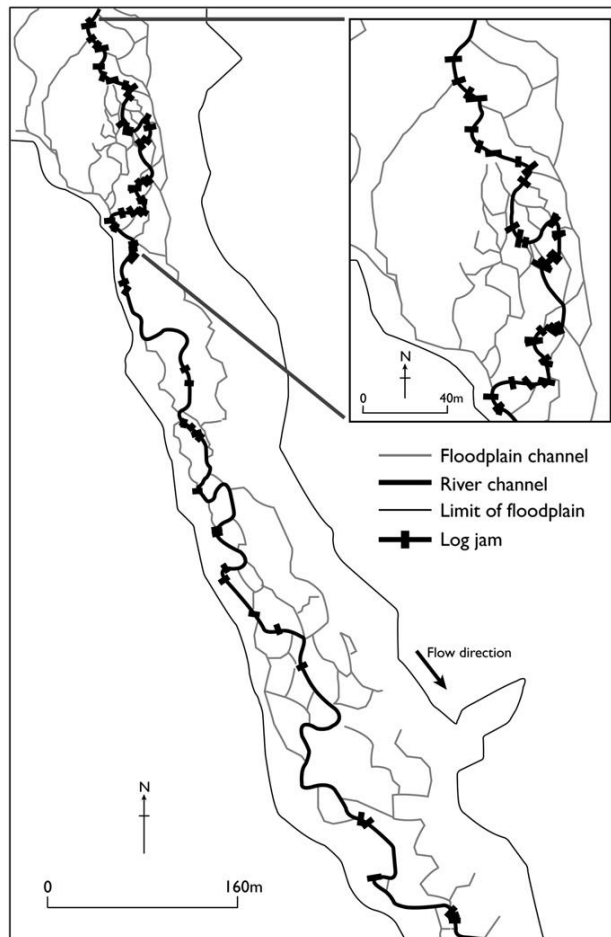


Figure 3.2 Relationships between log jams and channel avulsion (e.g., a rapid change in the location of the main channel that occurs during high flow, typically when the former main channel is blocked or filled in by sediment and/or debris). An example of this relationship is illustrated above for a channel reach in a 25 km² watershed in England. In many cases, the heads of newly formed floodplain channels occur where debris jams have formed. Source: Sear et al. (2010).

We suggest that incised channels in the Lagunitas Creek watershed result from historical and/or ongoing anthropogenic disturbances because:

- The San Geronimo Valley, Nicasio Valley, and the Lower Lagunitas Reach of Lagunitas Creek appear to be in natural aggradational or depositional settings. As has been documented in nearby Walker Creek (Haible, 1980) and Redwood Creek (Stillwater Sciences, 2004), it is plausible that the San Geronimo, Nicasio, and Lower Lagunitas valleys began to be deposited in the Holocene and that aggradation was continuous until the mid-nineteenth century. In the Central California Coast Range, the late Pleistocene and early Holocene, from approximately 9,000-to-15,000 years ago, was marked by a period of intensive debris flow activity in the San Francisco Bay Area that likely caused a significant increase in channel sediment supply, which also would facilitate aggradation,

not incision (Reneau et al., 1990). Also, lower Lagunitas Creek is located close to sea-level. Therefore, it is plausible that valley deposition here is related at least in part by a greater than 50 meter rise in sea-level (Atwater, 1977) that occurred in the San Francisco Bay Area following the end of the last ice age approximately 10,000 years ago.

- In confined channel reaches, as compared to the broad valleys described immediately above, sediment storage in the channels and valleys would be much lower, however, large woody debris loading and the size of the largest pieces of debris in the channels would have been much greater than at present resulting in closely spaced and persistent debris jams (Keller et al., 1995; Abbe and Montgomery, 2003), and a much higher frequency of pools and bars, greater diversity of substrate patch types, and channel filling in the backwaters of debris jams (Figure 3.3). In these confined valleys, incised channel reaches would only occur immediately downstream of debris jam formed steps.
- In San Geronimo Valley, it is plausible that intensive historical grazing and logging of old-growth redwoods resulted in significant storm runoff increases which could have provided a mechanism for channel incision. Other plausible drivers for incision that may have accompanied Euro-American settlement include ditching and draining of the valley floor to connect naturally disconnected tributaries, relocation of some channel reaches, and salvage/snagging of large woody debris.
- In Devils Gulch, incision may have resulted from, one or more of the following disturbances: logging of old-growth redwoods (increasing storm runoff); removal of large woody debris for salvage (lowering local base-level); and/or construction of the mill dam in 1856 on Lagunitas Creek a short distance upstream from its confluence with Devils Gulch (which could have caused the bed elevation on Lagunitas Creek to be lowered, and for this adjustment to propagate upstream along Devils Gulch) (see Section 3.3 for details).

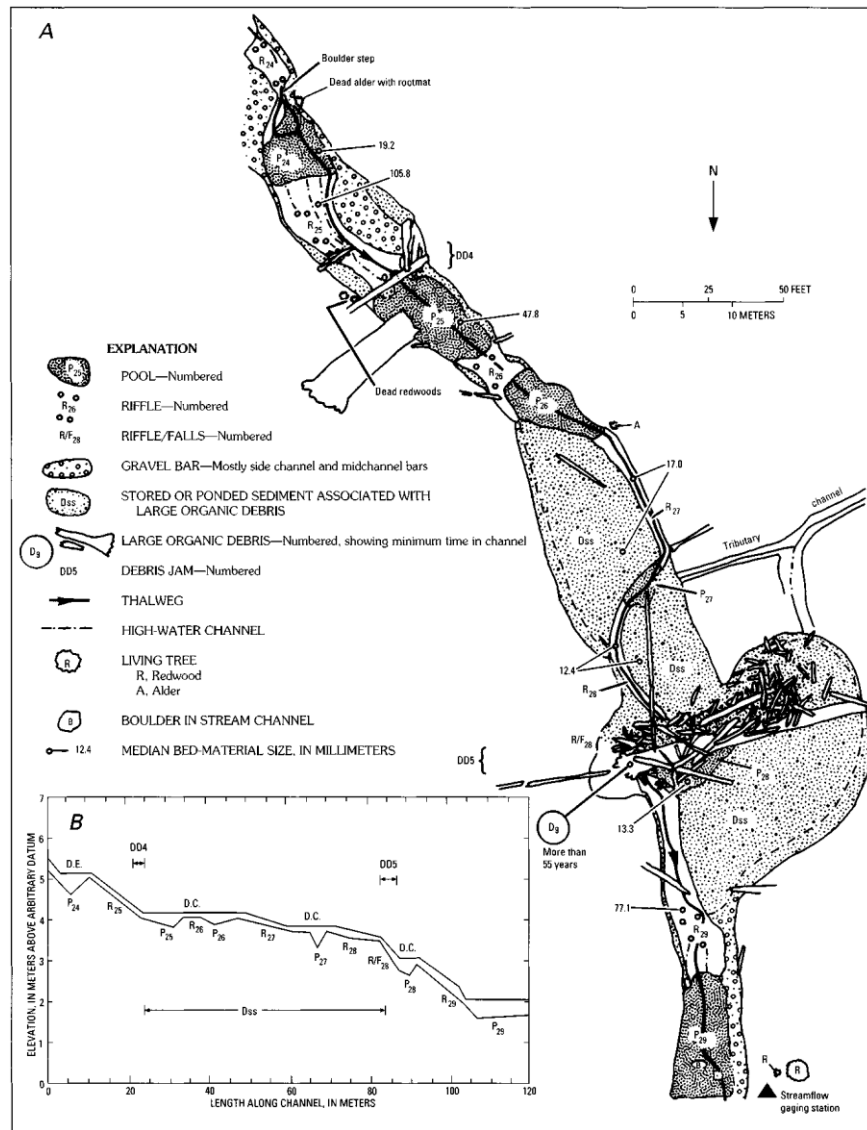


Figure 3.3: Planform in Lower Little Lost Man Creek, Redwood National Park (drainage area = 9.1 km²). Note: very high frequency of step-pool and pool-bar units formed by wood, and the heterogeneity in channel width, depth, and cover, and substantial alluvial storage. (Source: Keller et al., 1995, Figure 9)

- In the State Park Reach of Lagunitas Creek, removal of large woody debris jams (e.g., to reduce potential threats to bridges, roads, and rail lines, to salvage merchantable timber, to address perceived fish passage problems, etc.), logging related changes in runoff, response to dam removal (incision through mill pond deposits), and historical gravel mining in the Tocaloma Reach (causing a knick point to migrate upstream), could all have facilitated incision.

- In the Lower Lagunitas Reach, downstream of the confluence between Nicasio and Lagunitas creeks, a suite of disturbances could have triggered incision including: ditching and draining of the valley floor (which may have occurred to facilitate agricultural development); operation of a mill pond dam further upstream on; gravel mining, which was extensive in the late 1950s¹⁵; and/or construction of Nicasio Reservoir in 1959, which under natural conditions was the primary supply of coarse sediment to this reach. We think some combination of these disturbances caused or contributed to historical incision of this reach.
- In other nearby watersheds with a similar history of land use, we find channel incision also occurred during the historical period likely as a result of human disturbances¹⁶. Anastomosing channels, naturally disconnected tributaries, and floodplains wetlands were formerly common in all of these watersheds prior to disturbance. In general, these same typical natural channel forms, and incision and simplification resulting from land use disturbances (including removal of large woody debris), also have been documented in the Pacific Northwest (Collins and Montgomery, 2002), and Europe (Harwood and Brown, 1993).

In confined channels (e.g., Devils Gulch, narrow parts of San Geronimo Valley, and Lagunitas Creek in the State Park Reach), prior to Euro-American settlement, channels were more complex. Typically, they were not deeply incised and instead well-connected to floodplains. Pool frequency was higher and pools were more complex and deeper (Buffington and Montgomery, 1999b; Buffington et al., 2002). Also, there was much more alluvial storage (Keller et al., 1995; Figures 3.3). Much of the loss in complexity, and channel incision, likely result from anthropogenic disturbances that have reduced large woody debris loading including the following:

- Logging of old-growth and replacement by second-growth can substantially reduce woody debris recruitment and the size of the largest debris pieces delivered to channels (e.g., see, Lisle, 2002, Figures 2 and 3);
- Historical snagging/salvaging has reduced the amount of wood retained in channels;
- Deposition of large woody debris in Kent Lake has reduced downstream recruitment;
- As a result of incision, some fallen trees now remain perched above bankfull channel;

¹⁵ As evidenced by extensive open canopy and unvegetated floodplain areas where pits and mounds are discernible on late 1950s aerial photos.

¹⁶ Local streams where historical incision in response to land-use disturbances has been well documented include Walker Creek (Haible, 1980); Redwood Creek in Marin County (Stillwater Sciences, 2004); and Novato Creek (Collins, 1998).

- Through the 1990s in many local streams, debris jams often were removed or modified soon after formation because of (often incorrectly) perceived fish passage problems; and
- Bank hardening, primarily in San Geronimo Valley, has reduced rates of woody debris recruitment that otherwise would result from bank erosion and tree-fall;

3.3 Land Use History and Relation to Erosion and Sedimentation Rates

To provide context for evaluating the influences of land-use on erosion and sedimentation, we present a summary developed by Stillwater Sciences (2010) (p.10-14) including a land-use history presented in Table 3.1. Stillwater Sciences' main points and conclusions were:

- Natural processes (e.g., tectonic uplift and climatic events) and land-use activities are fundamental controls on erosion and sedimentation processes. The full adjustment of landforms to changes in the character of these controls takes many decades to several centuries or more to be completed.
- Following Euro-American settlement in 1850 and continuing until construction of Kent Lake in 1954, sediment delivery to Lagunitas Creek increased substantially, evidenced by the rapid expansion of the Lagunitas Creek delta in Tomales Bay (Niemi and Hall, 1996). Similar post-settlement increases in sediment delivery are documented in cores for Bolinas Lagoon (Bergquist, 1977, as cited in Niemi and Hall, 1996), and Big Lagoon (Meyer, 2003, as cited in Stillwater Sciences, 2004; and Wells, 1994, as cited in Stillwater Sciences, 2004).
- From the early 1960s through the early 1980s, following construction of Kent Lake and Nicasio Reservoir¹⁷, there was a significant reduction in sedimentation rate in the Lagunitas Creek delta (Niemi and Hall, 1996; and Rooney and Smith, 1999). In this same period, other changes also contributed to lower sediment supply including reduction in grazing, cessation of logging and gravel mining, and stricter land use regulations.
- Following a very large sediment pulse associated with the flood of record in January 1982, a doubling of storage capacity in Kent Lake that same year (with significant further reduction in downstream runoff and sediment transport capacity), and a more recent large sediment pulse in December 2005, discerning the combined effects of development on streambed conditions has become more complicated. Since 1982, or perhaps as early as the 1960s, there appears to have been a shift from a dominance of hillslope sediment sources to channel sources, as a result of renewed channel incision and associated bank erosion.

¹⁷ Collectively these two reservoirs trap all of the sediment and much of the runoff generated from approximately two-thirds of the total watershed area upstream of Olema Creek confluence.

Based on our own review of available information, we also add the following additional details:

- a) The paper mill described in Table 3.1 was constructed in 1856. To power it, a year-round dam was built on Lagunitas Creek, a short distance upstream of Devils Gulch (Figure 3.4).¹⁸ This dam likely prevented migration of anadromous fish (including coho salmon and other species) and degraded channel form and substrate conditions in Lagunitas Creek for several decades or more.
- b) In the 1930s, grazing replaced crops as the dominant agricultural practice. An extended drought, perhaps was a motivation for this change, as rainfall was below normal from 1926 through 1937 (MMWD, 2011, unpublished data). The drought ended with a very large storm in December 1937, and several very wet years followed. Considering the prevalence of clay-rich soils on slopes adjacent to San Geronimo Valley and the Tocaloma reach, under moderate-to-high stocking rates these areas would be vulnerable to significant soil compaction and reduction in ground cover, which would cause resultant decreases in soil permeability and infiltration capacity. Under such a scenario, overland flow would be widespread during storms leading to significant surface erosion from sheetwash, rilling, and gullies. Therefore, it is plausible that intensive grazing during the 1930s (or earlier) also may have contributed to an episode of channel incision in San Geronimo Creek as a consequence of storm runoff increases related to soil compaction and reduced ground cover.

¹⁸ Based on the size of timbers in the dam face, it appears to have been ≥ 10 -feet at its crest. Prior to fish ladder construction in 1886, it's likely that upstream migration by coho salmon, and Chinook salmon (if present), was precluded entirely. We do not know if the dam had a gate. If not, it would have trapped all bedload and much of the suspended load supplied from about 25% of the watershed with the potential to cause substantial degradation of channel form and substrate conditions, both upstream and downstream.

Table 3.1 Land-Use History for the Lagunitas Creek watershed

(Source: Stillwater Sciences, 2010, Table 2-1, p.11)

Period	Time period	Watershed activity/disturbance
European arrival and resource development	1850–1918	Establishment of San Geronimo, Lagunitas, Forest Knolls, and Woodacre. Establishment of farms (wheat, oats, barley, and potatoes), ranches (cattle and sheep), and infrastructure (permanent buildings, roads) [1860–1888]. Channelization, construction of levees, extraction of in-channel sediment, and diking of marshes at mouth of Lagunitas Creek for agricultural and development purposes. Establishment of paper mill on Lagunitas Creek initiates intensive logging (1865), North Pacific Railroad track built along Lagunitas (1873–1874), Sir Francis Drake road built (1892). Major fires in watershed (1878 and 1904). First water supply dam constructed (Lagunitas Reservoir 1872: 350AF).
Regulation and grazing	1919–1945	Start of flow impoundment of Lagunitas Creek. Impoundment of Alpine Lake (Alpine Dam 1918: enlarged 1924, 1941: 8,891AF). Change in dominant agriculture practice from crop farming to livestock (1930s). Continued logging in the watershed. Major fire in watershed (1945).
Intensive damming	1946–1982	Increase in population and development directly following World War II (post-1945). Intensive damming of Lagunitas Creek for water supply purposes. Impoundment of Bon Tempe Reservoir (1948: 4,017AF), Kent Lake (Peters Dam 1954, enlarged 1982: 32,895AF) and Nicasio Reservoir (Seeger Dam 1961: 22,430 AF). Continued extraction of natural resources. Mining of mercury ore in open pit mines (1940–1970) and removal of in-channel sand and gravel from stream bed at confluence of Lagunitas and Nicasio Creek (through 1961). End of logging in watershed (1960).
Raising of Peters Dam, planning & mitigation	1983–present	Increasing significance of San Geronimo Community Plan (from 1978). Increased impoundment of water/sediment within the watershed. Peters Dam (Kent Lake) raised 45 ft (completed 1982). Large storm in WY 1982 suspected to have reset channel conditions

Sources: Niemi and Hall 1996, Tomales Bay Watershed Stewardship Council 2003, SFBRWQCB 2002, and MMWD 2007



Figure 3.4: View of Samuel P. Taylor’s dam built in 1856 to power his first paper mill at Taylorville, Marin County, California circa 1889. Photo is provided courtesy of Anne T. Kent California Room, Marin County Free Library. This dam was located on Lagunitas Creek near Devils Gulch. Prior to fish ladder construction in 1886, upstream migration by coho salmon appears to have been completely blocked.

3.4 Source Analysis Summary

Stillwater Sciences (2010, pp. 13-30) reviewed previous sediment source inventories and a channel cross-section monitoring program conducted in the Lagunitas Creek watershed, interpreted time-sequential aerial photographs, conducted extensive field surveys, and modeled road surface erosion to estimate sediment delivery rates to channels and changes in channel sediment storage in the Lagunitas Creek watershed. Considering geology, topography, and land use/cover, they divided the watershed into landscape units inferred to be similar with regard to the types and rates of erosion and sediment delivery processes. This approach provided the basis for extrapolating process rates from areas surveyed in the field to the rest of the watershed. Six significant sediment delivery sources were identified:

- Gully and rill erosion
- Shallow landslides
- Deep-seated landslides
- Tributary channel incision and related bank erosion
- Mainstem channel incision¹⁹
- Road-related erosion processes

¹⁹ Bank erosion along Lagunitas Creek is not a significant sediment source.

The accuracy of estimated rates of sediment delivery to channels was evaluated by comparison to sediment production rates estimated for other nearby watersheds, channel sediment yield estimates for stations in the Lagunitas Creek watershed, and estuary sedimentation rates for Tomales Bay and other nearby watersheds. Subsequent to completion of Stillwater Sciences sediment budget, based on review of additional information, we doubled their estimated sediment delivery rates to channels from road-related erosion; based on the reasoning and approach described immediately below.

3.5 Revised Road Sediment Delivery Rates

Stillwater Sciences applied SEDMODL2, a GIS-based road erosion model to estimate total sediment delivery to channels. However, SEDMODL2 only estimates sediment delivery from surface-erosion processes acting on the road tread and adjacent unvegetated and/or disturbed areas. Stream-crossing erosion (e.g., caused when crossing overflows, where energy is not properly dissipated at an outfall; and/or when a crossing is diverted a forms a gully and/or triggers a landslide, etc.) is an important additional source not accounted for by this model. Similarly, road-related landslides (e.g., fill failures, side-cast, and/or where road drainage is diverted and/or concentrated onto an unstable slope) can be another important source. An additional challenge in applying SEDMODL2 to the Lagunitas Creek watershed is that it is an empirical model developed from measurements made on unpaved logging roads in the Pacific Northwest. In contrast on unpaved roads in the Lagunitas Creek watershed, car and light-truck traffic is the norm, roads are primarily recreational, ranch, residential, and/or for emergency access, and there is much greater inter-annual variation in precipitation, adding additional uncertainty to estimated sediment delivery to channels that is associated with surface-erosion processes acting on the road tread, cutbank, and/or inboard ditch.

In addition to Stillwater Sciences estimate of road-related sediment delivery, other information is available to estimate sediment delivery from road-related erosion. Field inventories to estimate future potential sediment delivery from road-related erosion have been completed on about half of the length of unpaved roads in the project area (39 miles) (Pacific Watershed Associates, 2007a, 2007b, and 2010). These inventories include field measurement of recent erosion and sediment delivery in/around stream crossings, and sediment delivery to channels from road-related landslides. Adding field-measured rates of stream crossing and landslide sediment delivery, it appears that Stillwater Sciences estimate of sediment delivery to channels from road-related erosion should be increased by about 50 percent (Napolitano, 2012c).

Pacific Watershed Associates (PWA) also estimated sediment delivery from road surface-erosion processes by application of a uniform denudation rate (0.02 feet per year) to a 25-foot wide road-tread and cutbank contributing area²⁰ on road-segments drained by an inboard ditch

²⁰ However, no information is provided in PWA (2007a, 2007b, and 2010) to support and/or describe how the average denudation rate (0.02 feet per year) and/or area (25-foot wide strip) of sediment production and delivery was determined. Some of the thinking underlying their method for estimating future sediment delivery from surface erosion processes is described in Weaver et al, 2006, pp. 34-35. Although, no references are cited to support the average denudation rate employed, they do state that the estimate is only accurate within an order-of-magnitude.

(and hence directly connected to, and inferred to be delivering 100 percent of the eroded sediment to stream channels). PWA's estimate of sediment delivery to channels from surface-erosion processes is about two-times the amount estimated by Stillwater Sciences (Napolitano 2012c). Splitting the difference between these two estimates of sediment delivery from road surface erosion, and then adding sediment delivery from stream crossing and road-related landslide erosion (that is not quantified by SEDMODL2), our revised estimate of total sediment delivery to channels from road-related erosion processes is 200 percent of the value calculated by Stillwater Sciences (2010)²¹ (see Napolitano 2012c).

3.6 Source Analysis Results

Table 3-2 presents sediment supply, by source category, to Lagunitas Creek near Point Reyes Station.

Table 3.2: Average annual sediment supply to Lagunitas Creek near Point Reyes Station in water years 1983 through 2008 (drainage area = 213 km²)

<i>Sediment delivery to channels:</i>	<i>(metric tons/year)</i>	<i>% of total sediment discharge</i>
Landslides, gullies, and soil creep	5,600	25
Road-related erosion	4,000	18
Subtotal =	9,600	43
<i>Changes in channel sediment storage:</i>	<i>(metric tons/year)</i>	<i>% of total sediment discharge</i>
Tributary incision	8,500	38
Mainstem incision	5,300	24
Mainstem aggradation (in Tocaloma)	-1,300	-6
Subtotal =	12,500	57
Total =	22,100	100

Notes: (1) Mainstem channel aggradation in the Tocaloma reach is a negative discharge because sediment is going into long-term storage there. (2) The combined source category of landslides, gullies, and soil creep includes deep-seated landslides, shallow landslides, and gullies, each of which is estimated to contribute about 1/3 of the amount in this source category (note: soil creep is minor, about 300 metric tons/yr). (3) All channel incision and road-surface erosion is inferred as anthropogenic. (4) Gully and landslide erosion is in part natural, and in part anthropogenic.

For the entire watershed, including upstream of reservoirs, the above sediment discharge rate (22,100 metric tons per year) translates into an average annual sediment discharge per unit watershed area (213.2 km²) of approximately **110 metric tons per km² per year** for water years 1983 through 2008.

²¹ Although this is a significant change to the estimate of road-related sediment delivery, because roads are not the largest sediment source in the watershed, our overall estimate of total sediment delivery to channels (from all sources) is not significantly different than the amount calculated by Stillwater Sciences.

Kent Lake and Nicasio Reservoir trap nearly all sediment delivered from upstream areas. However, in two major spawning tributaries, San Geronimo and Devils Gulch, the effect of reservoirs on sediment supply to channels is nil. Therefore, it is also useful to examine how sediment supply varies between unregulated tributaries (e.g., those that are not dammed), and along the mainstem based on distance from major tributary sources (e.g., San Geronimo Creek), dams, and distance from the reach undergoing aggradation. We do this in Table 3-3.

Table 3.3: Variability in average annual sediment supply to channels in the Lagunitas Creek watershed (water years 1983 through 2008)

<i>Sub-watershed</i>	<i>Drainage Area (km²)</i>	<i>Percent Impounded (%)</i>	<i>Road Erosion (t/km²/yr.)</i>	<i>Hillslope Processes (t/km²/yr.)</i>	<i>Channel Processes (t/km²/yr.)</i>	<i>Total supply (t/km²/yr.)</i>
San Geronimo	24	0	130	80	240	450
Devils Gulch	7	0	20	80	180	280
Cheda	3	0	4	120	190	310
Lagunitas at SP Taylor	89	63	40	30	90	160
Lagunitas near Point Reyes	212	70	20	30	60	110

Notes: (1) Dams trap more than half of the sediment delivered to channels. (2) Recent and/or active incision is documented in: a) alluvial reaches of San Geronimo Creek, Devils Gulch, and tributaries thereof; b) the mainstem of Lagunitas Creek in the State Park Reach, and in the Tocaloma Reach downstream of the confluence of Lagunitas with Nicasio Creek. (3) Although fine and total sediment supply are substantially elevated in tributaries that are not dammed (see discussion below), coarse sediment supply to Lagunitas Creek has been reduced substantially as compared to the historical period (1850-1960).

3.7 Accuracy of Estimated Sediment Supply Rates

Stillwater Sciences (2010, pp. 46-59) developed and/or reviewed two independent sources of data to assess the accuracy of the total sediment supply rates presented in Tables 3-2 and 3-3:

- a) Channel sediment yield estimates were derived for three locations that have long-term streamflow records and where sediment transport rates have been sampled on a limited basis. This approach involved development of a flow duration curve (e.g., frequency of occurrence of a flow of a give magnitude during the period of the sediment budget), and a streamflow versus sediment transport rating curve (derived from synchronous instantaneous measurements of streamflow discharge and suspended- and/or bed-load transport rate, and statistical procedures to develop a best-fit curve).
- b) Bathymetric surveys conducted in Nicasio Reservoir, over part of the reservoir for the 1961-through-2008 period, and the entire reservoir for the 1961-through-1976 period that can be used to estimate sedimentation rate. Volumetric estimates of sedimentation inferred from elevation changes along surveyed cross-sections were then multiplied by an assumed average bulk density of 1.6 metric tons per m³ to infer sedimentation rate in terms of mass. Considering storage capacity of Nicasio reservoir as compared to average annual inflow, it appears reasonable to conclude that trap efficiency is 95 percent $\pm$ 5 (Brune, 1953). Therefore, the estimated reservoir sedimentation rate is approximately equal to the watershed sediment supply rate (e.g., only a small fraction of sediment supplied to the reservoir is discharged from the dam).

We present and compare estimated channel sediment yields and reservoir sedimentation rates to estimated sediment supply rates in Table 3-4 below.

Table 3.4: Comparison of sediment supply estimates to channel sediment yields and/or reservoir sedimentation rates

<i>Location</i>	<i>Sediment Supply to Channels** (t/km²/yr.)</i>	<i>Channel Sediment Yield (t/km²/yr.)</i>	<i>Reservoir Sedimentation Rate (t/km²/yr.)</i>	<i>Yield (approximate % of Supply)</i>
San Geronimo Creek	450	230	...	50
Lagunitas Creek at SP Taylor	160	50	...	33
Nicasio Creek	330	...	350*	100
Lagunitas Creek at Point Reyes Station	110	80	...	75

Notes: *Reservoir sedimentation rate is for the 1961-2008 period; all other rates above are for water years 1983 through 2008. Estimates of sediment supply to channels were developed based on field surveys and analysis of time-sequential aerial photographs to identify erosion sites and calculate the mass of sediment delivery delivered through time. **Totals listed above are slightly higher than reported by Stillwater Sciences because we have doubled their estimated sediment delivery from road-related erosion.

For three of four channel locations where available data allows such comparisons, estimates are within a factor-of-two. At the Lagunitas Creek at SP Taylor site, the estimates are within about a factor-of-three. However, by using the rating curve approach to calculate channel sediment yield, it is likely that the yield estimates are lower than actual values (Ferguson, 1986, 1987). This fact and comparison to Nicasio Reservoir sedimentation suggest that sediment supply estimates derived from field surveys and interpretation of aerial photographs likely are within a factor-of-two or closer to actual sediment supply values.

3.8 Comparison to Natural Background

Through review and interpretation of geomorphic research conducted in other nearby similar watersheds, Stillwater Sciences' evaluated how sediment supply rates to channels estimated for water years 1983 through 2008 in the Lagunitas Creek watershed may compare to long-term natural background rates averaged over thousands of years (Table 3.5). This research includes:

- a) Estimated long-term rates of soil production on hillslopes in nearby Tennessee Valley (Heimsath et al., 1997; Heimsath et al., 1999; O'Farrell et al., 2007). Scientists engaged in this research, hypothesize that over the long-term soil production rates equal sediment delivery rates to channels, such that erosion and soil production are in an approximate balance.

- b) A detailed sediment budget prepared for Lone Tree Creek watershed located near Stinson Beach (Lehre, 1982). This study involved intensive measurement of process rates over a three-year study period, and extrapolation from the study period to estimate long-term rates based on inferences regarding the amount of time necessary for slide scars to heal.
- c) Long-term sedimentation records, covering thousands of years, for Bolinas Lagoon (Bergquist, 1977, as cited in Stillwater Sciences, 2004) and Big Lagoon in western Marin County (Meyer, 2003; and Wells, 1994; both as cited in Stillwater Sciences, 2004). Carbon fragments in the lagoon sedimentation cores can be used to date individual layers, and then extrapolate variation in deposition rate within the period represented by the core.

Table 3.5: Evaluating Natural Background Sediment Supply

<i>Data Source</i>	<i>Rate and Timeframe</i>	<i>Rate and Timeframe</i>	<i>Comments</i>
Big Lagoon Sedimentation	1 mm/yr. (1500 BC to 1850 AD)	11 mm/yr. (1850-1990s AD)	Factor of ten increase in sediment yield
Bolinas Lagoon	13-to-19 mm/yr. (1850 to 1900 AD)	3-to-4 mm/yr. (early twentieth century)	Watershed was clear-cut between 1849 and 1858; forest re-established by early 20 th century.
<i>Data Source</i>	<i>Soil Production Rate</i>	<i>Sediment Delivery Rate</i>	<i>Comments</i>
Redwood Creek Sediment Budget	169 t/km ² /yr. (natural background)	34-to-111 t/km ² /yr. (natural background)	Many headwater tributaries were naturally disconnected from main channels, such that sediment delivery rate to channels was much below the soil production rate; floodplain deposition also was significant in unconfined alluvial reaches. Incised channels were uncommon.
Lone Tree Creek Sediment Budget	≤60 t/km ² /yr.* (natural background)	214 t/km ² /yr. (1950s-1970s)	*Measured soil creep rates are four-to-eight times lower than rates of sediment removal by landslide erosion suggesting landslide rates have accelerated during the historical period.

Based on review of the data present in Table 3.5 above as compared to estimated current rates of sediment supply to channels presented in Table 3.3, Stillwater Sciences inferred that current rates of sediment supply to channels are two-to-ten times greater than inferred natural background rates, with the disparity being greatest in tributaries that have not been dammed.

The other inferred change is that the current sediment supply to Lagunitas Creek is richer in sand and finer grain sizes as a result of: a) construction of Kent Lake (upper Lagunitas Creek is underlain by harder bedrock than found in the San Geronimo Creek, and hence is richer in coarse sediment that does not break down as rapidly in transport); and b) addition of anthropogenic sources richer in fines (road-related erosion, construction activities, and grazing).

3.9 Sediment Supply from Urban Stormwater Runoff

Urban stormwater runoff also is a minor point source that Stillwater Sciences did not evaluate. In estimating sediment supply from urban stormwater runoff, we considered inputs from construction activities and road maintenance activities. In estimating sediment supply from construction activities, we have assumed a typical sediment delivery ratio of 33 percent (e.g., 33 percent of the eroded sediment is actually delivered to a stream channel). Using best professional judgment, we assume, ground disturbance associated with construction is ≤ 10 acres per year and average soil erosion rate is 10 metric tons per acre with Best Management Practices in place. Using these values, we calculate that average annual sediment supply to Lagunitas Creek from municipal stormwater and construction activities is approximately 30 metric tons per year. Sediment supply from the remaining urban stormwater runoff dischargers is estimated based on applicable factors such as rainfall, runoff coefficients, suspended sediment concentrations, and the acreage in different land uses (i.e. commercial, residential, and roadways). Table 7b presents the estimated sediment supply from urban stormwater sources.

Table 3.6: Urban Stormwater Sediment Load to Lagunitas Creek

Category	Assumptions/Data	Estimated Mean Annual Delivery Rate (metric tons/yr) ^a
Construction Stormwater	Ground disturbance: ≤ 10 acres Sediment delivery rate: 33% Average soil erosion rate: 10 metric tons/acre	30
Municipal Stormwater	Acreage of urban land use: 2150.3 acres ^b Runoff coefficient: 0.35 (typical urban coefficient is 0.35 (BASMAA, 1996)) Average rainfall: 40 inches/yr. TSS concentration: 100 mg/L ^c Sediment delivery rate: 50% ^d	70
a. Rounded to nearest hundred. b. Source: Stillwater Sciences (2009). c. WEF Manual of Practice No. 23/ASCE Manual No. 87, assumes median urban site (WEF and ASCE 1998) d. Assumes two-thirds of sediment is retained on land or removed via culverts, detention basins, etc.		

3.10 Summary

Based on the results of the sediment budget and literature review, we conclude the following:

- a) Prior to Euro-American settlement, most channels were not incised, and the channels that traverse broad valley reaches were branching in some reaches. Nearly all channels were well connected to adjacent floodplains that were covered by extensive wetlands. Channels are incised (or are actively incising), as a result of management actions that reduced large woody debris loading, increased shear stress on the channel bed, and/or as a result of the construction of large reservoirs that have reduced coarse bed material (gravel) supply.
- b) Although total sediment supply to Lagunitas Creek and its tributaries is elevated by a factor-of-two-or-more above the natural background rate, Lagunitas Creek and its tributaries incised during the historical period, and/or are still actively incising (primarily in headwater channels). In order for incision to occur, by definition channel sediment transport must exceed supply. This implies that disturbances influencing channel sediment transport capacity are even greater in magnitude than the disturbances influencing sediment supply. This “imbalance” is important to be aware of when considering actions to control adverse changes to the sediment budget.
- c) As a result of the construction of Peter’s Dam, coarse sediment supply in the State Park Reach of Lagunitas Creek is now much lower than it was during the 1850-to-1960 period. As a result, San Geronimo Creek now provides most of the coarse and fine sediment supplied to Lagunitas Creek in the State Park Reach. Therefore, actions to control fine and/or coarse sediment supply from San Geronimo Creek, not only have the potential to affect San Geronimo Creek, but also Lagunitas Creek in the State Park Reach.
- d) The above described conditions create challenges which have to be carefully considered in trying to develop an implementation plan to control adverse changes to the sediment budget for the Lagunitas Creek watershed. Looking at the problem another way though, some real opportunities become apparent like the value of floodplain restoration and large woody debris engineering as center pieces in a program to re-establish more favorable substrate conditions, and also to create a suite of more complex and interconnected habitats.

CHAPTER 4: WATER QUALITY OBJECTIVES AND NUMERIC TARGETS FOR SEDIMENT AND HABITAT CONDITIONS

Key Points

- Water quality objectives for settleable material (sedimentation), and population and community ecology (habitat complexity and connectivity) are not being met.
- Rates of fine sediment supply and streambed mobility are too high. Channels are incised, simplified, and disconnected from floodplains.
- To evaluate attainment of the water quality objective for settleable material, we define measurable targets for bed mobility and redd scour.
- To evaluate attainment of water quality objective for population and community ecology, we define measurable targets for large woody debris (LWD) and propose technical studies to guide actions to restore channel-floodplain connection.
- Although LWD and floodplains are not indicators of substrate quality, in addition to reductions in sediment discharge, both of these features need to be restored in order to attain the numeric targets for settleable material.
- The proposed targets are consistent with water quality objective and antidegradation policies.

4.1 Introduction

The water quality objectives for settleable material and population and community ecology contained in the Basin Plan are expressed as narrative statements:

- **Settleable material**

“Waters shall not contain substances in concentrations that result in the deposition of material that cause nuisance or adversely affect beneficial uses.”

- **Population and Community Ecology**

“All waters shall be maintained free of toxic substances in concentrations that are lethal to or that produce significant alterations in population or community ecology or receiving water biota. In addition, the health and life history characteristics of aquatic organisms in waters affected by controllable water quality factors shall not differ significantly from those for the same waters in areas unaffected by controllable water quality factors.”

To evaluate attainment of these water quality objectives, the Water Board is required to translate the above listed narrative statements into measureable criteria, or numeric targets for sediment and habitat conditions. Also, as described in Chapter 2 (Problem Statement), beneficial uses that are threatened by sediment impairment include cold freshwater habitat, preservation of rare and endangered species, and fish spawning. Therefore, we developed targets to link sediment to properly functioning habitat conditions for listed populations of coho salmon and steelhead, and for the entire native fish and wildlife assemblage. We defined target values for three parameters that are responsive to and/or influence sediment supply and transport, and also are related to the ecological requirements of coho salmon, steelhead, and other native species. These parameters are: 1) streambed mobility; 2) redd scour; 3) large woody debris loading. Also, we call for technical studies to guide projects to restore channel-floodplain connection. These in-channel targets and proposed studies to restore floodplain functions are described in detail in the sections that follow.

4.2 Streambed Mobility

Sediment Target

Tau-star (τ^*) is a dimensionless index of the relative amount of streambed mobility. The numeric target for the reach-average value of streambed mobility at bankfull stage, represented by the Shields Stress or “Tau-Star” (τ^*), is $0.03 < \tau^* \leq 0.06$, which corresponds to a partially to fully mobile streambed at bankfull stage. This is the natural range of variation in streambed mobility as characterized by the Shields Stress in most gravel-bedded channels, where the imposed shear stress at bankfull stage is only slightly greater than the amount required to mobilize streambed particles (Andrews, 1983). The target applies to gravel-bedded channel reaches where the adjacent valley flat is a floodplain (as defined in Section 4.5), and where: a) the streambed slope is between 0.001 and 0.03; and b) actual or potential spawning habitat is provided for anadromous salmonid species²². We propose the streambed mobility target to relate channel sediment supply and physical habitat structure to the growth and survival of juvenile anadromous salmonids in the Lagunitas Creek watershed.

Background and Rationale

In most gravel-bedded channels, grains that comprise the streambed are not mobilized, until flow depth approaches that achieved during the annual flood²³. At this threshold, grains on

²² Actual or potential habitat corresponds to all gravel-bedded channel reaches where streambed slope is between 0.001 and 0.03 located downstream of natural barriers to migration for steelhead, and excluding those channel reaches located upstream of municipal water supply reservoirs.

²³ This modest and infrequent natural transport regime (i.e., in most years, transport only occurs for a few hours to a few days) creates a dynamic equilibrium that structures pool-bar topography. Net erosion and deposition are balanced, and the average channel bed-elevation does not substantially increase (aggrade) or decrease (incise).

part-to-all of the streambed start to move and are transported downstream. When total sediment supply rate is substantially elevated and/or the supply becomes richer in sand, the streambed becomes much more mobile, and grains move and are entrained at a much lower threshold - during smaller, more frequent runoff events. Consequently, the streambed is scoured much more frequently and to a greater depth.

At present, total sediment supply to channels in the Lagunitas Creek watershed is at least two-times the natural background rate, and also is richer in percent sand and finer sediment (Stillwater Sciences, 2010). As sediment supply increases, the streambed becomes finer and more mobile (Dietrich et al., 1989). Cover (2012) found bed mobility to be strongly correlated to sediment supply²⁴ in several small tributaries to Lagunitas Creek that provide spawning and rearing habitat for coho salmon and steelhead (Figure 4.1). Lisle et al. (2000) also documented strong correlations between sediment supply and Shields Stress in larger gravel-bedded channels in northwestern California and Colorado across a wide range of sediment supply.

High bed mobility has biological significance. For example, reach-average depth of streambed scour is correlated to bed mobility (Haschenberger, 1999; Bigelow, 2005; May et al, 2009). Where scour is greater than the depth of egg burial at spawning sites, it can be a significant source of mortality during incubation for coho salmon and other anadromous salmonids (McNeil, 1966; Montgomery et al., 1996; Shellberg, 2010). Also, high rates of streambed mobility have been linked to persistent reductions in the biomass of benthic macro-invertebrates (Matthai and Townsend, 2000). Benthic macro-invertebrates are an important food source for

²⁴ Tau-star (τ^*) represents the balance between the force of the flowing water (that provides the impetus for particles in streambed to be mobilized) and the resistance to motion provided by the gravitational force (or the weight of the particles in the streambed). This balance of forces is represented by the following equation for Tau-Star:

$\tau^* = (\rho g R S) / (g(\rho_s - \rho) D_{50})$, where ρ is density of water, ρ_s is the density of the grains in the streambed, g is the gravitational force, R is the hydraulic radius (which is approximately equal to the average depth of flow in the channel), S is the water surface slope, and D_{50} is the median grain size of particles on the surface of the streambed.

It is important to note that only a fraction of the total boundary shear stress ($\rho g R S$, the flow energy) is available to mobilize grains that comprise the streambed. This is because bends, bars, bedrock, boulders, and large fallen trees, vegetation, and variations in channel width, and entrainment and transport of sediment, all create perturbations that extract energy from the flowing water. Therefore, the more complex and variable a channel (i.e., more bars, bends, obstructions, changes in width, and vegetation), the smaller the proportion of the total boundary shear stress that is available to mobilize the grains that comprise the streambed.

As can be inferred from examining the formula for τ^* , as the streambed becomes finer (i.e., D_{50} becomes smaller), which can occur as the rate of supply of sand and/or gravel to the channel increases, τ^* also will increase. Also, as the depth of flow in the channel increases, as a consequence of incision, τ^* also will increase. All of the channel reaches examined by Cover (2012) are deeply incised and the amount of large woody debris in the channels is very low. Therefore, in addition to elevated total and fine bed material supply, channel incision and lack of wood in channels, also elevate streambed mobility in most tributaries to Lagunitas Creek. The streambed mobility target reflects a healthy balance between channel sediment transport capacity and supply. Therefore, actions to control fine bed material supply, reduce incision, and/or increase complexity and roughness (i.e., increases in the amount of large woody debris in channels) all will contribute to attainment of the streambed mobility target.

juvenile salmonids. As such, elevated streambed mobility has the potential to reduce the growth and survival of juvenile salmonids.

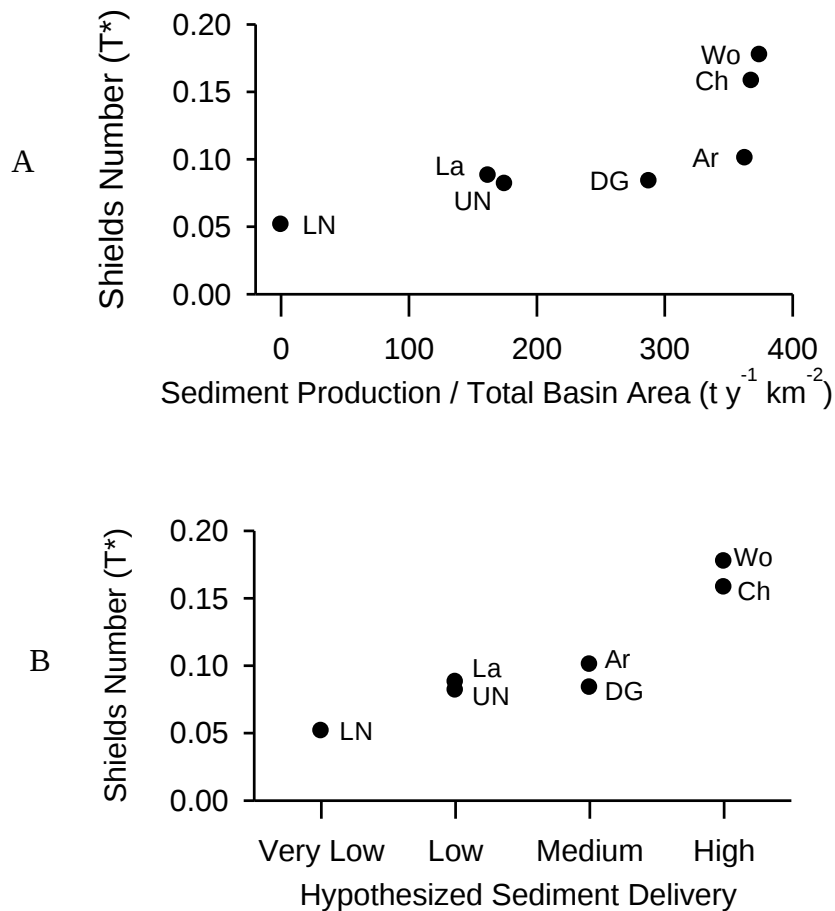


Figure 4.1: Relationship between Shields stress, an index of streambed mobility, and sediment delivery rate to Lagunitas Creek tributaries. LN = lower Nicasio Creek; La = Larsen Creek; UN = upper Nicasio Creek; Ar = Arroyo Creek; DG = Devils Gulch; Wo = Woodacre Creek; and Ch = Cheda Creek (Source: Cover, 2012). All sites surveyed are deeply incised and wood-poor (< 3 pieces of large woody debris per 100 m² of channel). Note: $\tau^* = 0.08$ -to- 0.10 in reaches where supply is medium, and 0.16 -to- 0.18 in reaches where supply is high.

In Lagunitas Creek, early life-stage mortality for coho salmon, from egg fertilization (typically in December or January) through the end of the dry season (in September or October, when juvenile population monitoring surveys are performed), is very high – from 94-to-99 percent²⁵ – and may be linked to increases in sediment supply and/or streambed mobility. In some years, early life-stage mortality limits smolt production. For example, in 6-of-17 years of record, the juvenile population at the end of the dry season was less than the estimated wet season carrying

²⁵ Values were estimated from data collected by the Marin Municipal Water District. We compared coho salmon redd counts in the preceding wet season to juvenile population sampling at/near the end of the following dry season, and assumed that the average number of eggs deposited in each redd was 2500. Percent survival = (juvenile population estimate) ÷ (# of redds × 2500 eggs/redd) × 100.

capacity for juveniles (6000 to 7000)²⁶ limiting smolt production in those years. Mechanisms have not been established, but based on strong correlation with large winter peak flows and/or spring runoff events (Ettlinger, 2007, as cited in Stillwater Sciences, 2008; Stillwater Sciences, 2008, pp. 42-44), it is plausible the mechanism(s) may include: redd scour; entombment; and/or involuntary entrainment of juveniles (resulting from a paucity of velocity refuges). Scour and entombment are both influenced by sediment supply.

Data characterizing redd scour at potential spawning sites in the Lagunitas Creek watershed is discussed in detail in Section 4.3. In summary, we hypothesize that: a) redd scour is elevated substantially and biologically significant in Woodacre Creek, Cheda Creek, and San Geronimo Creek; and b) redd scour may be biologically significant in Arroyo Creek, Devils Gulch, and also in Lagunitas Creek in the Tocaloma Reach during large floods (recurrence interval ≥ 5 -years), and/or for a period of years following a large sediment pulse (Table 4.2). Supporting rationale is presented in Section 4.3.

In addition to the effect of sediment supply increases on bed mobility and scour, channel incision and reduction in the amount of large woody debris from channels also likely have increased the amount of energy focused on the streambed during peak flows, and as such also contribute to elevated bed mobility and scour. Involuntary entrainment of coho fry, although not likely related to high rates of bed mobility can be addressed through enhanced large woody debris loading and floodplain connection, which also are needed to restore natural sediment transport and storage dynamics. These issues are examined in Chapter 6 (Implementation Plan).

The bed mobility target applies to gravel-bedded channel reaches with pool-riffle and/or plane-bed morphology, corresponding to streambed slopes that are between 0.001²⁷ and 0.03. These channel reaches provide the vast majority of the spawning and rearing habitat for coho salmon and steelhead (Buffington, 2004).

The TMDL implementation plan calls for an approximately 50% reduction in fine bed-material sediment supply, a substantial increase in floodplain area, and a two-to-six-fold increase in large woody debris loading (see Chapter 6, Implementation Plan). Based on geomorphic theory, likely response of the channel to a 50% reduction in sediment supply, a significant reduction in the component of tractive stress available to mobilize streambed particles as a result of increased wood loading and floodplain connection, will significantly reduce streambed mobility resulting in attainment of the streambed mobility target.

²⁶As hypothesized by Stillwater Sciences (2008) and supported by the results of four additional years of smolt trapping (Ettlinger and Andrew, 2011, p.9).

²⁷Typically, channels that have a streambed slope < 0.001 are sand-bedded (Parker, 2008, pp. 167-170), and do not provide significant spawning or rearing habitat for anadromous salmonids.

4.3 Redd Scour

Sediment Target

The watershed-wide median value²⁸ for the depth of scour (D_s) at actual or potential spawning sites for coho salmon and/or steelhead shall be ≤ 12 cm below the level of the overlying streambed substrate. This target applies to evaluation of the streambed response to sediment transport during peak flow discharges $\leq$ the 5-year recurrence interval event (annual maximum series). Channel reaches that provide actual or potential spawning habitat are as defined above in Section 4.2, Streambed Mobility. Potential spawning sites within those reaches can be identified based on the following characteristics: 1) median particle size diameter (D_{50}) in the surface layer of the streambed is between 16 and 64 mm; 2) surface area of the gravel deposit is ≥ 1.0 square meter; and 3) location at a riffle head, pool tail, pool margin, and/or it is a gravel deposit associated with a flow obstruction (e.g., woody debris, boulders, banks, etc.). We propose the above numeric target for redd scour depth as a water quality and habitat indicator to relate rate and sizes of sediment delivered to the channel, and its physical habitat structure, to the survival of incubating salmonid eggs-and-larvae in Lagunitas Creek and its tributaries.

Background and Rationale

Scour of spawning gravel can be a significant source of mortality to the incubating eggs and larvae of salmon and trout species (McNeil, 1966; Montgomery et al., 1996; Shellberg et al., 2010). The beds of natural gravel channels cut and fill during high flow events. How deeply they cut into their bed (scour depth) is a function of the force per unit area exerted by flowing water on the streambed, channel features that either concentrate or disperse flow energy (e.g., debris, vegetation, bedrock, gravel bars, etc.), and the abundance and sizes of sand and coarser sediment grains supplied to the channel (bedload). Human actions that increase bedload supply rate, and/or cause it to become finer, will also cause the streambed to become finer, facilitating an increase in the rate of bedload transport through a channel reach (Dietrich et al., 1989). As bedload transport rate increases, so do the mean depth and/or spatial extent of streambed scour (Carling, 1987) (Figure 4.2). Similarly, land-use activities that increase storm runoff peak and/or volume (forest clearing, pavement, etc.), and/or increase the amount of energy that is focused on the streambed at potential spawning sites for a given runoff event (e.g., removal of large debris jams, bank stabilization structures, road crossings, etc.), also have the potential to increase bedload transport rate, and therefore, streambed scour.

²⁸ Redd scour depth is highly variable and may follow an exponential distribution. Given a small sample, the mean value can be influenced strongly by values occurring near the extremes of the distribution. Therefore, the median value at the center of the distribution, is preferred because it is much less sensitive to this effect.

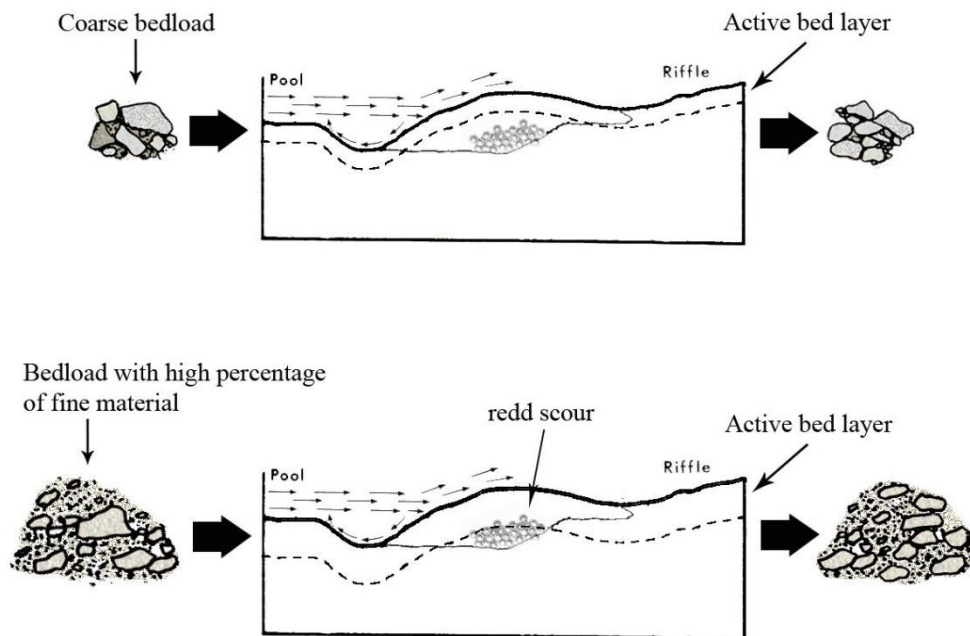


Figure 4.2: Influence of sediment supply on streambed scour at spawning sites (redds). When sediment supply increases and/or becomes richer in fines, depth of streambed scour is increased, exposing incubation eggs and larvae to increased risk of mortality via scour. Figures reproduced with permission from the American Fisheries Society.

Inferred Scour Risk under Current Conditions

Streambed scour has been monitored previously in the Shafter, State Park, and Tocaloma reaches of Lagunitas Creek, and also in San Geronimo Creek and Devils Gulch (Bratovich and Kelley, 1988; Stillwater Sciences, 2008; Balance Hydrologic, 2010). Results of those studies are summarized in Table 4.1.

Table 4.1: Previous redd scour monitoring in the Lagunitas Creek watershed.

Study	Chains	Array	Water Year	Peak (cfs)	R.I. ²⁹ (yr.)	Bed Condition	Sediment Supply	Results
Bratovich & Kelley (1988)	8 ³⁰	1 chain per artificial redd (8 sites)	1984 ³¹	1840	1.6	Fine	Very High	Median scour ≥ 10 cm ³²
Stillwater Sciences (2008)	32	4 chains per coho redd (8 sites)	2005	1760	1.6	Coarse	Medium	Median scour ≤ 1 cm
Balance Hydrologics (2010)	13	3-5 chains downstream end of glide (4-5 sites)	2003	2620	3.1	Coarse	Medium	Median scour = 3 cm ³³ in WY 2003-05
	18		2004	3230	5.0	Coarse	Medium	
	23		2005	1770	1.6	Coarse	Medium	
	15		2006	10200	≥ 25	Fine	Very High	Extreme scour in WY 2006; 7-of-15 chains not found

Each of the three studies utilized a different sampling strategy, and in all of the studies, a small number of sites were sampled (5-to-8 sites). These limitations acknowledged, looking at all of the data together as a group, redd scour does not appear to be a significant source of mortality for coho salmon in most years in the mainstem of Lagunitas Creek. However, review of the data suggests that it could be a significant source of mortality following a large sediment supply event, and/or in response to a large peak flow (recurrence interval ≥ 5 years). Under these conditions, within the mainstem of Lagunitas Creek, the Tocaloma Reach appears to have the highest scour risk.

Although little data is available to evaluate redd scour risk in Lagunitas Creek tributaries, scour risk can be evaluated there, indirectly based on the results of bed mobility studies (Cover, 2012).

²⁹ R.I. refers to the recurrence interval for the peak flow (annual maximum series). For example, there is a 20 % probability that a peak flow in any given year will be $\geq$ to the 5.0 year recurrence interval event.

³⁰ Also monitored two additional artificial redds in Lagunitas and four each in San Geronimo Creek and Devils Gulch in water year 1984. However, these chains were installed subsequent to the bankfull event, and later runoff events were smaller. Tributary sites experienced low to moderate scour.

³¹ Also monitored redd scour in water year 1983, the second wettest winter in the 20th century, and one-year after the January 4-5, 1982 storm, which delivered a huge amount of sediment. Scour was extreme and chains were lost.

³² It is unclear whether sediment deposited between storms was replaced after locating the point of inflection on the chord. To address this problem, median scour above only considers response to the bankfull event on December 25, 1983.

³³ Deep scour and/or fill inferred at several sites where chains were not found.

This is because scour is correlated to bed mobility (Bigelow, 2005; Haschenberger, 1999; May et al., 2009). Using this approach, we hypothesize that redd scour risk is high to very high in Woodacre, Arroyo, and San Geronimo creeks, and moderate-to-high in Devils Gulch. All are important spawning reaches for coho salmon. Predicted scour risk, by major spawning reach, is summarized in Table 4.2.

Table 4.2: Predicted redd scour risk by spawning reach.

Reach	Redd Density	Sediment Supply	Channel Incision	Bed Mobility	Potential Scour
Woodacre	High	≥ 2x Natural	High	Very High	Very High
Cheda	Low	≥ 2x Natural	High	Very High	Very High
Arroyo	High	≥ 2x Natural	High	High	High
San Geronimo	High-Medium	≥ 4x Natural	High ³⁴	High	High
Devils Gulch	Medium	≥ 2x Natural	High	High	Moderate-High
Lagunitas (Tocaloma)	Low	2x Natural	Low	Moderate	Moderate
Lagunitas (State Park)	Medium	2x Natural	High-Moderate	Low	Low-Moderate
Lagunitas (Shafter)	High-Medium	<< Natural	High	Very Low	Low

Notes: “Natural” refers to natural sediment supply rate (see Chapter 3, Source Analysis).

Because juvenile steelhead population estimates made at the end of the dry season have been consistently high in the Lagunitas Creek watershed irrespective of the timing of large floods and/or sediment supply events (Ettlinger et al., 2011), under current conditions we conclude that redd scour does not exert a significant influence on steelhead population dynamics. Conversely, in 6-of-17 years of record, the juvenile coho salmon population at the end of the dry season was less than the inferred winter rearing capacity (6000 to 7000 juveniles) indicating in those years, that very high mortality in early life stages limited coho salmon smolt production in the following year. As described in Section 4.2, redd scour may be one of the mechanisms contributing to very high levels of early life stage mortality. As such, our redd scour target focuses on protection of coho salmon.

³⁴ Some reaches have re-established pool-riffle morphology and inset floodplains. These reaches presumably have a lower magnitude of bed mobility and scour, as compared to narrower reaches with no floodplain.

Inferred Level of Protection

To develop the redd scour numeric target, we first reviewed available data regarding egg burial depth for coho salmon. van den Berghe and Goss (1984) found a strong correlation between egg burial depth and size of spawning female coho salmon. Applying their relationship, and using data that characterizes the size distribution of spawning female coho salmon in nearby Waddell Creek (Figure 4.3) to approximate the size distribution in Lagunitas Creek, we predict that 95 percent-or-more of all spawning female coho salmon in the Lagunitas Creek watershed will bury their eggs ≥ 12 cm or more below the depth of the original level of the streambed (e.g., the level prior to spawning and redd construction). Our calculations and key assumptions are as follows:

1. We assume that the size distribution for female coho salmon in Waddell Creek (Figure 4.3; developed from Shapovalov and Taft, 1954, Table 8, p. 42-45) provides a reasonable approximation of the size distribution of female coho salmon in the Lagunitas Creek watershed. Shapovalov and Taft operated a trap near the mouth of Waddell Creek during the spawning season in water years 1934 through 1942, and in that period captured 980 female coho salmon. Waddell Creek drains to the Pacific Ocean, approximately 90 miles south of Lagunitas Creek.
2. Mean fork length for female coho salmon in Waddell Creek = 64.29 cm. Assuming a normal distribution, the fork length of 95 percent of females will fall within two standard deviations of the mean. The standard deviation = 4.67 cm. Mean (64.29 cm) – [2 x Standard Deviation (4.67 cm)] = 54.95 cm.
3. Apply the relationship of Van den Berghe and Goss (1984):

Egg burial depth below the original level of the streambed (cm) = $-10.44 + 0.411 \times \text{female fork length (cm)}$; $R^2 = 0.61$.

Egg burial depth = $-10.44 + 0.411 \times (54.95) = 12.14$ cm below the original level of the streambed (prior to redd construction).

Because most of the published data describing coho salmon egg burial depth (see Devries, 1997), has been reported in relation to the level of the overlying gravel (e.g., the streambed level following redd construction), we use the overlying gravel as the datum in the numeric target. Considering the pattern of excavation and burial during redd construction, the level of the overlying gravel in all cases should be greater or equal to the original level of the bed (see Devries, 1997, Figure 1, p. 1691). Therefore, if 95 percent of all female coho salmon bury their eggs 12 cm-or-more below the original level of the streambed, the depth of burial below the overlying gravel will be even greater. Considering the published data reported in Devries (1997, Table 1, p. 1689), for all of the studies that reported egg burial depth in relation to the level of the overlying gravel, the mean depth of the top of the egg pocket in all cases was ≥ 12 cm, and in all but one study the top of the egg pocket was ≥ 15 cm below the overlying gravel.

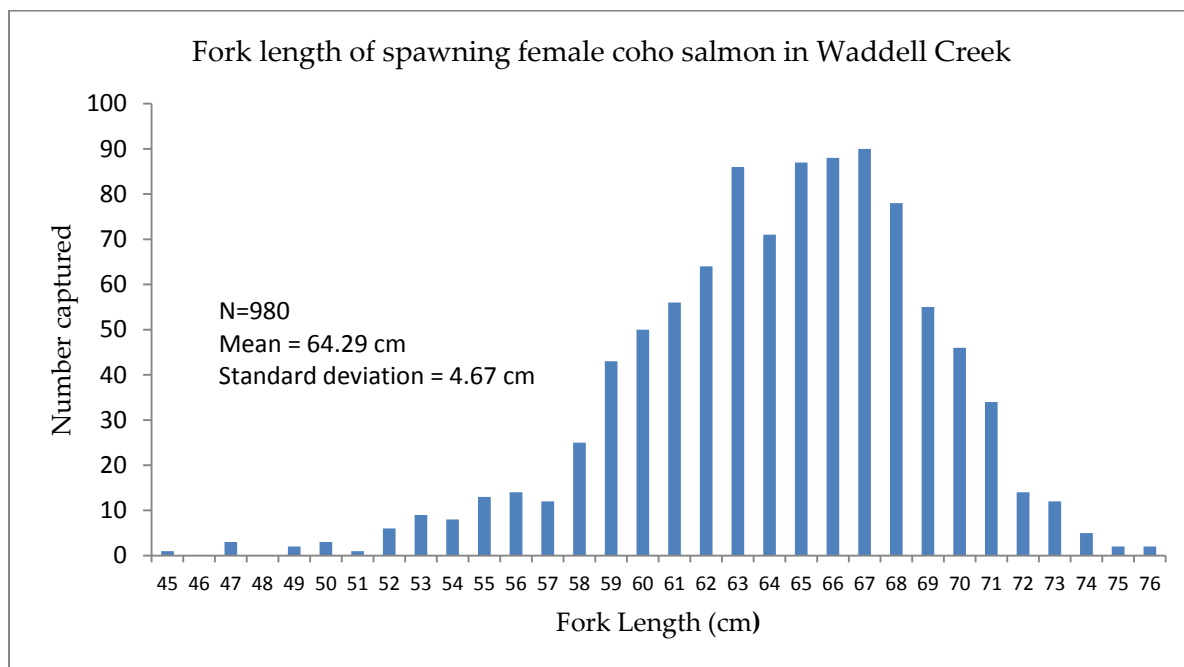


Figure 4.3: Size distribution of spawning female coho salmon captured in Waddell Creek, water years 1934 through 1942 (Source: Shapovalov and Taft, 1954).

To assess the potential effect of attainment of the redd scour target on coho salmon population dynamics, we prepared a simple model that also factors in other sources of mortality during incubation, and applies reasonable values for survival in other life stages (Table 4.3). We ran the model under very poor ocean conditions to evaluate whether the target could help to maintain stable smolt production, even in periods when large runoff events and poor ocean conditions coincide to influence smolt production and/or the number of returning adults. We find that if under current conditions redd scour has contributed to very high levels of early life stage mortality in some years, following attainment of the redd scour target, survival to emergence should be 30 percent-or-greater in years when the peak flows have recurrence intervals ≤ 5 years. This egg-to-fry survival value is above the average value for wild coho salmon populations reported in Table 15-1, p. 254 in Quinn (2005). Assuming survival from fry-to-smolt in the Lagunitas Creek watershed is equal to the average for wild populations (16.5 percent), also reported in Quinn (2005), then it appears that coho salmon smolt production would remain stable with attainment of the redd scour target, suggesting it is protective.

Table 4.3: Influence of the redd scour target on coho salmon population dynamics

Initial smolt population	Returning adults¹	Redds²	Eggs³	95% buried > 12 cm⁴	67% not entrained⁵	50% survival during incubation⁶	Resultant smolt population⁷
6,500	98	49	120,050	114,047	76,032	38,016	6,272
¹ Ocean survival set = 1.5%, which was the survival value for Lagunitas Creek watershed smolts that entered the ocean in spring 2008 and returned to spawn in water year 2010.							
² Redds = adults ÷ 2							
³ 2450 eggs per redd, based on the following. Average fork length for a coho salmon female = 64.95 cm. Per Shapovalov and Taft, 1954 (p. 60), the estimated number of eggs ≈ 2450.							
⁴ By the relationship of van den Berghe and Goss (1984), and using the Waddell Creek population data, 95% of females can bury all of their eggs at depth > 12 cm below the original level of the streambed.							
⁵ Scour target is relative to median value. Therefore, at ½ of sites, scour depth < 12 cm, and 100% eggs remain in place. At the other ½ of sites where scour > 12 cm, given an exponential distribution of scour (Haschenberger, 1999), and typical distribution for egg burial (see, Tripp and Poulin, 1986; Figure 6), we estimate that 1/3 of eggs will remain in-place. ½ * 100% + ½ * 33% = 67% not entrained.							
⁶ Given a 50% reduction in sediment supply per TMDL, absent redd scour effects we input a 50% value for egg survival during incubation into the model. In early 1980s, even under high sediment supply, Bratovich and Kelley (1988) estimated that absent redd scour mortality the average egg survival during incubation was > 50% (not considering the effects of scour). Note: This parameter accounts only for mortality related to the incubation environment. When the other causes for mortality from spawning-to-emergence that are considered in our simple model, also are factored in, the resultant average value for egg-to-fry survival is approximately 33 percent: 95% (of eggs buried) x 67% (eggs not entrained) x 50% (egg survival during incubation) ≈ 33 percent. For comparison, Quinn (2005) estimates that the average value for egg-to-fry survival for coho salmon, for wild or naturally rearing populations is approximately 25 percent; slightly lower than we predict will be the case following a 50% reduction in sediment supply and a > 100 percent increase in wood loading.							
⁷ We input the average value for fry-to-smolt survival for wild populations (16.5 percent) reported in Table 15-1, p. 254 in Quinn (2005).							

Other Potential Causes for High levels of Early Life Stage Mortality

If redd scour is not a significant cause or contributing factor to the very high levels of early life stage mortality for coho salmon that have been documented in 6-of-17 years of record, then entombment or involuntary entrainment of fry would appear to be the most plausible mechanisms in such years (see Stillwater Sciences, 2008, pp. 42-44). If entombment is significant under current conditions, with attainment of the sediment TMDL and the numeric targets for bed mobility and redd scour, we predict that mortality via entombment would no longer exert a

significant influence on coho salmon population dynamics. This is because both total bedload supply, and the percentage in the sand and fine gravel size classes, would be reduced significantly as a result of the 50% reduction in total sediment supply to channels required to attain the TMDL.

If involuntary entrainment of fry is an important source of mortality, this mechanism can be addressed by increased large woody debris loading in channels (e.g., the volume of large woody debris per unit channel area), and/or increasing the length of the channel that is connected to a floodplain because these features/habitats provide low velocity refuges that are rare or lacking under in incised channel reaches. Also, enhancement of wood loading and floodplain connection has the potential to significantly increase smolt production in all years, reduce redd scour and bed mobility, and to sort and meter fine sediment. Therefore, we also propose a target for large woody debris loading, and call for detailed technical studies to identify reach specific prescriptions for projects to increase floodplain connection.

4.4 Large Woody Debris Loading

Habitat Targets for Redwood Channel Reaches

Within 10 years of adoption of the Basin Plan amendment, the watershed-wide average value for large woody debris loading in redwood channels shall be $\geq 300 \text{ m}^3/\text{ha}$. Redwood channels are defined as those where the adjacent valley floor and/or hillslopes are vegetated primarily by coast redwood forest. The target applies only in channel reaches that provide actual or potential spawning habitat for anadromous salmonids (as defined in Section 4.2). Example redwood channel reaches in the Lagunitas Creek watershed include the Shafter and State Park Reaches of Lagunitas Creek, and most of the length of Devils Gulch and Arroyo Creek.

The natural range of variability in large woody debris loading in channels draining old-growth redwood forests spans an eighteen-fold range, from approximately 250-to-4500 m^3/ha , highlighting a primary challenge in trying to develop a defensible target value (see, Lisle, 2002, for a good discussion of this issue). On the other hand, current values for large woody debris loading in redwood channel reaches in the Lagunitas Creek watershed, sampled over approximately 20 percent of the length of Lagunitas Creek, are only 50-to-170 m^3/ha (Lawrence et al., 2012), suggesting present-day loading may be significantly below the lower end of the natural range. Furthermore, the median value for large woody debris loading in managed redwood channels (e.g., those draining previously logged forests), is approximately 300 m^3/ha (Knopp, 1993)³⁵, or about two-to-six times the measured amount in redwood channels in the Lagunitas Creek watershed.

³⁵ The median value is calculated from 48 channel reaches (Appendix D, p. 56, Knopp, 1993). Note: since Knopp characterizes loading per 100 meters, and the channels they surveyed varied greatly in size, in order to determine loading values per unit area of channel, we used a hydraulic geometry relationship developed for Russian River tributaries that relates drainage area to channel width, in order to transform the data into loading values in m^3/ha (Napolitano, 2012b, unpublished analysis).

Considering all of the above, and the critical importance of large woody debris in shaping suitable habitat for coho salmon, we establish the large woody debris loading target at 300 m³/ha, which is approximately equal to the 10 percent value for natural redwood channels³⁶ (Figure 4.4 and Table 4.4) and the median value for managed redwood channels (Knopp, 1993).

Acknowledging the very wide range of large woody debris loading in natural redwood channels, within five years of Basin Plan amendment adoption, the Water Board will work with other stakeholders to develop reach-specific large woody debris budgets and a related feasibility analysis to guide establishment of medium- and long-term targets for woody debris to be achieved within twenty-five and fifty-years of Basin Plan amendment adoption.

Habitat Targets for Hardwood Channel Reaches

Within 10 years of adoption of the Basin Plan amendment, the watershed-wide average value for large woody debris loading in hardwood channels shall be ≥ 100 m³/ha. Hardwood channels are defined as those where the adjacent valley flat is vegetated by a hardwood forest (typically some combination of willow species, white alder, California bay laurel, bigleaf maple, tan oak, and/or Oregon ash). The target applies only to channel reaches that provide actual or potential spawning habitat for anadromous salmonids (as defined in Section 4.2).

Example hardwood channels include most of the length of San Geronimo and Cheda creeks, and the Tocaloma Reach of Lagunitas Creek. Review of available wood loading data for Lagunitas Creek watershed (Lawrence et al., 2012), suggests that a 2-to-3 fold increase is required in most hardwood channels to achieve the target, which corresponds to the median value for large woody debris loading in hardwood channels located on public lands (Opperman, 2005). We note that all of the hardwood channels surveyed by Opperman (2005), including those on public lands, likely have experienced historical land-use activities that reduced large woody debris loading below natural reference values, complicating establishment of a protective target.

As described above for redwood channels, working with other stakeholders the Water Board will develop reach-specific large woody debris budgets and a related technical feasibility analysis for hardwood channel reaches within five years of Basin Plan amendment adoption, in order to establish large woody debris loading targets to be achieved within twenty-five and fifty-years of Basin Plan amendment adoption.

³⁶ 90 percent of old-growth redwood channels have more wood (Harmon, 1986, Table 6, pp. 198-199).

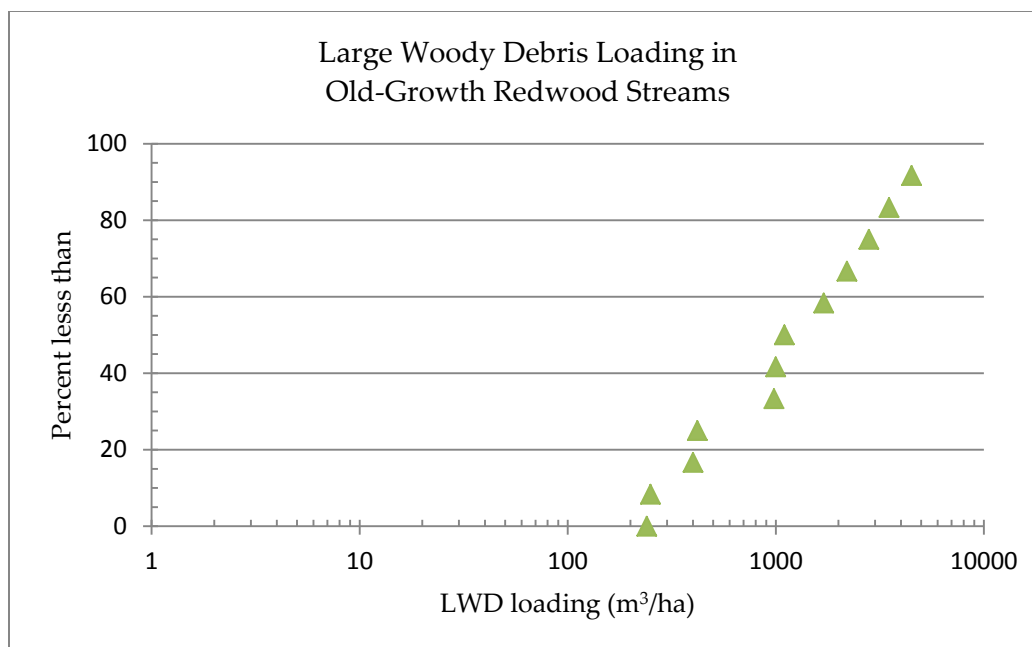


Figure 4.4: Large woody debris loading (volume per unit area of channel) in streams draining old-growth coast redwood forests (source: Harmon, 1986, pp. 198-199).

Table 4.4: Large woody debris loading in channels draining old-growth coast redwoods

Stream name	Drainage area (km ²)	Channel width (m)	Reach length (m)	Large woody debris loading (m ³ /ha)
Gans West Creek	0.5	4.8	90	1100
Low Slope Schist Creek	0.5	3.8	90	1000
Hayes Creek	1.5	4.5	132	3500
Little Lost Man Creek, Upper	3.5	6.4	253	2800
Little Lost Man Creek, Lower	9.1	9.6	596	980
Prairie Creek at Hope Creek	0.7	2.3	115	4500
Prairie Creek at Little Creek	3.5	3.9	107	240
Prairie Creek at Forked Creek	6.6	4.7	200	250
Prairie Creek at Zig Zag Creek	8.2	6.7	232	420
Prairie Creek at Natural Tunnel	11.2	8.0	269	2200
Prairie Creek at Brown Creek	16.7	11.0	335	1700
Prairie Creek at Campground	27.2	18.5	395	400

Source: Harmon, 1986, Table 6, pp. 198-199.

Background and Rationale

Collins et al. (2012) have proposed the floodplain- large wood cycle hypothesis. Drawing upon an extensive body of literature (see Tables 2 and 3, pp. 465-466, therein) they postulate that key pieces of large woody debris, those large enough to resist transport even during large floods,

are the primary agent structuring complex and interconnected channel and floodplain habitats in forested watersheds in the Pacific Coastal Ecoregion³⁷. Also, as a corollary hypothesis, they propose that when land-use activities reduce the size of the largest trees recruited to channels and/or the rate of input of key pieces in general, this causes the physical habitat structure in channels to become greatly simplified.

Anadromous salmonids in Pacific Coastal Ecoregion, as well as all other native aquatic and riparian species, have evolved to exploit the complex and interconnected habitat structure created by large wood. Coho salmon, for example prefer deep pools with good cover alternating with gravel riffles, and well shaded channel reaches that are connected to adjacent floodplains by debris jams that cause floodplain patches, alcoves, and side channels to form. All of these habitats are formed and maintained by key pieces of large woody debris.

As described in Chapter 3 (Section 3.2, Historical Reference Model), much of the reduction in large woody debris loading and consequent loss of habitat complexity and connection, results from historical and/or current land-use activities including the following:

- Nineteenth Century logging of old-growth redwood forests and replacement by second-growth has reduced the total amount of wood and size of the largest trees that are delivered to channels. Figure 4.5 compares two physically similar channels, one draining an old-growth redwood forest and the other a second-growth redwood forest to illustrate this effect.
- At or near the time of European-American settlement, in order to facilitate agriculture, grazing, and building on floodplains, it is likely that most large fallen trees and snags were removed from channels, and that some channel reaches were relocated and/or ditched to reduce valley floor flooding.
- As a consequence of the construction of Kent Lake and Nicasio Reservoir, large woody debris that would otherwise be transported to downstream reaches, is instead intercepted and deposited in these reservoirs.
- As a result of historical incision, channels are narrower and much deeper, and therefore more of the trees that fall toward the channels are not delivered and instead remain perched above the channels.
- Up until the late 1990s and/or more recently, in most cases, debris jams were removed or modified soon after formation because of perceived negative impacts with regard to bank erosion, flooding, and/or fish passage.

³⁷ Lagunitas Creek watershed is within the Pacific Coastal Ecoregion, which extends along the west coast of North America from southeast Alaska through the California Coast Range, south into the Santa Cruz Mountains (Naiman and Bilby, 1998, Figure 1.1, pp. 6-7).

- Installation of bank stabilization structures is widespread along San Geronimo Creek, reducing the rate of woody debris recruitment that would otherwise result from bank erosion and tree-fall.
- Residential development and associated landscaping along San Geronimo Creek and Woodacre Creek has reduced the areal extent of the riparian corridor and the density of mature native trees contributing to a reduction in recruitment of large woody debris to these channels (see Stillwater Sciences, 2009, pp. 3-7, 3-14, 3-27, and 3-31).

Considering the above, we conclude that large woody debris loading in most redwood and hardwood channel reaches in the Lagunitas Creek watershed has been substantially reduced.

Abbe and Montgomery (2003) show that “key pieces”, those that are large enough to remain in place even during large floods, typically have a length $\geq 0.5 \times$ bankfull channel width, and a diameter $\geq 0.5 \times$ bankfull channel depth. They also find that the type and frequency of debris jams vary in a predictable fashion as a function of channel size (see Abbe and Montgomery, 2003, Figures 11 and 12, pp. 101-102).

Some of the largest trees now growing in the riparian corridor along much of the length of the State Park and Tocaloma reaches, appear to be large enough, that upon recruitment, could act as key pieces and exert a significant influence on channel complexity and/or floodplain connection. In some cases, to address the short term deficit in wood loading in the channel, it may be worthwhile to explore potential benefits and impacts of toppling a few of these mature riparian trees intact in order to increase loading in channels in the near-term. Before considering this option however, other potential sources that present fewer potential environmental impacts should be explored first. For example, in some reaches there may be large fallen trees perched above the channel on adjacent terraces and/or hillslopes that could be moved into the channel and act as key pieces. Also, it may be possible to import key pieces intact, or to re-assemble such pieces, collected from nearby locations on roads, hillslopes, and/or from Kent Lake (as has been the practice of MMWD in recent years).

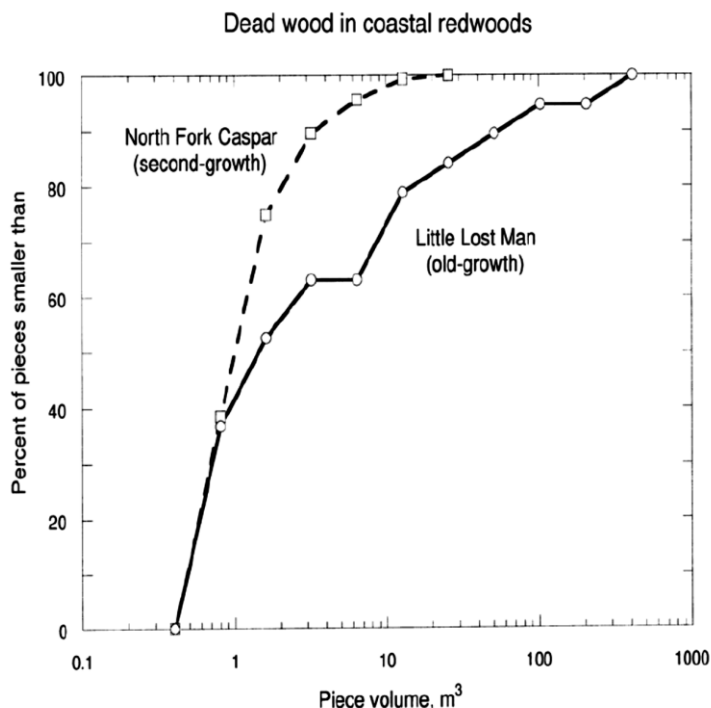


Figure 4.5: Comparison of large woody debris loading in a second-growth versus an old-growth redwood channel. Cumulative frequency distributions for number of pieces of large woody debris in North Fork Caspar Creek draining a mature second-growth redwood forest, and Little Lost Man Creek a similar sized channel draining an old-growth redwood forest (Source: Lisle, 2002). Note 25 percent of the pieces of wood in Little Lost Man Creek are $\geq 10 \text{ m}^3$, whereas pieces this large or bigger are missing from the North Fork of Caspar Creek.

Enhancement of large woody debris loading in the Lagunitas Creek watershed likely will require both: a) short-term efforts to increase the number of key pieces in the channel and their effectiveness³⁸ with regard to specific habitat restoration objectives; and b) active management of riparian forests adjacent to the channels to accelerate growth of trees large enough to act as key pieces. For example, strategic installation of a few dozen key pieces in the State Park Reach (e.g., with a key piece being a meter-or-more in diameter, 50 meters-or-more in length, and having an intact rootball), could significantly enhance channel habitat complexity therein and help to reconnect the channel to its former floodplain over a significant proportion of its length.

³⁸ Effectiveness with regard to shaping habitat is a function primarily of piece size relative to channel size, and the orientation and exposure of the piece to flow.

4.5 Floodplain Restoration

A floodplain is as defined by Dunne and Leopold (1978):

“The floodplain is the flat area adjoining a river channel constructed by the river in the present climate and overflowed at times of high discharge. It is inundated on the average once every one or two years (p. 600).”

Floodplains provide essential winter rearing and refuge habitats for coho salmon including alcoves and side channels (Bustard and Narver, 1975; Nickelson et al., 1992a and b; Tschapinski and Hartman, 1983). Floodplain loss is thought to be a primary factor in the decline of coho salmon populations throughout the Pacific Coastal Ecoregion (Nickelson et al., 1992a; Beechie et al., 2001; Giannico and Hinch, 2003), and locally in the Lagunitas Creek watershed (Stillwater Sciences, 2008) where the coho salmon population is at risk of extinction. Floodplains also provide winter rearing and refuge habitat for juvenile steelhead (Swales and Levings, 1989; Solazzi et al., 2000; Stillwater Sciences, 2008), and essential habitat for many other native fish and wildlife species within the wet season and/or throughout the year.

Under natural reference conditions it is likely that all channel reaches along Lagunitas Creek that provided habitat for California freshwater shrimp, were well connected to their adjacent floodplains (Section 3.2 of this report; see also Martin et al, 2009, p. 603). Restoring floodplain connection in channel reaches that have incised during the historical period and are disconnected at present, especially in the Lower Lagunitas and Tocaloma reaches, would greatly enhance the quality and quantity of potential habitat for California freshwater shrimp because floodplain reconnection will: a) increase length/area of perennial side channels (creating additional pools and undercut banks); b) increase the area of riparian habitat in willow and/or alder forest type (their exposed/submerged roots in pools and glides provide excellent habitat); c) increase the total area of low velocity habitat in the main channel and create potential high velocity refuge sites (in side channels); d) increase future large woody debris recruitment and loading in channels (as a result of enhanced connectivity between the channel and floodplain); and e) increase the area of sand and/or fine gravel patches in the channel (a result of lower total shear stress on the streambed during high flow and an increased large woody debris loading).

Within the Lagunitas Creek watershed, a suite of historical and/or ongoing land-use activities have caused channels to become deeply incised, such that historical floodplains have been isolated and converted to terraces that are infrequently or very rarely inundated even during extreme high flows with recurrence intervals $\geq$ several decades. The only significant remaining floodplain, approximately 5 kilometers in length, is located adjacent to Lagunitas Creek in the upper Tocaloma Reach.

For salmonids, in addition to the primary impact of the loss of access to floodplain habitats, conversion of floodplains into terraces also adversely affects substrate conditions in channels. Linkages are as follows. A significant fraction of the sand and finer sediment being carried by a

river during high flow may be deposited on a floodplain when it is inundated going into long-term storage, and therefore, is not a source of fine sediment deposition in the streambed³⁹. Because terraces are only rarely inundated, they do not provide significant sediment storage and metering. Terrace bank erosion also is a significant human-caused source of sand and finer sediment delivery to channels (Stillwater Sciences, 2010).

Another impact of conversion of floodplain to terraces on channel substrate conditions is that high flows are contained in the channel even during extreme events (recurrence interval ≥ 50 years). Therefore, the shear stress exerted on the streambed is significantly amplified, greatly increasing bed mobility and scour for all flows above the former bankfull reference value (recurrence interval = 1.5-to-2.5 years). Biological consequences of high bed mobility may include higher rates of direct mortality to salmonids during incubation (Montgomery et al., 1996), and indirect influences on growth and survival of juvenile salmonids as a result of lower biomass of benthic macro-invertebrates (Matthai and Townsend, 2000).

The Basin Plan amendment calls for detailed technical studies to characterize reach-specific opportunities and/or priorities for floodplain restoration. Floodplain restoration would involve actions to increase the elevation of the streambed and/or to decrease the elevation of the adjacent valley flat, in order to increase the frequency, area, and/or duration of inundation of the adjacent valley flat. As a result, stream and riparian habitat connectivity and complexity is enhanced including: a) formation of side channels and alcoves (that provide essential habitat for coho salmon and other native species); b) establishment of diverse vegetation and substrate patch types; c) enhanced recruitment and loading of large woody debris; d) a substantial increase in fine sediment storage on floodplains; and e) a reduction in shear stress (elevated rates of streambed mobility) in the channel during large storms (because a greater proportion of discharge is conveyed on the floodplain).

Potential opportunities and constraints influencing floodplain restoration potential are a function of sediment supply, flow regime, valley and channel size and geometry, riparian forest type, historical disturbances and channel changes, development, present-day land uses, and infrastructure. There are four primary channel reaches where floodplain restoration might be considered: 1) San Geronimo Creek; 2) Lagunitas Creek in the State Park Reach; 3) Lagunitas Creek in the Tocaloma Reach; and 4) Lagunitas Creek in its Lower Reach.

Floodplain restoration opportunities in the San Geronimo Creek watershed are limited as a result of the close proximity of many buildings to the channel throughout most all of its length. If the land adjacent to the channel was restored to an active floodplain, these buildings would

³⁹ In nearby Redwood Creek, which drains Muir Woods, approximately 70 percent of the total sediment supply to the channel upstream of Big Lagoon, prior to historical incision of the channel, went into long-term storage in the floodplain (see Stillwater Sciences, 2004). Similarly, a sediment budget for the Pescadero Creek watershed, which drains into the Pacific Ocean in San Mateo County, demonstrates that prior to Euro-American settlement, about 30 percent of the total channel sediment supply went into long-term storage in floodplains (Trso, 2012, unpublished data).

experience frequent flooding, a higher water-table, and the potential for channel avulsion (the channel forming in a new location on the valley floor during a large storm event). For these reasons, we do not expect large-scale floodplain restoration projects to be feasible in most channel reaches in the San Geronimo Valley.

In contrast, along much of the length of Lagunitas Creek in the State Park, Tocaloma, and Lower Lagunitas reaches, land adjacent to the channel is publically owned, and in many locations existing infrastructure would not be threatened by floodplain restoration⁴⁰.

The reach with the greatest potential with regard to enhancement of ecological function, if it is feasible to re-aggrade the channel and connect it to its historical floodplain, would be the Lower Lagunitas Creek reach (beginning at the confluence of Lagunitas Creek with Nicasio Creek and continuing downstream to Highway 1), where the valley width (historical floodplain) is much greater than anywhere else in the watershed. Based on its slope, drainage area, hardwood riparian forest type, reference sediment supply, and valley width, and considering the research of Beechie et al. (2006), we hypothesize that under natural reference condition this was the most complex and ecologically significant floodplain within the watershed. If it could be reconnected to its historical floodplain, it is reasonable to expect that the area of side channel and alcove habitat that is available in the watershed would be more than doubled, greatly increasing the quantity of winter rearing habitat for coho salmon and steelhead, and the year-round habitat for California freshwater shrimp. However, this reach is also the most deeply incised of any within the watershed, and therefore, likely the most challenging to restore.

In contrast, the State Park Reach, might be the most straightforward to enhance, but arguably may also be expected to yield much smaller potential ecological benefits as the channel is steeper, drainage area/channel width is much lower, the channel is moderately confined throughout most of its length, and the adjacent riparian forest is Coast redwood. Considering these attributes, if the channel was reconnected to its historical floodplain, there would be fewer side channels, and the diversity of riparian patch types would be much lower than in Lower Lagunitas or Tocaloma. Nevertheless, it might be possible to significantly increase winter rearing habitat for coho salmon and steelhead, and to enhance channel habitat diversity and function (e.g., to increase the frequency of forced pool-riffle units, the quality of pool habitats, and the length/area of side channels and alcoves).

Although the idea of a floodplain area target (as proposed in an earlier draft of this Basin Plan amendment) is intriguing, utilizing available information there are several challenges associated with its definition including: a) accurately estimating the current area of floodplain; b) evaluating the potential benefits of incremental increase in floodplain area; and c) in determining what is feasible and would result in optimal ecological and water quality benefits.

⁴⁰ In a few locations Sir Francis Drake Blvd., Platform Bridge Road, and/or the Petaluma-Point Reyes Road are located close to the channel precluding floodplain restoration. However, in most locations this is not a problem.

A discussion of these issues is included in Chapter 6 (Alternatives Analysis). Considering these challenges, we conclude that detailed technical studies need to be conducted first to develop a solid understanding of the opportunities, constraints, and potential benefits of floodplain reconnection before implementing large-scale projects. Water Board staff recommends giving these studies and subsequent implementation projects top priority for TMDL contract and Water Board grant programs, and working in partnership with other stakeholders as needed to achieve significant ecological and water quality benefits.

4.6 Summary

Upon attainment of the three numeric targets, large woody debris loading would be more than doubled, and bed mobility and redd scour would operate within the natural range in the channel reaches where these targets apply. Also, assuming a 100 percent-or-greater increase in the area of side channels and alcoves (as a result of floodplain restoration projects), we hypothesize that coho salmon smolt production could be doubled (assuming winter carrying capacity for juvenile coho salmon is primarily a function of the floodplain and channel area that provides suitable refuge habitat during all stages, from winter baseflow through flood stages with recurrence intervals of a few decades-or-more). If smolt production can be doubled, given a similar range of ocean conditions as experienced in the 1998 to 2011 period⁴¹, in future years the average size of the adult spawning run could be approximately 1000-or-more, and the maximum run could approach 2500 (Table 4.5). As a result, it is plausible that the Lagunitas Creek watershed coho salmon population might be able to achieve the down-listing target for adult abundance specified by NOAA Fisheries, which corresponds to 1300 adults per year returning to spawn over four consecutive generations (with a generation defined by three consecutive brood years).

⁴¹ by comparison of juvenile and/or smolt production to the number of spawning adults

Table 4.5: Number of coho salmon that would have returned to spawn in water years 1998 through 2011, assuming prior implementation of restoration actions to double smolt production and returning adults.

Water Year	Actual Number Adult Spawners	Doubling Adult Spawners
1998	758	1516
1999	454	908
2000	460	920
2001	692	1384
2002	750	1500
2003	350	700
2004	984	1968
2005	1266	2532
2006	394	788
2007	874	1748
2008	346	692
2009	54	108
2010	134	268
2011	204	408
Minimum =	54	108
Average =	551	1102
Maximum =	1266	2532

Note: above estimates for returning adults are estimated simply by doubling the number of redds counted in spawner surveys conducted throughout the watershed, including the Olema Creek tributary, in the named year. Note: we also estimate that the ocean survival rate from smolt-to-adult during the corresponding periods of ocean residence varied by a factor-of-eight, from 1.5-to-12 percent. Estimated smolt production also varied by more than a factor-of-three from 2100-to-6700 (Ettlinger and Andrew, 2011, Table 4-1). High rates of early life stage mortality occur in about one-third of all years under current conditions. If these mechanisms are addressed by enhancement of habitat complexity and connectivity, then smolt populations in future years would be predicted to be much more stable, and the average number of returning adults would be significantly greater than estimated above.

CHAPTER 5: LINKAGE ANALYSIS, TMDL, AND ALLOCATIONS

Key Points

- The Lagunitas Creek sediment TMDL equals about 120% of natural background upstream of Devils Gulch, and it equals about 110 % of natural background upstream of Olema Creek.
- Attainment of the TMDL at these two locations will require sediment inputs to be reduced by approximately 50 percent.

5.1 Introduction

In this chapter, we evaluate linkages between sediment supply, streambed substrate conditions, and channel sediment storage, as needed to determine the total maximum daily load (TMDL) and related allocations by source category. By definition, the TMDL is the total sediment load that can be discharged into Lagunitas Creek without violating water quality standards.

Linking channel conditions to sediment supply is challenging because channel form and sediment deposits reflect the temporal and spatial integration of sediment inputs to and transport through stream channels. In addition to sediment supply, channel transport capacity and storage are influenced by: a) magnitude, duration, and frequency of high flows; b) channel slope and depth; and c) channel roughness, or elements that concentrate or disperse flow energy. For these reasons, time lags between sediment input and discharge may be several years to decades or more, and specific channel responses to changes in sediment supply may vary substantially. These challenges acknowledged we used the following iterative approach to link sediment supply to channel conditions:

- First, we reviewed sediment TMDLs established for similar natural stream channels, where the TMDL was defined as a percentage of the natural background and set equal to the load in a reference watershed or a reference time period⁴², where beneficial uses and water quality objectives are/were attained. We used this approach to develop an initial estimate of the relative magnitude of the TMDL.
- Then, we applied a process-based approach (Beechie et al., 2010) to further refine the estimated TMDL, by considering the TMDL in the context of natural sediment transport and storage processes, and associated habitat structure in stream channels in the Lagunitas Creek watershed. We used this approach to confirm that rates of sediment delivery to channels, and rates of channel sediment transport called for by the TMDL, support full restoration of natural sediment dynamics, and associated habitat complexity

⁴² Where water quality standards are attained including water quality objectives for sediment, and where salmonid populations are robust.

and connectivity in channel reaches that provide actual or potential habitat for anadromous salmonids⁴³.

- To link the TMDL to the numeric targets, we reviewed Cover (2012) who examined relationships between sediment supply and bed mobility in small tributaries to Lagunitas Creek. Based on our review, we predict upon achievement of the TMDL, that the streambed mobility target will be attained.

5.2 Reference Load Expressed as a Percentage of Natural Background

We propose expressing the sediment TMDL as a percentage of the natural background sediment input rate. Our reasoning is as follows:

- a) Lagunitas Creek has a Mediterranean climate and an active tectonic setting, therefore, natural sediment input rates are highly variable, and native stream species are adapted to large infrequent sediment pulses associated with natural disturbances (e.g., large storm events, wildfires, and major earthquakes); however,
- b) Native fish and aquatic wildlife species are not adapted to chronic delivery of sand and finer sediment, and/or to substantial alteration of natural channel transport and storage processes. Under the natural sediment regime, fish-bearing channels were buffered from the full impact of large infrequent sediment pulses by the sediment storage, metering, and sorting functions provided by debris jams and floodplains, and by the fact that many tributaries were naturally disconnected (See Section 3.2).

In order to determine what percentage above natural background will result in the attainment of sediment-related water quality standards, we reviewed sediment TMDLs established for physically similar stream channels, where the TMDL was defined as a percentage of the natural background and set equal to the load in a reference watershed, where beneficial uses and water quality objectives are/were attained. We used this approach to develop an initial estimate of the relative magnitude of the TMDL.

The two sediment TMDLs we identified that relied on reference approach are:

- 1) Redwood Creek in Humboldt County, where the TMDL was established by comparison to reference sub-watersheds; and

⁴³ Actual or potential habitat corresponds to all gravel-bedded channel reaches where streambed slope is between 0.001 and 0.03 located downstream of natural barriers to migration for steelhead, and excluding those channel reaches located upstream of municipal water supply reservoirs.

- 2) Noyo River on the Mendocino Coast where the load was established by comparison to a reference time-period.

In both cases, a reference state was identified where salmonid populations are/were robust, and inferentially, where water quality objectives for sediment-related parameters are/were attained. For Redwood Creek, the sediment load corresponding to robust steelhead and salmon populations equals 117 percent of natural background. For Noyo River, the sediment TMDL equals 125 percent of natural background. To be consistent with the level of protection afforded in these two watersheds, the sediment TMDL for Lagunitas Creek should not be greater than 125 percent of natural background.

The sediment budget for the Lagunitas Creek watershed quantifies present-day rates of sediment delivery to channels and channel sediment storage changes at two locations in Lagunitas Creek: immediately upstream of Devils Gulch, and immediately upstream of Olema Creek (see, Stillwater Sciences, 2010). However, the sediment budget study does not provide a specific estimate of the natural background sediment supply, only the conclusion that the supply has increased “somewhere from double to over an order of magnitude over such background rates” (Stillwater Sciences, 2010, pp. 3-4).

Therefore to estimate natural sediment supply in Lagunitas Creek we reviewed data collected in other similar nearby watersheds (see Sediment Source Analysis), which is summarized in Box 5.1. By this approach, prior to European-American settlement, we estimate that the natural background sediment supply averaged about 70 metric tons per km² per year in Lagunitas Creek upstream of Devils Gulch, and it averaged about 50 metric tons per km² per year in Lagunitas Creek upstream of Olema Creek. Natural supply is lower near the mouth immediately upstream of Olema Creek, primarily because floodplain deposition increases in the downstream direction. 125 percent of natural background would correspond to 88 metric tons per km² per year in Lagunitas Creek upstream of Devils Gulch, and 63 metric tons per km² per year in Lagunitas Creek upstream of Olema Creek. Loading during the sediment budget period (1983 through 2008), was approximately 230 percent of natural background in Lagunitas Creek upstream of Devils Gulch, and it was approximately 210 percent of natural background in Lagunitas Creek upstream of Olema Creek.

5.3 Process-Based Approach

Addressing the problem of channel incision has special priority because in addition to its prominence in the sediment budget, incision also fundamentally disrupts natural sediment transport and storage processes, and causes channel habitat to be greatly simplified and the channel to be disconnected from its floodplain. These impacts can be addressed by increasing large woody debris loading and restoring floodplains in alluvial channel reaches. In addition to these direct restoration actions, efforts to control sediment delivery to channels arising from road-erosion, gullies, and landslides will have the collateral benefit of reducing storm runoff and fine bed-material input into actively incising channel reaches.

To achieve a TMDL ≤ 125 percent of natural background, all significant sediment sources need to be reduced on average by about 50 percent. Considering the priority to address cumulative effects of channel incision, constraints of existing development, and the uncertainty in estimating sediment delivery process rates, we propose the following approach and reductions:

- 1) **67% reduction in sediment from incision in Lagunitas and San Geronimo creeks:**
During the 1983 through 2008 sediment budget period, bank erosion was insignificant along Lagunitas and San Geronimo creeks. Almost all sediment input from channel incision in these reaches was the result of lowering of the streambed, expressed by the erosion of gravel bars and riffles. Streambed lowering and resultant habitat simplification can be addressed throughout Lagunitas Creek, and locally along San Geronimo Creek by installation of engineered log jams⁴⁴ designed to force bar-pool units to form, and/or to create winter rearing habitat. Also, it may be feasible to reconnect the channel to its floodplain in the Lower Lagunitas Reach, downstream of Nicasio Creek, and also locally in the State Park Reach.
- 2) **33% reduction in sediment delivery from incision along tributaries:** Many incised tributary channels are actively widening, such that approximately 50 percent of total sediment delivery from channel incision therein results from bank erosion. However, narrow incised tributary channels have to widen first in order to re-establish complex channel habitat and an inset floodplain. Therefore, we do not recommend bank erosion control as a water quality attainment strategy⁴⁵. This constraint significantly limits the percent reduction in sediment input that we can achieve from this source category⁴⁶. Instead, as described above for Lagunitas and San Geronimo creeks, it may be more effective to install engineered log to provide local controls for bed-elevation, increase bar/riffle frequency, and/or to create winter rearing habitat. In Devils Gulch, it also may be feasible to reconnect the channel to its floodplain along part of its length.

⁴⁴ It appears feasible to control all future incision on Lagunitas Creek, and two-thirds of the future incision on San Geronimo Creek (see implementation plan). In the near-term, engineered log jams designed to emulate naturally formed log jams, could be installed in locations along the channel where jams would be expected to form naturally, and where they would not threaten public safety or property. These and all other channel restoration actions are premised on voluntary participation of private landowners in cooperative restoration projects. In these same channel reaches, over the mid- and long-term, riparian forests could be actively managed to accelerate growth of large trees as needed to increase recruitment of key pieces of large woody debris to the channel (e.g., fallen trees that are large enough to remain in-place in the channel even during large floods). The location, orientation, and exposure of key pieces also could be actively managed to optimize functional benefits and longevity of debris jams.

⁴⁵ Incised tributary channel reaches where the channel slope is ≤ 0.02 provide a significant amount of potential spawning and rearing habitat for anadromous salmonids. At present, channel width-to-depth ratio in these tributary reaches is typically much less than 12-to-1, making conditions unfavorable for the deposition of gravel bars (Jaeggi, 1984). Gravel bars are integral to physical habitat structure in these channel reaches, and pre-requisite to formation of inset floodplains.

⁴⁶ Alternatively, banks could be set-back and channels widened as part of a channel restoration program. However, the costs and short-term impacts of implementing such a program on a large-scale may be very high. This issue is discussed in Chapter 6 (Implementation Plan).

Box 5.1: Estimating Natural Sediment Supply to Lagunitas Creek

1. Measurements of long-term rates of soil production on hillslopes can be used to estimate rates of sediment delivery to headwaters channels, assuming that over the long-term (e.g., several thousand years), all soil is delivered to the channel network.
2. Soil production rates have been measured at two nearby locations: Tennessee Valley, in the Marin Headlands (O'Farrell et al., 2007), and Inverness Ridge (Burke et al., 2007). Applying these rates to the Lagunitas Creek watershed, we estimate the natural rate of sediment delivery to channels was **≤ 200 metric tons per km² per year**.
3. Under natural conditions, much of the sediment delivered to headwater channels did not make it into larger alluvial channels. Detailed historical studies conducted in several Bay Area watersheds document naturally disconnected tributary channels that discharged into alluvial fans or un-channeled valleys prior to reaching larger alluvial channels (Stillwater Sciences, 2004, pp. 21-22 and Figure 7; San Francisco Estuary Institute, 2008, Figure 3.1 in this report). In nearby Redwood creek in Muir Woods, one-third of the watershed area was naturally disconnected. Assuming a similar fraction for Lagunitas Creek watershed, then delivery to alluvial channels was **≤ 133 metric tons per km² per year**.
4. Prior to European-American settlement, we also infer that valley fills adjacent to San Geronimo and Lagunitas creeks were active floodplains (See Section 3.2 for a detailed discussion). As such, a significant fraction of the total sediment supply was deposited therein, further reducing sediment supply to alluvial channel reaches.
5. Data comparing sediment delivery from headwater channels to floodplain deposition are available in three local watersheds: a) Redwood Creek/Muir Woods, where about 70% of sediment delivery went into floodplain storage (Stillwater Sciences, 2004, pp. 5-6, 18, and 36-37); b) Stemple Creek located on the border between Marin County and Sonoma County, where >50% of estimated sediment delivery went into floodplain storage (Ritchie, 2004); and c) Pescadero Creek in coastal San Mateo County, where about 30% of sediment delivery went into floodplain storage (Trso, unpublished data, 2012).
6. In estimating natural sediment supply to Lagunitas Creek upstream of Devils Gulch, we infer that the San Geronimo Valley was a large natural floodplain, and also that large natural floodplains were inundated with construction of Bon Tempe and Alpine reservoirs. Therefore, we estimate that 50 percent of total sediment supply from headwaters channels went into floodplain storage, and as such, natural supply to **Lagunitas Creek upstream of Devils Gulch was ≤ 70 metric tons per km² per year**.
7. Additional extensive floodplains are/were located in the Tocaloma and Lower Lagunitas reaches of Lagunitas Creek. As such, Redwood Creek provides the best analog, and we infer that natural sediment supply to **Lagunitas Creek upstream of Olema Creek was ≤ 50 metric tons per km² per year**.

- 3) **50% reduction in sediment delivery to channels from road-erosion:** after incision, this source category has the next highest priority for control because road erosion is rich in sand and finer sediment, and the actions required to treat this source, also will be effective in reducing storm runoff (which may contribute to erosion of actively incising tributary channels). Furthermore, well designed and maintained roads are less expensive to operate, as repair costs are much lower.
- 4) **50% reduction in sediment delivery to channels from mass wasting and gullies:** This level of reduction in sediment delivery can be accomplished through existing land management and regulatory programs, and it gets us to 125 percent-or-less of natural background at both locations along Lagunitas Creek (Table 5.2).

5.4 Linkage Analysis

Cover (2012) found streambed mobility to be strongly correlated to sediment supply in several small tributaries to Lagunitas Creek that provide spawning and rearing habitat for coho salmon and steelhead (Figure 4.5). The TMDL in Lagunitas Creek upstream of Devils Gulch equals 120 percent of natural background, and the TMDL upstream of Olema Creek equals 111 percent of natural background (Table 5.2). Achieving these TMDLs during a future period with similar hydrologic conditions as those that prevailed during the 1983 through 2008 study period, would require average annual sediment supply be reduced by approximately 50 percent at both locations corresponding to 83 metric tons/km²/year in Lagunitas Creek upstream of Devils Gulch and 55 metric tons/km²/year in Lagunitas Creek upstream of Olema Creek.

Reviewing Figure 4.5, if sediment delivery to the channel network in a small tributary to Lagunitas Creek was ≤ 100 metric tons per km² per year, both TMDLs are below this value, it appears that bed mobility could drop below 0.06 (the upper limit for numeric target). Exploring another line of reasoning, the numeric target corresponds to the natural range of variation in streambed mobility as characterized by the Shields Stress in most gravel-bedded channels, where the imposed shear stress at bankfull stage is only slightly greater than the amount required to mobilize streambed particles (Andrews, 1983). Therefore, we predict by increasing the area and frequency of gravel bars, the amount of large woody debris, and reconnecting the channel to its floodplain locally in some reaches, it is likely that the bed mobility target will be achieved in Lagunitas Creek. Similarly, considering the correlation of streambed mobility to redd scour at the reach-scale (Hashenberger, 1999; Bigelow, 2005; May et al., 2009), we also infer that the redd scour target will be attained. Large woody debris targets and recommended studies to define floodplain restoration actions would result in partial restoration of habitat complexity and connectivity, and related channel sediment transport and storage dynamics, and as such are directly linked to attainment of water quality standards.

5.5 TMDL and Allocations

Consistent with the approach used in other northwestern California streams, and based on predicted attainment of the spawning streambed mobility numeric target, the TMDL for sediment in Lagunitas Creek is established at 7,400 metric tons per km² per year upstream of

Devils Gulch, which corresponds to about 120 percent of natural background at this location during the 1983 through 2008 study period (Figures 5.2a and 5.3). Similarly, the TMDL for sediment in Lagunitas Creek is established at 11,800 metric tons per km² per year upstream of Olema Creek which corresponds to about 111 percent of natural background at this location during the 1983 through 2008 study period (Figures 5.2b and 5.3). Allocations by sediment source category are specified as a percentage of the natural background. An estimate of the percent reduction from current proportion of the total load is also provided.

5.6 Margin of Safety

The Clean Water Act, Section 303(d) and associated regulations at 40 CFR § 130.7 require that a TMDL include a margin of safety that takes into account any lack of knowledge concerning the relationship between the pollutant loads and desired receiving water quality. The margin of safety may be employed implicitly by making conservative assumptions (USEPA, 1991). For the Lagunitas creek sediment TMDLs, we employed conservative assumptions in setting the numeric targets for streambed mobility and redd scour that we conclude will yield significant benefits above and beyond those needed to address sediment-related water quality objectives. Specifically, attainment of the numeric targets for streambed mobility redd scour will involve sediment source reductions (to enhance **quality** of spawning and rearing habitat) **and** channel restoration actions to enhance the **quantity** and connectivity of spawning and rearing habitat in Lagunitas Creek and its tributaries. This will be accomplished through channel restoration projects that will increase the habitat area in riffles, gravel bars, alcoves, and side channels, and the amount of flood plain habitat that is inundated during the annual flood (see Chapter 6). As such, the streambed mobility and redd scour targets provides additional benefits to salmonids above those required solely to achieve sediment-related water quality standards.⁴⁷

5.7 Seasonal Variation and Critical Conditions

The TMDL must describe how seasonal variations were considered. Sediment input to channels in the Lagunitas Creek watershed and its effects on beneficial uses are inherently variable on seasonal, annual, and longer timeframes. For this reason, the TMDL and allocations are designed to apply to the sources, and are expressed as a percentage of the natural load during the period of interest.

In the California Coast Range, almost all sediment delivery to channels occurs during the wet season. Although rainfall patterns vary on seasonal, inter-annual, and longer timeframes, review of long-term precipitation data for sites in the Lagunitas Creek watershed indicates that in most years 90% or more of all precipitation occurs between the months of October and April. Sediment input to channels from natural process sources are positively correlated to precipitation volume and/or intensity. Shallow landslide failures whether caused by natural processes or land use activities, typically occur during high intensity precipitation events

⁴⁷ We should also point out that the only approach that is probably feasible (for reducing sediment supply from channel incision and associated bank erosion) from the standpoint of obtaining Clean Water Act permit approvals is one that would lead to net enhancement of stream-riparian habitat conditions.

occurring when the soil is already wet as a result of antecedent rainfall. Sediment delivery to channels from shallow landslide failures in the Lagunitas Creek watershed is low during most

Table 5.1a: Load allocations for Lagunitas Creek, upstream of Devils Gulch (drainage area = 88.8 km²)

Source Category	Load During 1983-2008		Estimated Reductions Needed (percentage)	Load Allocations	
	Metric tons/year	Percent of Natural Background		Metric tons/year	Percentage of Natural Background
Landslides, Gullies, and Soil Creep	2600	42	50	1300	21
Roads	3600	58	50	1800	29
Tributary Channels: Channel Incision and Bank Erosion	5000	80	33	3300	53
San Geronimo and Lagunitas Creeks: Channel Incision and Bank Erosion	2900	47	67	1000	16
TOTAL	14,100	227	33-to-67	7,400	119
Natural Background Sediment Supply ≤ 70 t/km²/year inferred from: 1. Hillslope Soil Production Rate = Sediment Delivery Rate to Headwater Channels = 200 t/km²/year 2. Minus 33% of watershed area that was naturally disconnected from mainstem Lagunitas 3. Minus 50% of sediment delivered to upper Lagunitas Creek that went into floodplain storage					

Table 5.1b: Load allocations for Lagunitas Creek, upstream of Olema Creek (drainage area = 213.2 km²)

	Load During 1983-2008		Estimated Reductions Needed (percentage)	Load Allocations	
	Metric tons/year	Percent of Natural Background		Metric tons/year	Percentage of Natural Background
Landslides, Gullies, and Soil Creep	5600	53	50	2800	26
Roads	4000	38	50	2000	19
Tributary Channels: Channel Incision and Bank Erosion	8500	80	33	5700	53
San Geronimo and Lagunitas Creeks: Channel Incision and Bank Erosion	4000	38	67	1300	12
TOTAL	22,100	209	33-to-67	11,800	110
Natural Sediment Supply = 50 t/km²/year inferred from: 1. Hillslope Soil Production Rate = Sediment Delivery Rate to Headwater Channels = 200 t/km²/year 2. Minus 33% of watershed area that was naturally disconnected from mainstem Lagunitas 3. Minus 50-70% (60% = best estimate) of sediment delivered to lower Lagunitas that went into floodplain storage.					

wet seasons, and high during very wet years (winter of 1997-1998) and/or during very high intensity storms (e.g., January 4-5, 1982 and New Year's Eve in 2005). Gullies, almost all of which in the Lagunitas Creek watershed are associated with land-use activities, are typically formed during high intensity storm events at sites where land use activities have intensified peak rates of storm runoff. Most channel incision and associated bank erosion along Lagunitas Creek and its tributaries occurs during large infrequent runoff events (e.g.,

Table 5.2: Wasteload Allocations for Urban Runoff and Wastewater upstream of Olema Creek

Point Source Category	Current Load		Reductions needed (percentage)	Wasteload Allocations	
	Metric tons/year	Percentage of Natural Background		Metric tons/year	Percent of Natural Background
Construction Stormwater-NPDES Permit No. CAS000002	80	0.8	0	50	0.8
Municipal Stormwater NPDES Permit No. CAS000004	20	0.2	0	20	0.2
TOTAL	100	1	0	100	1
Note: Above estimates for loads, percent reductions, and allocations are rounded to two significant figures					

recurrence intervals greater than 10 years), and/or in years of average or above normal runoff that immediately follow such events. Other land-use related sources, such as sheetwash erosion associated with roads are chronic, in that they occur during the wet season almost every year, with rates being proportional to precipitation.

Critical conditions with regard to flow are addressed through implementation actions to protect or enhance baseflow as described in Chapter 6. Other critical water quality parameters are also addressed including the target for redd scour that addresses sediment-related water quality objectives and water quality objectives for habitat complexity (e.g., as an aspect of population and community ecology). Implementation actions are also recognized to protect and/or enhance fish passage, stream temperature, and baseflow (including development of guidelines for the protection of instream flow for salmonids).

CHAPTER 6: IMPLEMENTATION PLAN

Key Points

- The Water Board's legal authorities to control pollution are derived from the state Porter-Cologne Act and the federal Clean Water Act.
- The implementation plan describes a program of actions to attain water quality objectives for settleable material, and for population and community ecology.
- Actions to reduce sand and finer sediment delivery focus on management of roads, grazing areas, and addressing the problem of channel incision.
- Necessary reductions in sediment delivery from grazing areas can be achieved through continued implementation of existing ranch management and state pollution control programs (e.g., the Water Board pollution control permit for grazing operations)
- Necessary reductions in sediment delivery from roads can be achieved by adopting a new state pollution control program.
- The preferred approach to address effects of incision on sediment delivery and habitat is collaborative restoration to increase large woody debris in channels and reconnect the channel to its floodplain, in reaches where this is safe and feasible.

6.1 Introduction/Overview

Total sediment delivery to Lagunitas Creek and/or its tributaries is two-or-more times the natural background rate and also richer in sand and finer sediment. The primary sources of sediment to Lagunitas Creek are:

- Channel incision and associated bank erosion, which accounts for about 60% of the total;
- Gully erosion and landslides resulting from natural processes, legacy land-use disturbances (e.g., 19th century logging and intensive historical grazing), and also roads, account for about 20% of the total; and
- Road surface erosion along the tread of dirt roads, and on the cut banks and in the inboard ditches on all roads, account for about 20% of the total load.

All channel incision and road-related erosion is human-caused, and part of the gully and landslide erosion is human-caused as well.

Channel incision is the result of multiple direct and indirect historical and ongoing disturbances occurring throughout the watershed. Working together watershed stakeholders can implement projects to address channel incision by restoring a balance between channel sediment transport

capacity and supply, and partially restoring channel habitat complexity and connection to the floodplain. Actions would include installation of engineered log jams and riparian management and restoration efforts to substantially increase the number and size of large fallen trees in channels, and projects to reconnect the channel to its floodplain in reaches where these actions would not threaten public safety or damage property.

Sediment delivery to channels from land-use related gully and landslide erosion can be reduced substantially through continued implementation of existing regulatory programs for grazing and construction activities.

Roads also cause landsliding and gully erosion, and contribute sediment to channels via road surface erosion. To address these road-related sources of sediment delivery, staff recommends developing a new Water Board administered pollutant control program: a conditional waiver of waste discharge requirements (see details below).

6.2 Legal Authorities and Requirements

The Water Board's legal authorities to require water pollution control actions are derived from the state Porter-Cologne Act and federal Clean Water Act. The Porter Cologne Water Quality Control Act gives Water Boards the authority to issue waste discharge prohibitions, waste discharge requirements (WDRs), and/or waivers thereof, to control discharge of pollutants from point-and-nonpoint sources⁴⁸ into the waters of the state (California Water Code 13000 et seq). In 2004, the state adopted a policy for implementation and enforcement of its nonpoint source pollution control program (NPS program)⁴⁹, which requires all nonpoint pollution sources that could affect water quality shall be regulated under waste discharge requirements or waivers, and/or waste discharge prohibitions. Under the adopted NPS program, waivers of waste discharge requirements must be conditioned on a monitoring program to ensure that water quality is protected.

6.3 Approaches to Achieve Allocations

Roads

In water years 1983 through 2008, we estimate about one-fourth of total sediment delivery to Lagunitas Creek upstream of Devils Gulch, and about one-fifth upstream of Olema Creek, was from roads (Tables 5.2a and 5.2b), and the percent contribution to fine sediment supply was higher because road sediment delivery is comprised largely of sand and finer grains.

Furthermore roads are a chronic sediment source, contributing in nearly all years, as opposed to other large sources, which are only significant in wet years.

Stillwater Sciences (2010, Table 4.1, p. 61) estimates that in water years 1983 through 2008, about 80 percent of all road-related sediment delivery was produced in the San Geronimo Creek

⁴⁸ Point sources typically are discharges of pollutants from a discrete conveyance (or pipe). Nonpoint sources are everything else that has not been defined as a point source (e.g., vineyards, rangelands, roads, etc.).

⁴⁹ The policy can be obtained at http://www.swrcb.ca.gov/water_issues/programs/nps/docs/oalfinalcopy052604.pdf.

watershed, which has a much higher density of roads than in other parts of the watershed. In the San Geronimo Creek watershed, there are about 72 miles of roads, 19 miles of trails⁵⁰, and 10 miles of driveways, about 70 percent of this network is publically owned (Lynx Technologies, 2007, unpublished data). Not including trails and driveways, the density of roads in the San Geronimo Creek watershed is 7.4 mi/mi², about half is paved and about half are unpaved (dirt or gravel). The density of the roads in the lower Lagunitas Creek watershed is much lower and estimated to be about 3.4 mi/m² with a similar percentage in public ownership (Lynx Technologies, 2007, unpublished data). The total length of roads over the entire project area is 135 miles.

Many aspects of road erosion-control projects can make them attractive to public agencies that award grants for water quality and/or habitat enhancement, and/or to the landowners and managers who depend on the roads. For example, rural unpaved roads are among the most cost effective sediment sources to control⁵¹, and pro-active investments to stormproof roads pay significant dividends through large reductions in future costs for maintenance and repairs. Well designed and maintained roads also provide much better driving conditions.

In evaluating the nature and scope of a regulatory program to control sediment delivery from roads, we note that substantial progress has been made within the past decade in reducing sediment delivery from unpaved roads located on lands managed by the Marin County Open Space District within the San Geronimo Creek watershed. These roads represent about one-third of the total length of unpaved roads within the TMDL project area (27 miles, as estimated by Lynx Technologies, 2007, unpublished data). We commend the Open Space District for implementing treatments at all priority erosion sites that could deliver to channel reaches that provide habitat for steelhead and/or coho salmon. We also commend the California Department of Fish and Wildlife, which provided substantial grant funding and technical support.

Progress also is being made in other public parklands within the watershed. The Marin Municipal Water District is taking a leadership role in efforts to inventory and treat erosion problems on unpaved roads on their own property, and also in Samuel P. Taylor State Park and the Golden Gate National Recreation Area (in total, there are 33 miles of unpaved roads in these parks, as estimated by Lynx Technologies, 2007, unpublished data).

In addition to the unpaved roads located on public lands, there are about 21 miles of privately owned unpaved roads in the project area (Lynx technologies, 2007, unpublished data), that need to be inventoried and treated to control erosion problems. Almost all of these roads (20

⁵⁰Width was the primary attribute used to distinguish a road from a trail. Trails are typically ≤ 4 feet wide and only are open to hikers, mountain bikers, and/or horseback riders. Many features classified as trails actually appear to be former roads (Lynx Technologies, 2007, pp. 7 and 12).

⁵¹ For unpaved roads, typical costs are less than \$50 per cubic yard of sediment savings (e.g. sediment prevented from entering a stream channel) (See for example, PWA, 2007a).

miles) are located on ranch properties, which already are regulated under the Water Board's pollutant control program for grazing operations in the Tomales Bay watershed (Order R2-2013-0039).

Discharges of sediment to channels from publically owned roads are not currently regulated by the Water Board. Nevertheless, consistent with the memorandum of understanding (MOU) for the maintenance and management of unpaved roads in the Lagunitas Creek watershed (MMWD et al., 2001), public agencies have completed field inventories to identify all significant sites of sediment delivery from their unpaved roads within the project area (PWA 2007a, PWA 2007b, PWA 2010, and Stetson, 2013).

To ensure that effective sediment source controls are implemented on all public roads – paved and unpaved-, Water Board staff recommend that WDRs or a conditional waiver of WDRs be adopted to meet the road sediment delivery performance standard (See Table 4.2 in the Proposed Basin Plan amendment). The required actions would be for.

1. The County of Marin, Department of Public Works, within five years of TMDL adoption, to conduct an inventory of its paved roads within the project area to identify sediment delivery sites, and produce a schedule for treatment, as needed to achieve road sediment delivery performance standard.
2. The California Department of Parks and Recreation within SP Taylor State Park, and the US National Park Service within that portion of the Golden Gate National Recreation Area that is in the TMDL project area, to control sediment delivery sites on unpaved roads to achieve the performance standard for road-related sediment delivery.
3. All public agencies with jurisdiction over roads within the project area to adopt and implement road maintenance guidelines to protect aquatic habitat, water quality, and salmonid fisheries; conduct an annual training program for road maintenance staff, and once every three years submit a report that documents implementation, and/or recommends adaptive updates to the maintenance practices.

Considering the significance of the Lagunitas Creek watershed for coho salmon, and the impact of excessive sedimentation, road erosion control projects likely should continue to receive strong support from public agencies providing grants including the Water Board, which could help to defray a significant portion of the total cost.

Gullies and Landslides

Gullies and landslides account for about 20-to-25 percent of the total sediment delivery to channels, which are the result of:

- a) Natural processes;
- b) Legacy land-use disturbances (e.g., intensive historical grazing; 19th century logging; residential development in upland areas of San Geronimo Creek watershed); and/or
- c) Active/ongoing land-uses including problem roads (that concentrate storm runoff), some new construction projects, and/or continued active grazing in and around active or dormant gullies and landslides.

Continued implementation of existing state and/or local regulatory programs including the Water Board's pollutant control programs for grazing operations that covers all active livestock operations in Tomales Bay watershed, state and local regulatory programs to control pollutant discharges associated with construction projects, together with natural recovery of second-growth forests, amendment of the County stormwater permit to control excessive sediment delivery generated by road-related erosion (see previous section) will be effective in achieving TMDL load allocations for gullies and landslides.

On properties where livestock grazing is active, reductions in sediment delivery from actively eroding gullies and landslides can be accomplished through: a) pasture management practices to achieve targets for residual dry matter; b) installation of fencing to exclude grazing from active or potentially active landslides and gullies; c) biotechnical stabilization of gullies and/or shallow landslides; and d) implementation of retrofits to problem roads.

Channel Incision

During water years 1983 through 2008, channel incision and associated bank erosion was the largest human-caused sediment source, representing about 60 percent of total sediment supply. Channel incision also greatly increases sediment transport rates, degrades channel habitat complexity, and disconnects the channel from the floodplain. We hypothesize that substantial reduction in the number and size of large fallen trees in channels, ditching and draining of valley floors (connecting naturally disconnected tributary channels to facilitate agriculture development), and dam construction are the primary causes for channel incision.

In future years, further significant lowering of the elevation of the streambed in these channel reaches is unlikely because hard bedrock is exposed in the channel bed in many locations along San Geronimo Creek and in the Shafter and State Park reaches of Lagunitas Creek, such that the rates of sediment delivery from incision are expected to decrease. Future primary concerns relating to incision are further stripping and/or removal of gravel from the streambed (increasing the frequency/extent of bedrock channel sub-reaches), and persistent simplification of channel habitat complexity and disconnection from the floodplain.

With incision and less large woody debris in channels, pool habitat has been degraded (i.e., pool frequency, depth, and cover have been significantly reduced) and bedrock sub-reaches – that

provide little or no spawning habitat and very poor rearing habitat – are now more common. Also, as incision has progressed, channels have become much narrower, such that deposition/formation of gravel bars and inset floodplain is inhibited. Therefore, bank erosion and resultant channel widening (in narrow incised reaches) is a necessary ingredient to support recovery/restoration of complex channel habitat and the formation of an inset floodplain. Also, in many locations, over the past twenty-to-fifty years, the rates of bank erosion have been quite low (0.1-to-0.2 feet/year). For these reasons, bank erosion should not automatically be considered a threat to buildings or other critical infrastructure in most or all locations.

In the Lagunitas Creek watershed, excluding the San Geronimo Creek sub-watershed, dam construction appears to be a significant contributing factor to channel incision (Stillwater Sciences, 2010, p. 3, and pp. 80-82). Incision has reduced the length of channel that is connected to the floodplain and also has contributed to a reduction in large woody debris loading (via increases in shear stress on the channel bed during large runoff events). The paucity of debris jams and disconnection from the floodplain likely have reduced carrying capacity for juvenile coho salmon and steelhead, contributing to significant reductions in smolt production and fitness (Stillwater Sciences, 2008, p. 8, 12, 17, 27, and 62).

Also specified in Water Rights Order 95-17, the Marin Municipal Water District is required to reduce sedimentation and achieve an appreciable improvement in fisheries habitat conditions. Based on our review of the results of a long-term program of streambed monitoring (Balance Hydrologics, 2010), we conclude that although the district has implemented a laudable sediment control and habitat enhancement program, appreciable improvement in fisheries habitat conditions and reduced sedimentation have not been demonstrated (Napolitano, 2009). Considering the nature of sediment supply to Lagunitas Creek, which is dominated by channel incision (Stillwater Sciences, 2010), and the fact that incision also is the primary agent for loss of habitat complexity and connectivity downstream of the dams, it does not appear that an appreciable improvement in habitat conditions will be realized until some of the impacts of channel incision - the primary source of sediment and cause of habitat degradation - are addressed.

Attainment of the numeric targets for settleable material and population and community ecology are premised on a significant reduction in sedimentation and an appreciable improvement in habitat conditions. Therefore upon attainment of these targets, Water Board staff predicts that these requirements of Water Rights Order 95-17 will be achieved. Similarly, we hypothesize that implementation of the habitat restoration actions that are called for by the Basin Plan amendment, will facilitate attainment of NOAA Fisheries population target for down-listing the Lagunitas Creek watershed population, which corresponds to 1300 returning adult coho salmon per year achieved over four consecutive generations (See Numeric Targets for a detailed discussion). Given achievement of the numeric targets and a doubling of side channel and alcove habitat area, we think that this key milestone on the path toward recovery of these populations can be achieved within the next 20 years.

There are tremendous opportunities to restore habitat complexity and connectivity in the Lagunitas Creek watershed. Along most of Lagunitas Creek and also its tributaries, except San Geronimo, the channel and adjacent valley flat are located within state and/or federal parks where potential conflicts with existing development and land uses are limited. The only significant constraint is being able to ensure that the integrity and function of roads and bridges are not inadvertently compromised. These approaches are described in detail in the sections that follow (“Wood in Channels” and “Floodplain Restoration,” pp.84-89).

In contrast to Lagunitas Creek, in the San Geronimo Creek tributary watershed, dams are not a cause or contributing factor to channel incision because there is a series of hard bedrock steps - “The Ink Wells” – that control bed elevation at the mouth of San Geronimo Creek where it joins Lagunitas Creek⁵². In this part of the watershed, likely causes and/or contributing factors for incision may include:

- Substantial reduction in the number and size of large fallen trees in channels⁵³;
- 19th century ditching (connecting) of naturally disconnected channels;
- Intensive grazing during the 19th and continuing into the mid-20th century; and
- Residential development in the Woodacre area following WW II.

In San Geronimo Creek watershed, further incision can be controlled and the complexity of the channel physical habitat structure can be enhanced through installation of engineered log jams in locations where these structures would not threaten human safety or property (see Abbe et al, 2003b). The amount of sediment savings and habitat enhancement that can be achieved is limited, however because many homes and critical infrastructure often are located very close to the creek. Types of debris jams that may provide natural analogs to guide design of engineered log jams along San Geronimo Creek and its tributaries include:

- a) Bank input jams (one-or-more fallen trees, that are partially perched above the channel) that form small bars and pools, that could be installed safely at many locations along San Geronimo Creek and in its tributaries;

⁵² The hard meta-volcanic rock exposed in the channel bed greatly limits the rate at which the channel can cut down into its bed at this location. Therefore, when/if Lagunitas Creek experienced an episode of incision in response to construction of Peters Dam, the resultant lowering of base-level on Lagunitas Creek would not also propagate upstream and cause San Geronimo Creek to cut down into its bed.

⁵³ There are many causes for this including nineteenth century logging of old-growth redwoods (mature second-growth redwoods are much smaller, and therefore, typically much more easily mobilized by high flows, so they are not effective in trapping gravel and sand, and aggrading the channel), aggressive snagging, salvage, and debris removal activities that were common practices up until recent decades. Also, once the channels became incised, they also narrowed, and now when trees fall toward the channel, many are perched above it, as a consequence of the fact that the probability of a tree falling into a narrow deep channel is much less than into a wide shallow channel.

- b) Log steps (a single log forming a low dam) and/or small channel-spanning debris dams (composed of several logs) that could be installed in bedrock reaches of tributaries to force step-pool units to form, and thereby greatly enhance spawning and rearing habitat and limiting additional incision;
- c) Bankfull-bench jams, that create pool-bar units and local floodplain patches that also could be installed in tributaries or along San Geronimo Creek, in reaches where buildings and roads are not near the channel, and/or where the incised channel already has widened substantially; and/or
- d) Valley jams (a large number of large fallen trees that form a jam that is wider than the existing channel) to facilitate channel aggradation and widening and formation of multi-threaded channels, which might be appropriate along the North Fork of San Geronimo Creek, upstream of the Dickson Weir, to reconnect the channel to its historical floodplain⁵⁴.

As described above, incision of San Geronimo Creek and its tributaries is largely the result of legacy land-use activities, both direct disturbances to channels and indirect disturbances throughout the watershed that are widely distributed in space and time, and as such, it is not possible for an individual landowner in most cases to effectively address or to bear responsibility for the problem of channel incision. Therefore, Water Board staff endorses the formation of voluntary stewardships to facilitate implementation of reach-scale projects to control channel incision and partially restore habitat functions in the San Geronimo Creek watershed. Public funding to support such efforts should be prioritized in reaches where both potential gains in habitat function are significant, and necessary landowner support and participation can be achieved. Examples of the types of channel reaches that may have a high potential for enhancement include those that are:

- a) Along the North Fork of San Geronimo Creek, upstream of the Dickson Weir, where it may be safe and feasible to aggrade the channel and reconnect it to a broad historical floodplain;
- b) Adjacent to reaches where coho salmon spawning density already is high;
- c) At/near tributary confluences, where backwater conditions may be created or enhanced to increase winter rearing habitat capacity for coho salmon and steelhead;
- d) In reaches where an inset floodplain can form or be constructed, and/or where an inset floodplain already has formed, and an alcove or side channel could be constructed; and/or

⁵⁴ If feasible and compatible with adjacent agricultural land-uses, and implemented in combination with restored fish passage upstream of the Dickson Weir, there appears to be the potential to create a significant amount of very high quality winter rearing habitat for coho salmon.

- e) Where bank habitat suitable to provide winter high flow refuge habitat for salmonids and other native aquatic species can be created and maintained.⁵⁵

Wood in Channels

Much more wood is needed in channels (at a minimum a two-to-six-fold increase) in order to achieve the TMDL and related targets for sedimentation and habitat complexity and connectivity. During the historical period, there has been a significant reduction in the number and size of large fallen trees in channels in the Lagunitas Creek watershed (for discussion, see Section 4.4). This change has been a key factor in channel incision, simplification of channel habitats, disconnection of the channel from its floodplain, elevated rates of streambed mobility, and increases in fine sediment deposition (See Sections 2.1 and 4.4).

Anadromous salmonids in Pacific Coastal Ecoregion, as well as all other native stream and riparian species, have evolved to exploit complex and interconnected habitat created by large wood. Coho salmon, for example prefer deep pools with good cover alternating with gravel riffles, and well shaded channel reaches that are connected to adjacent floodplains, alcoves, and side channels. All of these habitats are formed and maintained by key pieces of large woody debris. Drawing on an extensive body of research, Collins et al. (2012) postulate that key pieces of large woody debris - those large enough to resist transport even during large floods⁵⁶ - are the primary agent structuring complex and interconnected channel and floodplain habitats in forested watersheds in the Pacific Coastal Ecoregion⁵⁷. Also, as a corollary hypothesis, they propose that when land-use activities reduce the size of the largest trees recruited to channels and/or the rate of input of key pieces in general, this causes the physical habitat structure in channels to become greatly simplified.

Research examining natural process-form relationships governing debris jams in the Nisqually and Queets rivers, large rivers in the Pacific Northwest that have experienced minimal disturbance⁵⁸ provides insight about the types of debris jams that were present in Lagunitas Creek prior to disturbance (Collins and Montgomery, 2002; Abbe and Montgomery, 2003). Along Lagunitas Creek in SP Taylor State Park and Golden Gate National Recreation Area, prior to disturbance we hypothesize that bar-apex jams were common in unconfined reaches (Figure 6.2), and flow-deflection Jams would have been common throughout (Figure 6.3) (see Abbe and Montgomery, 1993, Figure 11). Both bar-apex and flow-deflection jams are effective in forming bar-pool units, side channels, and floodplain patches.

⁵⁵ In some locations where bank erosion presents a significant threat to a home or other building, installation of a flow-deflection jam (see below, Figure 6.3) or bank input jam may be effective in providing protection and in creating habitat.

⁵⁶ In general, key pieces of debris (e.g., large fallen trees) have a diameter $\geq$ one-half bankfull depth and length $\geq$ one-half bankfull width with an intact root-wad.

⁵⁷ Lagunitas Creek is within the Pacific Coastal Ecoregion, which extends along the west coast of North America south into the Santa Cruz Mountains (Naiman and Bilby, 1998, Figure 1.1, pp. 6-7).

⁵⁸ The Queets is largely pristine, and the Nisqually, although logged in the 19th century, today has extensive reaches with mature riparian forest where the channel can recruit large trees.

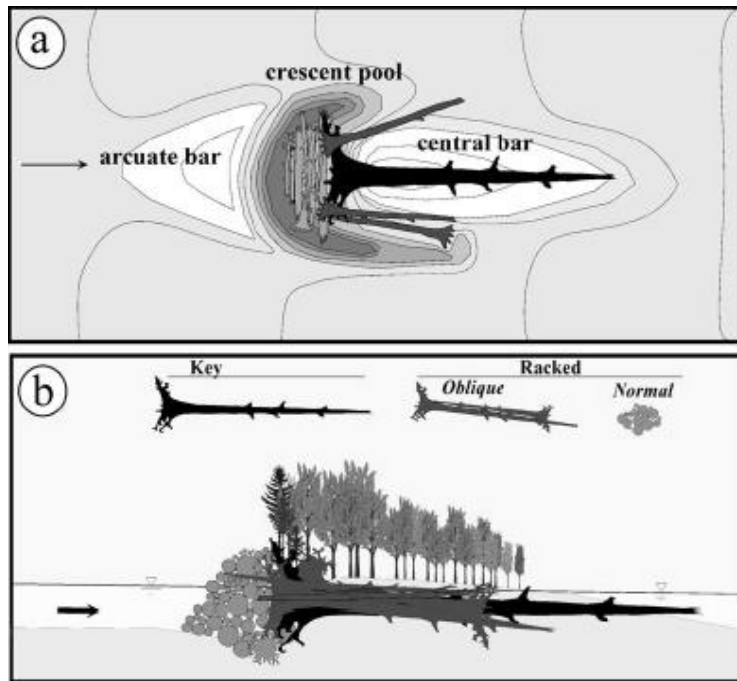


Figure 6.1: A bar-apex jam in plan (a) and profile (b) view (Source: Abbe and Montgomery, 1993). Prior to disturbance, we hypothesize that bar-apex jams were common in unconfined reaches of Lagunitas Creek where it now flows through SP Taylor State Park and the Golden Gate National Recreation Area (see Abbe and Montgomery, 1993, Figure 11). These jams create natural branching channels, pools and gravel bars, and long-lasting floodplain patches.

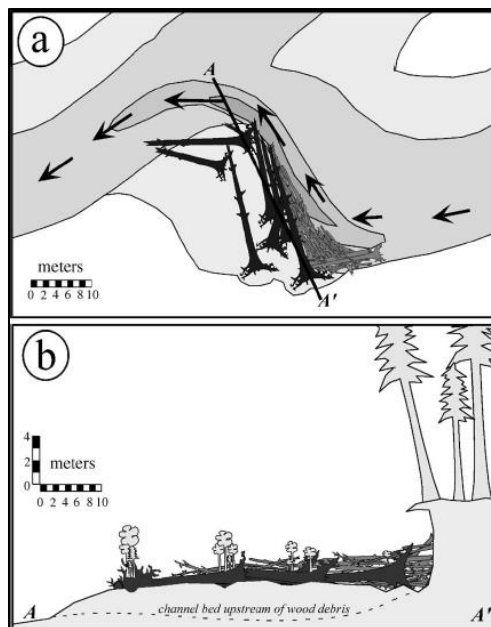


Figure 6.2: A flow-deflection jam in plan and cross-section views (Source: Abbe and Montgomery, 1993). Like bar-apex jams, these also form local floodplain patches, pools, and gravel bars. Based on review of Abbe and Montgomery 1993, we also hypothesize that flow-deflection jams were common in unconfined reaches along Lagunitas Creek.

Analysis of relationships governing debris jam formation in reference channels like the Queets River and Nisqually River, together with careful examination of naturally formed debris jams found in Lagunitas Creek today, can help to create a template for the placement of key pieces and/or design of engineered log jams, that could help address the near-term wood deficit in Lagunitas Creek watershed. The approach of using natural process-form relationships to guide design and construction of engineered log jams has been successfully implemented in many other streams and rivers in northwestern California (Fiori Geosciences, 2012), Washington State (Pess et al., 2011; Abbe et al., 2003a), and southeastern Australia (Brooks et al., 2004).

Another approach gaining favor where potential risks to public safety and property are low, is to topple large whole-trees intact (e.g., trees large enough to form stable jams), and then to let the channel design the jams itself (Figure 6.4). This approach can be implemented at a fraction of the cost of a traditional hard engineered log jam. Toppling trees and letting the channel form its own jams, might work well on Devils Gulch in reaches where wood loading and channel complexity is low, and large redwood or Douglas fir are growing adjacent to the channel. There also appear to be some locations along Lagunitas Creek, where there are natural constrictions and bends in the channel, there is a good buffer between the channel and road, and massive redwoods and Douglas fir, a meter or more in diameter, are growing near the channel.



Figure 6.3: Inman Creek project in the Garcia River watershed implemented by the Nature Conservancy in partnership with the Conservation Fund, and Department of Fish and Wildlife.

In summary, increasing large woody debris loading (the number of large fallen trees in the channel) by a factor of two-to-six will greatly enhance the structural complexity of channel habitat and its connection to the floodplain. Many plane-bed reaches will be converted to pool-riffle reaches, average pool depth and cover will be enhanced, the size and frequency of riffles and gravel bars will be increase, and the total length of side channels and percent of channel length connected to the floodplain also will be increased. As a result, we predict there will be a significant increase in winter and summer carrying capacity for juvenile coho salmon and steelhead trout.

Floodplain Restoration

Floodplains provide essential winter rearing and refuge habitats for coho salmon including alcoves and side channels (Bustard and Narver, 1975; Nickelson et al., 1992a and b; Tschaplinski and Hartman, 1983). Floodplain loss is thought be a primary factor in the decline of coho salmon populations throughout the Pacific Coastal Ecoregion (Nickelson et al., 1992a; Beechie et al., 2001; Giannico and Hinch, 2003), and locally in the Lagunitas Creek watershed (Stillwater Sciences, 2008) where the coho salmon population is at risk of extinction. Floodplains also provide winter rearing and refuge habitat for juvenile steelhead (Swales and Levings, 1989; Solazzi et al., 2000; Stillwater Sciences, 2008), and essential habitat for many other native fish and wildlife species within the wet season and/or throughout the year.

Within the Lagunitas Creek watershed, a suite of historical and/or ongoing land-use activities have caused channels to become deeply incised, such that historical floodplains have been isolated and converted to terraces that are infrequently or very rarely inundated even during extreme high flows with recurrence intervals $\geq$ several decades. The only significant remaining floodplain, approximately 5 kilometers in length, is located adjacent to Lagunitas Creek in the Tocaloma Reach upstream of its confluence with Nicasio Creek.

Once channels have incised, there are essentially four approaches that can be employed to re-establish connection to floodplains⁵⁹:

- 1) Grade control and natural sediment deposition to aggrade the channel;
- 2) Grade control and earth moving to aggrade the channel;
- 3) Passive restoration of an inset floodplain via bank erosion and channel widening; and
- 4) Active restoration of an inset floodplain via earthmoving and biotechnical engineering.

Approaches 1) and 3) typically require several decades-or-more to re-establish the connection between the channel and floodplain (Beechie et al., 2008). Also, Approach 1) is premised on sufficiency of sediment supply both to the reach you are trying to aggrade and to all

⁵⁹ Approaches 1) and 2) reconnect the channel to its historical/former floodplain, by re-establishing its former bed elevation. Approaches 3) and 4) create a new floodplain at a lower elevation, and the width of the inset floodplain is typically much narrower than the former/historical floodplain because the inset floodplain is nested within and confined by the higher and wider historical floodplain.

downstream reaches (to avoid inadvertently contributing to a new episode of incision downstream).

Approaches 2) and 4) are much more expensive because they involve significant earth moving and import and/or export of fill. These approaches have the advantage however of immediately reconnecting the channel to its floodplain, and of being feasible in many locations throughout the channel network.

Grade control, associated with Approach 1) and Approach 2), can be accomplished using engineered log jams (typically steps or valley jams, see Abbe et al., 2003b), and/or by construction of biotechnical (boulder steps) or traditional engineering structures.

Another approach for re-aggrading incised channels (reconnecting them to their floodplains) that is rapidly gaining favor is to re-establish beaver colonies in streams where beaver are or were native. With modest human intervention – construction of starter dams in reaches that are favorable for beaver colonization and also where the starter dams are predicted to have a high probability of remaining in-place for a period of years – it may be possible with little disturbance or cost – to rapidly enhance channel habitat complexity and connection of the channel to the floodplain (see, Pollock et al., 2012). Also, we note that a recent scientific review makes a persuasive case for concluding that beaver were native to most streams in coastal California including those in the Bay Area (Lanman et al., in-press, 2014).

Potentially the most promising location to explore floodplain restoration, with regard to its ecological potential⁶⁰, would be along Lagunitas Creek downstream of its confluence with Nicasio Creek in the Golden Gate National Recreation Area because it appears that historically, this reach had a broad floodplain that likely provided excellent over-winter habitat for coho salmon, steelhead, and other native fish and aquatic wildlife species. At present, most of this reach is very deeply incised and habitat is greatly simplified, and it appears to provide little or no winter rearing habitat for coho salmon or steelhead, and little or no habitat for California freshwater shrimp. Also, its location, directly downstream of the high functioning Tocaloma Reach (that in general provides very high quality winter rearing habitat), presents the possibility of building out from, and expanding the contiguous length of channel that provides complex channel and inter-connected floodplain habitat by a few miles-or-more.

There are few buildings or other infrastructure in the Lower Lagunitas Reach and valley width is greatest here (in theory making it easier to accommodate both ecosystem restoration and existing infrastructure). Also, prior to construction of Seegar Dam, Nicasio Creek was a very large source of coarse sediment supply and deposition in this reach. Therefore, it's possible the adjacent valley flat (now a terrace but historically a floodplain) is composed at least in part of sand and gravel. If so, using Approach 4) to try to restore floodplain connection, as the former floodplain/current terrace was excavated and lowered, some of the material removed could be

⁶⁰ Also, arguably perhaps the most challenging, as the channel is very deeply incised in this reach.

used as fill to re-aggrade the channel and/or could sold as aggregate (reducing potential sediment import or export costs)⁶¹. Approaches 1) or 2) - re-aggrading the channel - would require a very large volume of coarse sediment, much of which perhaps could be dredged and transported from Nicasio Reservoir.

Other locations that appear promising with regard to floodplain restoration potential include incised and unconfined reaches along Devils Gulch, McIsaac Creek, and Cheda Creek, and also along Lagunitas Creek in SP Taylor State Park, in incised and unconfined reaches where the channel and Sir Francis Drake Boulevard are not close together and/or where the road is or could be protected from erosion and flooding. With regard to these reaches, as part of a broader feasibility analysis, it would be important to also evaluate potential effects of upstream or tributary floodplain restoration on the continuity of coarse sediment supply to downstream reaches in order to avoid unintended impacts to downstream channel, floodplain, and wetland functions.

Opportunities for floodplain restoration appear quite limited along most of San Geronimo Creek and its tributaries because many houses and other buildings are located close to the creek⁶². In some locations, passive restoration of an inset floodplain by allowing bank erosion and channel widening to occur would be compatible with existing development, where buildings are located far enough away, such that future predicted widening would not be a threat. In these locations, inset floodplain widths would be small compared to more promising potential locations elsewhere in the watershed that are described above.

In addition to substantial enhancement of habitat complexity and connectivity for coho salmon, steelhead, and other native fishes, floodplain restoration also would increase fine sediment storage and substantially reduce shear stress on the channel bed during large floods. The fine sediment storage benefits associated with floodplain restoration would not be limited just to water quality restoration, but also could be significant with regard to carbon sequestration. Under natural conditions, floodplains likely stored one-third-or-more of the sediment supplied to fish-bearing channels (Stillwater Sciences, 2004; Ritchie et al., 2004; Trso, 2012). In addition, the floodplains provide sites for growth of massive long-lived coast redwood and Douglas fir, and then contribute large fallen trees that trap much of the coarse and fine woody material that is transported in the channels. As such, it is possible there might be additional interest and potential funding for floodplain restoration with regard to potentially significant carbon sequestration benefits.

⁶¹ Although gravel mining is no longer active in this reach, a sand and gravel supply business (with stock pile sites and trucks) is still in operation near the confluence of Lagunitas and Nicasio creeks.

⁶² A possible exception could be along the North Fork of San Geronimo Creek upstream of the Dickson Weir.

Evaluation and Monitoring

Three types of monitoring are recommended to assess progress toward achievement of numeric targets and load allocations for sediment:

- 1) Implementation monitoring to document actions to reduce fine sediment discharge and enhance habitat complexity and connectivity.
- 2) Upslope effectiveness monitoring to evaluate effectiveness of sediment control actions in reducing rates of sediment delivery to channels
- 3) In-channel effectiveness monitoring (e.g., streambed mobility and redd scour) to evaluate channel response to management actions and natural processes

Implementation monitoring would be conducted by landowners or designated agents. The purpose of this type of monitoring is to document that sediment control and/or habitat enhancement actions specified herein actually occur.

Staff recommends that the Water Board working in partnership with other government agencies conduct upslope effectiveness monitoring, which could include an update of all-or-part the watershed sediment budget (Stillwater Sciences, 2010), to re-evaluate rates of sediment delivery to channels from land-use activities and natural processes (ten-years subsequent to Basin Plan amendment adoption) in the fall of 2024, when sediment delivery associated with land-use activities are projected to be reduced by 25 percent-or-more.

In-channel effectiveness monitoring should be conducted by local government agencies with scientific expertise and demonstrated capability in working effectively with private property owners (to gain permissions for access), as needed to develop a representative sample of stream habitat conditions, in relation to sediment supply and transport within the watershed. In-channel effectiveness monitoring needs to include measurements of redd scour and streambed mobility to evaluate attainment of water quality objectives for settleable material.

Streambed mobility will be measured in channel reaches with adjacent floodplains. The length of a streambed mobility measurement reach should be $\geq 10 \times$ (Bankfull Channel Width) to obtain a reliable estimate of the reach-average slope, which exerts a significant influence on the calculated value of τ^* . The methods described in Cover (2012) provide a sound basis for estimating reach-average values for streambed mobility.

Redd scour will need to be measured at 30-or-more potential spawning sites, with 4-or-more scour measurements per spawning site to establish a high level of statistical confidence in estimated values ($\geq 95\%$ confidence and $\geq 80\%$ power). Methods for conducting field surveys to estimate depth and frequency of redd scour described in Schuett-Hames et al. (1999a) provide a sound basis for estimating median value of redd scour. Redd scour sampling sites should be stratified based on estimated average annual sediment supply rate.

Large woody debris loading in channels also needs to be surveyed and assessed to evaluate attainment of the numeric targets for large woody debris loading, and to guide development of reach-specific prescriptions for installation of engineered log jams and riparian management actions to maintain or exceed the target values in future years through natural recruitment. Lawrence et al. (2012) and Schuett-Hames et al. (1999b) provide guidance regarding methods for surveys to estimate large woody debris loading. Desired level of statistical confidence is 90% and desired level of power is 80% for estimate values of wood loading in redwood and hardwood channel reaches.

Desired measurement frequency for streambed mobility, redd scour, and large woody debris is once every three years. At a minimum, repeat surveys will be conducted every five years.

In addition to the above described monitoring program to evaluate attainment of numeric targets for sediment, the Water Board may monitor turbidity (and/or estimate sediment supply to channels) in a subset of the channel reaches where streambed mobility and/or redd scour also are measured.

Adaptive Implementation

In concert with the monitoring programs, described above, the Lagunitas Creek Sediment Reduction and Habitat Enhancement Plan and TMDL will be updated as necessary. At a minimum, in adaptively updating the Basin Plan amendment, we also will consider the results of validation monitoring conducted to confirm or reject hypotheses regarding effects of actions to enhance large woody debris loading and floodplain area on population dynamics of coho salmon, steelhead, and California freshwater shrimp. The Water Board also will consider the results of salmonid population monitoring programs including juvenile population estimates, adult spawner surveys, and smolt outmigration surveys performed to evaluate the status and trends of these populations, and also related analyses of smolt population dynamics in response to changes in the quantity and quality of freshwater habitat.

The Marin Municipal Water District (MMWD) has conducted long-term monitoring to estimate juvenile coho salmon and steelhead populations and the population of adult coho salmon since water year 1995, and also the population of adult steelhead since water year 2002 (see <http://marinwater.org/controller?action=menuclick&id=442>). Beginning in water year 2006 and continuing through present, MMWD also has operated a trap to estimate the number and fitness of coho salmon and steelhead smolts (juvenile fish migrating from freshwater into the ocean). MMWD's efforts are supplemented by additional surveys by the Salmon Protection and Monitoring Network (SPAWN) in the San Geronimo Creek sub-watershed, and by the US National Park Service in the Olema Creek sub-watershed.

The above described population censuses provide a basis for evaluating the population status and trends for coho salmon and steelhead in the Lagunitas Creek watershed. In addition, recommendations provided within the "California Coastal Salmonid Monitoring Program" (CMP) (Adams et al., 2011) and future updates to this document, should be considered in

refinement of the protocols used to conduct redd counts and adult spawner surveys, and for juvenile population censuses in the Lagunitas Creek watershed. The CMP has been formally incorporated into recovery planning efforts for coho salmon in coastal California to provide a basis for evaluation of the status and trends of individual populations and also at the ESU-level (Adams et al., 2011; pp. 13-14). Redd counts can be converted to accurate estimates of the number of spawners based on the methods described in Gallagher and Gallagher (2005), and Gallagher et al. (2007). These methods are recommended to reduce bias, and improve accuracy and precision of estimates of adult abundance, which are fundamental to recovery planning. The CMP also indicates that Juvenile censuses will provide the primary basis for evaluation of the spatial structure of populations, and recommends protocols for snorkel surveys to estimate juvenile population abundance and spatial structure.

In Summary

Absent the concerted efforts of many dedicated people working together over the past thirty years, it is unlikely that coho salmon would still be found in Lagunitas Creek today. To recover native coho salmon and steelhead populations however, we must make substantial additional progress in our efforts to enhance water quality, habitat complexity, and habitat connectivity, and this progress is needed in the near-term. Let us embrace this challenge and as we move forward, inspired by the tenacity and majesty of these iconic fishes. In closing, we offer these words:

“Find your place on the planet. Dig in, and take responsibility from there.”

- Gary Snyder

CHAPTER 7: REGULATORY ANALYSES

7.1 Overview

This section includes the required regulatory analyses for the proposed Basin Plan amendment. These include: a) an evaluation of the potential environmental effects of reasonably foreseeable actions to comply with the Basin Plan amendment, as required under the California Environmental Quality Act (CEQA); and b) an assessment of agricultural water quality program costs (California Water Code, Section 13141).

7.2 Environmental Checklist

Under the Board's certified regulatory program for basin planning, the Board must satisfy the substantive requirements of Cal. Code of Regs., title 23, sec. 3777(a), which requires a written report that includes a description of the proposed activity, an alternatives analysis, and an identification of mitigation measures to minimize any significant adverse impacts. Section 3777(a) also requires the Water Board to complete an environmental checklist as part of its substitute environmental documents. Additionally, the Board must comply with Public Resource Code sec. 21159 when adopting performance standards such as those in the proposed Basin Plan amendment. Section 21159 requires the environmental analysis to include: (1) the reasonably foreseeable environmental impacts of the method of compliance; (2) the reasonably foreseeable mitigation measures; and (3) the reasonably foreseeable alternative means of compliance with a rule or regulation. The analysis must take into account a reasonable range of environmental, economic, and technical factors, population and geographic areas, and specific sites. Section 21159 further states that Board is not required to engage in speculation or conjecture, or to conduct a project-level environmental analysis.

This section contains the environmental checklist for the proposed Basin Plan amendment, and includes the required analyses mentioned above. The explanation following the checklist provides details concerning the environmental impact assessment. Based on this analysis, Water Board staff concludes that adoption of the proposed Basin Plan amendment would not cause any significant adverse environmental impacts.

ENVIRONMENTAL CHECKLIST

1. **Project Title:** **Lagunitas Creek Watershed Fine Sediment Reduction and Habitat Enhancement Basin Plan Amendment**
2. **Lead Agency Name and Address:** California Regional Water Quality Control Board,
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, California 94612
3. **Contact Person and Phone Number:** Mike Napolitano
(510) 622-2397
4. **Project Location:** Lagunitas Creek Watershed, Marin County,
California
5. **Project Sponsor's Name and Address:** California Regional Water Quality Control Board,
San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, California 94612
6. **General Plan Designation:** Not Applicable
7. **Zoning:** Not Applicable
8. **Description of Project:**

The Water Board proposes an amendment to its water quality control plan (Basin Plan) to establish a total maximum daily load (TMDL) for sediment in stream channels in the Lagunitas Creek watershed, and an implementation plan to achieve the TMDL and related goals for stream-riparian habitat enhancement. The project area includes the entire land area and all channels draining into and including Lagunitas Creek, below Peters and Seegar dams, downstream to the confluence of Lagunitas Creek with Olema Creek (see Figure 2.1). The project would involve management actions and erosion control projects to reduce fine sediment delivery (e.g., sand, silt, and clay) to Lagunitas Creek and its tributaries, and management actions to increase the amount of large woody debris in channels including through construction/installation of engineered log jams. Large woody debris additions would occur primarily in public parklands. Details are provided in the explanation following the Environmental Checklist below. The project establishes a total maximum daily load for sediment established at ≤ 120 percent of natural background and numeric performance standards for: a) sediment delivery from roads; and b) residual dry matter in grazing areas. It also establishes numeric targets for streambed mobility and redd scour that

define attainment of narrative water quality objectives for sediment and settleable material, and numeric targets for the amount of large woody debris in channels to define attainment of water quality objectives relating to habitat complexity. Performance standards and numeric targets apply throughout the project area. To avoid potentially significant impacts to cultural resources, biological resources, and/or hydrology and water quality, the project also includes the following environmental protection measures to:

- a) Design requirements for engineered log jams, so that they do not fully span the channel, to avoid potential blockage of movement by California freshwater shrimp, and to achieve consistency with the *California Freshwater Shrimp Recovery Plan* (USFWS, 1998);
- b) Requirements for hydrologic and geomorphic analyses, consistent with Abbe (2003b), and the Marin County General Plan, (Goal EH-3 and Implementing Program, EH-3.f, Marin County, 2007) to support design of engineered log jams, including avoidance of significant increases in flooding or erosion, for all structures installed in channel reaches with adjacent residential, commercial, and/or for public facility uses;
- c) Implementation of stormwater pollution prevention plans (approved by the Water Board) for all road-erosion control and/or engineered log jam construction projects, and as needed, limitations on the construction period for compliance projects to the August through October, and not using heavy equipment within ¼ mile of any nesting site for Northern Spotted Owl to avoid potentially significant impacts to all special status bird species, and/or potentially significant impacts to water quality;
- d) Conduct of pre-construction notification, education, inspection, and monitoring around sensitive cultural resource sites and to protect special status species;
- e) Best management practices for survey and relocation of special status species; and
- f) Best management practices for diversion and de-watering of stream channels for construction of engineered log jams and/or at stream crossings on roads (to control road-related sediment delivery to channels).

9. Surrounding Land Uses and Setting:

Surrounding land uses include a mix of recreation, agricultural, commercial, and residential uses. The headwaters of Lagunitas Creek originate on the northwest slope of Mount Tamalpais. Lagunitas Creek continues downstream to Tomales Bay, a coastal estuary shaped by and which defines the trace of the San Andreas Fault system. Lagunitas Creek and its tributaries provide critical habitat for California freshwater shrimp, coho salmon, steelhead, Pacific lamprey, California red-legged frog, and northwestern pond turtle. Conservation and recovery of its coho salmon population is a critical component of the larger effort to recover this species within the Central California Coast ESU. In the watershed, within the Golden Gate National Recreation Area, there are several parcels

leased for livestock grazing. Sir Francis Drake Boulevard, which parallels Lagunitas Creek for more than 5-miles, is a primary arterial road connecting the coast with the bayside of Marin County.

10. Other public agencies whose approval is required (e.g., permits, financing approval, or participation agreement.)

The California State Water Resources Control Board, the California Office of Administrative Law, and the U.S. Environmental Protection Agency must approve the proposed Basin Plan amendment. In addition, actions taken to achieve the Basin Plan amendment including installation of engineered log jams in stream channels and/or replacement or retrofit of road-crossings over stream channels (to reduce fine sediment delivery), would require permits from: the US Army Corps of Engineers (Clean Water Act Section 404 permit); the US Fish and Wildlife Service (Endangered Species Act Section 7 Consultation); NOAA Fisheries (Endangered Species Act Section 7 Consultation); the California Department of Fish and Wildlife (Streambed Alteration Agreement); the San Francisco Bay Regional Water Quality Control Board (Clean Water Act Section 401 permit); and the County of Marin, Community Development Agency. Other road-erosion control projects that would be implemented to achieve performance standards for sediment delivery from roads, will involve substantial earth moving, and therefore, would require discretionary permits from the County of Marin, Community Development Agency.

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
I. AESTHETICS: Would the project:				
a) Have a substantial adverse effect on a scenic vista	☐	☐	☐	☒
b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings within a state scenic highway	☐	☐	☐	☒
c) Substantially degrade the existing visual character or quality of the site and its surroundings?	☐	☐	☐	☒
d) Create a new source of substantial light or glare which would adversely affect day or nighttime views in the area?	☐	☐	☐	☒
II. AGRICULTURE AND FOREST RESOURCES: In determining whether impacts to agricultural resources are significant environmental effects, lead agencies may refer to the California Agricultural Land Evaluation and Site Assessment Model (1997) prepared by the California Dept. of Conservation as an optional model to use in assessing impacts on agriculture and farmland. In determining whether impacts to forest resources, including timberland, are significant environmental effects, lead agencies may refer to information compiled by the California Department of Forestry and Fire Protection regarding the state's inventory of forest land, including the Forest and Range Assessment Project and the Forest Legacy Assessment Project; and the forest carbon measurement methodology provided in Forest Protocols adopted by the California Air Resources Board. Would the project:				
a) Convert Prime Farmland, Unique Farmland, or Farmland of Statewide Importance (Farmland), as shown on the maps prepared pursuant to the Farmland Mapping and Monitoring Program of the California Resources Agency, to non-agricultural use?	☐	☐	☐	☒
b) Conflict with existing zoning for agricultural use, or a Williamson Act contract?	☐	☐	☐	☒
c) Conflict with existing zoning for, or cause rezoning of, forest land (as defined in Public Resources Code section 12220(g)), timberland (as defined by Public Resources Code section 4526), or timberland zoned Timberland Production (as defined by Government Code section 51104(g))?	☐	☐	☐	☒
d) Result in the loss of forest land or conversion of forest land to non-forest use?	☐	☐	☐	☒
e) Involve other changes in the existing environment which, due to their location or nature, could result in conversion of Farmland, to non-agricultural use or conversion of forest land to non-forest use?	☐	☐	☒	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
III. AIR QUALITY: Where available, the significance criteria established by the applicable air quality management or air pollution control district may be relied upon to make the following determinations. Would the project:				
a) Conflict with or obstruct implementation of the applicable air quality plan?	☐	☐	☐	☒
b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?	☐	☐	☒	☐
c) Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non- attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors)?	☐	☐	☐	☒
d) Expose sensitive receptors to substantial pollutant concentrations?	☐	☐	☐	☒
e) Create objectionable odors affecting a substantial number of people?	☐	☐	☐	☒
IV. BIOLOGICAL RESOURCES: Would the project:				
a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies, or regulations, or by the California Department of Fish and Wildlife or U.S. Fish and Wildlife Service?	☐	☒	☐	☐
b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, and regulations or by the California Department of Fish and Wildlife or US Fish and Wildlife Service?	☐	☐	☒	☐
c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act (including, but not limited to, marsh, vernal pool, coastal, etc.) through direct removal, filling, hydrological interruption, or other means?	☐	☐	☒	☐
d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?	☐	☒	☐	☐
e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance?	☐	☐	☐	☒
f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan?	☐	☐	☒	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
V. CULTURAL RESOURCES: Would the project:				
a) Cause a substantial adverse change in the significance of a historical resource as defined in §15064.5?	☐	☐	☐	☒
b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to §15064.5?	☐	☐	☒	☐
c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?	☐	☐	☐	☒
d) Disturb any human remains, including those interred outside of formal cemeteries?	☐	☒	☐	☐
VI. GEOLOGY AND SOILS: Would the project:				
a) Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:				
i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to Division of Mines and Geology Special Publication 42?	☐	☐	☐	☒
ii) Strong seismic ground shaking?	☐	☐	☐	☒
iii) Seismic-related ground failure, including liquefaction?	☐	☐	☐	☒
iv) Landslides?	☐	☐	☐	☒
b) Result in substantial soil erosion or the loss of topsoil?	☐	☐	☒	☐
c) Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse?	☐	☐	☐	☒
d) Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property?	☐	☐	☐	☒
e) Have soils incapable of adequately supporting the use of septic tanks or alternative waste water disposal systems where sewers are not available for the disposal of waste water?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
VII. GREENHOUSE GAS EMISSIONS: Would the project:				
a) Generate greenhouse gas emissions, either directly or indirectly, that may have a significant impact on the environment?	☐	☐	☐	☒
b) Conflict with an applicable plan, policy, or regulation adopted for the purpose of reducing the emissions of greenhouse gases?	☐	☐	☐	☒
VIII. HAZARDS AND HAZARDOUS MATERIALS: Would the project:				
a) Create a significant hazard to the public or the environment through the routine transport, use, or disposal of hazardous materials?	☐	☐	☒	☐
b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and accident conditions involving the release of hazardous materials into the environment?	☐	☐	☒	☐
c) Emit hazardous emissions or handle hazardous or acutely hazardous materials, substances, or waste within one-quarter mile of an existing or proposed school?	☐	☐	☐	☒
d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code Section 65962.5 and, as a result, would it create a significant hazard to the public or the environment?	☐	☐	☐	☒
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☒
f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☒
g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?	☐	☐	☐	☒
h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
IX. HYDROLOGY AND WATER QUALITY: Would the project:				
a) Violate any water quality standards or waste discharge requirements?	☐	☐	☐	☒
b) Substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a net deficit in aquifer volume or a lowering of the local groundwater table level (e.g., the production rate of pre-existing nearby wells would drop to a level which would not support existing land uses or planned uses for which permits have been granted)?	☐	☐	☐	☒
c) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, in a manner which would result in substantial erosion or siltation on- or off-site?	☐	☐	☒	☐
d) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner which would result in flooding on- or off-site?	☐	☒	☐	☐
e) Create or contribute runoff water which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff?	☐	☐	☐	☒
f) Otherwise substantially degrade water quality?	☐	☐	☐	☒
g) Place housing within a 100-year flood hazard area as mapped on a federal Flood Hazard Boundary or Flood Insurance Rate Map or other flood hazard delineation map?	☐	☐	☐	☒
h) Place within a 100-year flood hazard area structures which would impede or redirect flood flows?	☐	☒	☐	☐
i) Expose people or structures to a significant risk of loss, injury or death involving flooding, including flooding as a result of the failure of a levee or dam?	☐	☐	☒	☐
j) Inundation by seiche, tsunami, or mudflow	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
X. LAND USE AND PLANNING: Would the project:				
a) Physically divide an established community?	☐	☐	☐	☒
b) Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?	☐	☐	☒	☐
c) Conflict with any applicable habitat conservation plan or natural community conservation plan?	☐	☐	☒	☐
XI. MINERAL RESOURCES: Would the project:				
a) Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?	☐	☐	☐	☒
b) Result in the loss of availability of a locally-important mineral resource recovery site delineated on a local general plan, specific plan or other land use plan?	☐	☐	☐	☒
XII. NOISE: Would the project result in:				
a) Exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies?	☐	☐	☐	☒
b) Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?	☐	☐	☒	☐
c) A substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☐	☒
d) A substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☒	☐
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☒
) For a project within the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
XIII. POPULATION AND HOUSING: Would the project:				
a) Induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example, through extension of roads or other infrastructure)?	☐	☐	☐	☐
b) Displace substantial numbers of existing housing, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☐
c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☐
XIV. PUBLIC SERVICES:				
a) Would the project result in substantial adverse physical impacts associated with the provision of new or physically altered governmental facilities, need for new or physically altered governmental facilities, the construction of which could cause significant environmental impacts, in order to maintain acceptable service ratios, response times or other performance objectives for any of the public services:	☐	☐	☐	☒
Fire protection?	☐	☐	☐	☒
Police protection?	☐	☐	☐	☒
Schools?	☐	☐	☐	☒
Parks?	☐	☐	☐	☒
Other public facilities?	☐	☐	☐	☒
XV. RECREATION:				
a) Would the project increase the use of existing neighborhood and regional parks or other recreational facilities such that substantial physical deterioration of the facility would occur or be accelerated?	☐	☐	☒	☐
b) Does the project include recreational facilities or require the construction or expansion of recreational facilities which might have an adverse physical effect on the environment?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
XVI. TRANSPORTATION/TRAFFIC: Would the project:				
a) Conflict with an applicable plan, ordinance or policy establishing measures of effectiveness for the performance of the circulation system, taking into account all modes of transportation including mass transit and non-motorized travel and relevant components of the circulation system, including but not limited to intersections, streets, highways and freeways, pedestrian and bicycle paths, and mass transit?	☐	☐	☐	☒
b) Conflict with an applicable congestion management program, including, but not limited to level of service standards and travel demand measures, or other standards established by the county congestion management agency for designated roads or highways?	☐	☐	☐	☒
c) Result in a change in air traffic patterns, including either an increase in traffic levels or a change in location that results in substantial safety risks?	☐	☐	☐	☒
d) Substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)?	☐	☐	☐	☒
e) Result in inadequate emergency access?	☐	☐	☒	☐
f) Conflict with adopted policies, plans or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities?	☐	☐	☐	☒
XVII. UTILITIES AND SERVICE SYSTEMS: Would the project:				
a) Exceed wastewater treatment requirements of the applicable Regional Water Quality Control Board?	☐	☐	☐	☒
b) Require or result in the construction of new water or wastewater treatment facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☒
c) Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☒
d) Have sufficient water supplies available to serve the project from existing entitlements and resources, or are new or expanded entitlements needed?	☐	☐	☐	☒
e) Result in a determination by the wastewater treatment provider which serves or may serve the project that it has adequate capacity to serve the project's projected demand in addition to the provider's existing commitments?	☐	☐	☐	☒

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
XVII. UTILITIES AND SERVICE SYSTEMS (Cont.): Would the project:				
f) Be served by a landfill with sufficient permitted capacity to accommodate the project's solid waste disposal needs?	☐	☐	☐	☒
g) Comply with federal, state, and local statutes and regulations related to solid waste?	☐	☐	☐	☒
XVIII. MANDATORY FINDINGS OF SIGNIFICANCE				
a) Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, substantially reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory?	☐	☒	☐	☐
b) Does the project have impacts that are individually limited, but cumulatively considerable? ("Cumulatively considerable" means that the incremental effects of a project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects)?	☐	☒	☐	☐
c) Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly?	☐	☐	☒	☐

EXPLANATION

Project Description

The proposed project is an amendment to the Water Quality Control Plan (Basin Plan) for the San Francisco Bay Region. It would establish a Total Maximum Daily Load (TMDL) for sediment in Lagunitas Creek and its tributaries, and an implementation plan to achieve the TMDL and related stream-riparian habitat rehabilitation objectives. The project includes:

- Performance standards for sediment discharges from roads, rangelands, parks, and open space;
- Numeric targets for streambed mobility, redd scour, and the amount of large woody debris in stream channels; and
- Processes by which sediment control best management practices and stream-riparian habitat rehabilitation projects are proposed and implemented.

To achieve the Lagunitas Creek sediment TMDL and the habitat rehabilitation goals specified in the Basin Plan amendment, for the land types and roadways listed in Tables 4.1 through 4.3 of the Basin Plan amendment, the entire Lagunitas Creek watershed, except areas upstream of municipal reservoirs, needs to be included in the proposed sediment control programs⁶³.

The goal of the Basin Plan amendment is to improve environmental conditions by addressing sediment discharges and enhancing stream-riparian habitat complexity and connectivity. The Basin Plan amendment would include targets for fine sediment (primarily sand) concentrations in the bed of Lagunitas Creek and/or in its tributaries that are expressed as numeric criteria for streambed mobility and redd scour depth, and establish sediment allocations necessary to achieve the targets. The Basin Plan amendment implementation plan would require actions to achieve the performance standards, targets, and allocations for sediment, and recommend actions to enhance large woody debris loading as needed to enhance habitat complexity and connectivity to support recovery of listed populations of California freshwater shrimp, steelhead, and coho salmon. The proposed Basin Plan amendment would affect all segments of Lagunitas Creek and its tributaries located downstream of municipal water supply reservoirs.

The proposed Basin Plan amendment contains sediment allocations for dischargers and discharge categories. Consistent with state law, the Water Board is limited in

⁶³ These include land areas draining into Kent Lake and Nicasio Reservoir.

prescribing the manner of compliance. Therefore, the Basin Plan amendment does not prescribe specific projects through which dischargers and discharge categories are to meet the sediment allocations.

The implementation plan would require actions to reduce sediment discharges associated with key sources: roads, grazing lands; and parks and open space. Required actions by landowners include 1) submittal of reports of waste discharge (ROWDs) and 2) compliance with waste discharge requirements (WDRs) or WDR waiver conditions.

The proposed Basin Plan amendment also recommends actions that will enhance other habitat attributes necessary for the conservation of native fishes and to support recovery of listed populations of California freshwater shrimp, steelhead, and coho salmon by increasing stream habitat complexity and connectivity to floodplains.

While the Water Board would not directly undertake any actions that could physically change the environment, adoption of the proposed Basin Plan amendment would result in future actions by landowners, municipalities and other agencies to comply with the requirements of the Basin Plan amendment and these actions may result in a physical change to the environment. The environmental impacts of such physical changes are evaluated below, to the extent that they are reasonably foreseeable. Changes that are speculative in nature do not require environmental review.

Until the parties that must comply with requirements derived from the Basin Plan amendment propose specific projects, many physical changes cannot be anticipated. That said, it is reasonably foreseeable that the following activities may take place to comply with the Basin Plan amendment: (1) minor construction, (2) earthmoving operations, (3) planting of native riparian vegetation species in stream-riparian corridors; (4) placement of large woody debris in stream channels; and (5) waste handling and disposal. Although these activities are reasonably foreseeable methods of compliance, the implementation plan does not specify the nature of these actions. Therefore, this analysis considers these actions in general programmatic terms. To illustrate the possible nature of these activities, some examples are described in Table 7.1.

TABLE 7.1: Reasonably Foreseeable Compliance Projects

Management Category	Types of Actions
Road-erosion control and prevention projects	Environmental changes may include : a) installation, repair, or replacement of road crossings (i.e., culvert, bridges, and fords) over channels; b) installation and maintenance of trash racks at road crossings; c) installation of ditch relief culverts and cross-drains along inboard ditches on roads; d) soil excavation at road-related landslides; e) construction of rolling dips or out-sloped road segments on dirt roads; f) sediment and/or vegetation removal to maintain conveyance capacity along inboard ditches and/or at stream crossings; and/or g) removal of road berms (as needed).
Stream habitat enhancement actions	Environmental changes may include: a) minor earth moving and vegetation removal to provide construction access and staging for heavy equipment and hand labor crews; b) earth moving (excavation and grading) to install log jams (comprised of several large trunks with intact root-wads); c) water diversion and dewatering of the construction area; d) soil bioengineering to minimize post-construction erosion where streambanks are set-back to facilitate jam installation and/or to construct an inset floodplain; e) stockpiling of excavated material in adjacent uplands; f) planting of native riparian tree and ground-cover species.

- **Minor construction.** Basin Plan amendment-related construction projects would generally be small. Examples may include: a) installation/replacement and/or retrofit of road crossings (e.g., replacement of culverts and/or bridges, retrofits of culvert to include downspouts, etc.), b) installation or repair of trash racks upstream of road crossings to avoid blockage of crossings; c) installation and/or repair of ditch relief culverts and/or cross-drains to reduce concentrated runoff from roads; and d) construction of temporary dams/diversions in stream channels to divert streamflow and dewater the construction area at sites where large woody debris jams are installed.
- **Earthmoving operations.** For example, earthmoving to reduce road-related erosion will involve re-contouring the surface of some unpaved roads to disperse concentrated runoff (e.g., outsloping of road segments, construction of rolling dips, construction of water bars), removal of road berms, soil excavation at road-related landslides), and soil bioengineering

to reshape and stabilize road-related gullies. Earth moving to increase large woody debris in channels may include excavation/fill of stream banks and/or in the streambed to buttress key pieces of wood into the channel; b) minor excavation and/or fill to provide temporary access for heavy equipment and/or hand labor crews to the construction sites.

- ***Enhancement of vegetation and woody debris in riparian corridors and stream channels.*** To attain the proposed numeric target for the amount of large woody debris (large fallen trees), there would be a two-to-six fold increase in large woody debris in channels, and a consequent enhancement of the diversity of riparian habitat patch types, and in the total area of riparian habitat adjacent to Lagunitas Creek and its tributaries. This would be accomplished in part by construction/installation of dozens of engineered and/or anchored log jams (see further description below), enhanced natural recruitment (through targeted planting and management of riparian habitats), and consistent with the Woody Debris MOU (MMWD et al., 2007), the protection of ecologically significant large woody debris in stream channels (FishNet 4C, 2004).
- ***Waste Handling and Disposal.*** Contaminated soil could be discovered during earthmoving or other activities associated with erosion control, and/or habitat enhancement. In some cases, disposal could be arranged on site (e.g., constructing a containment facility). In others, soil or other contaminated materials could be sent for disposal. While implementation projects could reasonably generate contaminated soil for disposal, possible amounts are unknown. This waste would, however, be generated only on a temporary basis and parties would be required to comply with specific reporting, handling, transporting, and disposal requirements. To the extent such hazardous waste is removed from the environment and disposed of in appropriate waste management sites, it would result in an environmental benefit.

These examples are not intended to be exhaustive or exclusive. Several conceivable actions that could be taken as a result of the Basin Plan amendment require speculation, and therefore, cannot be evaluated. For example, although the implementation plan calls for studies to evaluate potential opportunities for floodplain restoration, actual outcomes and specific actions resulting from the proposed study are too speculative however to determine at this time. Also, as discussed above, even in cases where some physical changes are foreseeable, the exact nature of these changes is often speculative pending specific project proposals that will be ultimately put forth by those subject to requirements derived from the Basin Plan amendment.

Environmental Analysis

There are two types of sediment reduction and/or habitat enhancement projects called for in the Basin Plan amendment to achieve the TMDL and the numeric targets for sediment and habitat condition that would involve the following actions on the ground:

1. Road erosion-control projects to reduce the supply of sand and finer sediment that is delivered to channels; and
2. Management actions and/or construction of engineered log jams to increase the number and size of large fallen trees in channels (as needed to meter and store fine bed material, control channel incision, and enhance channel habitat complexity and connectivity to the floodplain).

The following section is organized by source control actions. First, we describe actions to increase large woody debris in channels, as needed to achieve the numeric targets called for in the Basin Plan amendment. Second, we describe actions to control sediment delivery to channels from road-related erosion. Then, we assess the environmental effects of wood addition and road erosion control projects.

Other actions to control fine sediment delivery from grazing areas, and new and/or redevelopment projects are not considered in this analysis because they are already in-place as part of previously adopted pollution control permits administered by the Water Board and/or the County of Marin, and these programs will continue whether or not the proposed Basin Plan is approved.

Actions to increase large woody debris loading in channels

The Basin Plan amendment includes numeric targets for large woody debris in channels. Based on review of recent surveys of large woody debris (LWD) loading in reaches of Lagunitas Creek, San Geronimo Creek, and Devils Gulch (Lawrence, 2012), we estimate that the total volume of large woody debris in channels needs to be increased by a factor of two-to-six within ten years of approval of the Basin Plan amendment (approval is expected in 2014, so the target would need to be achieved in 2024). As an example, to visualize how many large fallen trees would be in the channel given attainment of the LWD target, we estimate that in Lagunitas Creek within SP Taylor State Park, there would be at least 20 additional bar-apex jams, at least 10 additional flow-deflector jams, and at least 3 additional meander jams throughout the approximately 4-mile long reach (see, Figures 6.2 and 6.3 for examples of these debris jam types⁶⁴).

The reasonably foreseeable actions that could occur to achieve the targets include the following:

- 1) Management actions to promote natural recruitment to and retention in channels of large woody debris (consistent with the *Woody Debris MOU* [for management of wood in channels on public lands within the watershed], MMWD et al., 2007). These include:

⁶⁴ We infer these were the most common types of debris jams along Lagunitas Creek under natural reference conditions in what is now SP Taylor State Park; see pp. 79-84 of this document for additional details.

- a) Protection of potential sources of large woody debris - standing and fallen trees in channels, on the valley flat, and/or upslope within 200 feet of the valley flat;
 - b) Riparian reforestation projects;
 - c) Import of LWD sources deposited in Kent Lake to downstream reaches;
 - d) Identification of opportunities for potential LWD enhancement projects in channel reaches on public lands including MMWD, County of Marin, Marin County Open Space District, California State Department of Parks and Recreation, and the US National Parks Service;
 - e) Implementation of the FishNet 4C best management practices for retention and function of large woody debris in channels (FishNet 4C, 2004), which involve avoidance of removal of large fallen trees in/around channels, where there is not a significant threat to roadways, bridges, or other public facilities, and in the case of a threat, modification of debris jams only to the extent necessary to resolve the threat.
- 2) Similarly, on private lands, for the purposes of the CEQA analysis, conservatively we assume that a program of management actions will occur to enhance natural recruitment to and retention in channels of large woody debris that would occur in San Geronimo Creek watershed. The primary elements of a program in the San Geronimo Creek watershed would include protection of mature native riparian trees (consistent with regulations of the County of Marin for Stream Conservation Areas), implementation of the FishNet 4C best management practices for retention and function of large woody debris in channels (FishNet 4C, 2004), and the Water Board providing support for development of reach-based stewardships along San Geronimo Creek and its tributaries, where interested landowners could work together cooperatively on a voluntary basis in partnership with the County of Marin through its Landowner Assistance Program.
- 3) Construction/installation of engineered log jams, and/or construction of traditional anchored log jams that are placed in stream channels to achieve specific management objectives. Engineered log jams are designed to emulate naturally formed jams that can remain stable in channels even during very large floods without the use of artificial anchoring such as cables (see Abbe et al., 2003; Brooks et al., 2004; Pess et al., 2011; and Fiori Geosciences, 2012). The architecture and arrangement of large fallen trees in naturally formed debris jams is primarily a function of recruitment processes (e.g., bank erosion, wind throw, debris flows, landslides, etc.), the size of the trees in relation to channel size, and transport and deposition along channels. Large fallen trees will be arranged into distinct debris jam types that vary as a function of the location within the

drainage network and the wood recruitment and transport processes (see Abbe and Montgomery, 2003, for examples). The stability of natural and engineered log jams results from recruitment or installation of key pieces of woody debris that are oriented optimally with regard to exposure and orientation to flow. “Key pieces” are defined as those having a length $\geq$ one-half the width of flow at bankfull and diameter $\geq$ one-half depth of flow at bankfull (pp. 101-102 in Abbe and Montgomery, 2003).

Anchored log jams include a variety of types of structures that utilize large woody debris together with rock, and soil and are premised on soil bioengineering principles used to stabilize eroding streambanks, and/or many traditional types of stream habitat enhancement structures. Common types of anchored log jams used to enhance habitat include divide logs, digger logs, spider logs, and combination habitat structures that utilize logs, root-wads, and boulders in combination (see California Department of Fish and Game, 1998, pp. VII-10 through VII-31).

Log jam construction (all types) involves: a) minor earth moving and/or vegetation removal in riparian corridors and/or uplands to provide access for heavy equipment and/or hand labor crews; b) earth moving in the channel bed and/or banks to install log jams (typically comprised of several large trees with root-wads intact with tree length's $\geq$ one-half of channel width, and tree diameter's $\geq$ one-half channel depth during the annual flood (recurrence interval = 1.5 years); c) stream channel diversion and dewatering within the construction area; d) soil bioengineering⁶⁵ to minimize post-construction erosion at sites where streambanks are set-back to enhance channel width-to-depth ratio and/or to construct an inset floodplain.

In development of this environmental analysis, consistent with the Marin County General Plan (Policy EH-3.2 and Implementation Program EH-3.f), we assume that hydraulic analyses will be performed in all channel reaches, where a jam collapse could present a significant risk to streamside buildings, roadways, bridges, and/or other critical infrastructure (e.g., pipelines). Please also see the related analysis of potential effects on Hydrology and Water Quality that follows later in this chapter.

There are several special status species that could occur within stream and/or riparian habitats that would be accessed for construction, and/or where engineered log jams would be installed. In all stream and riparian habitat areas, the County of Marin requires that a Biological Site

⁶⁵ Soil bioengineering is defined consistent with USDA (2002) as “the use of living and nonliving plant materials in combination with natural and synthetic support materials for slope stabilization, erosion reduction, [habitat enhancement], and vegetative establishment.”

Assessment be prepared to determine whether any special status animal or plant species may occur within the project area (County of Marin, General Plan, Implementing Programs, Bio 4.g).

Actions to control sediment delivery to channels associated with road-related erosion

To achieve the TMDL and numeric targets for sediment, the Basin Plan amendment calls for an approximately 50 percent reduction in sediment delivery to channels⁶⁶ that is associated with existing roads, which encompass approximately 135 miles within the project area (Lynx Technologies, 2007, unpublished data). Approximately 84 miles are dirt or gravel covered (75 percent of which are publically owned), and 51 miles are paved (over 90 % of which are publically owned).

In the project area, there are 21 miles of dirt roads that are privately owned, 20 miles of which are located on ranches regulated under the Water Board pollution control permit program for grazing in the Tomales Bay watershed. The environmental analysis for the Basin Plan amendment considers implementation of road erosion control projects on approximately 82-miles of dirt or gravel surfaced roads (61 miles of which are publically owned and 21-miles that are privately owned) and 51-miles of paved roads (47-miles of which are publically owned), or a total 133 miles.

Public agencies with jurisdiction over dirt roads in the project area include: the Marin Open Space District; the US National Park Service (Golden Gate National Recreation Area); the California Department of Parks and Recreation (Samuel P. Taylor State Park); and the Marin Municipal Water District. The County of Marin, Department of Public Works, has jurisdiction over all of paved public roads (47-miles) within the project area. These public agencies, together with the County of Marin and the Marin Resource Conservation District, have entered into a memorandum of understanding (MMWD et al., 2001) to work in partnership to reduce road-related erosion and sediment delivery to channels throughout the Lagunitas Creek watershed. Road erosion inventories completed on all unpaved publically owned roads provide the primary basis for evaluation of the locations, scale, and types of actions that could be implemented to reduce road-related erosion (PWA, 2007a; PWA, 2007 b; PWA, 2010; and Stetson Engineers, 2013). Some of the erosion control projects recommended in these inventories have already been completed or are in the planning stages including about 27-miles of dirt roads under the jurisdiction of the Marin Open Space District. Nevertheless to be conservative, and err on the side of over-estimation of potential impacts, we also include these projects which may be completed prior to Basin Plan amendment approval in the analysis of the potential effects of compliance with the Basin Plan amendment. The types of reasonably foreseeable actions to achieve the TMDL and performance standards for roads include the following:

- a) Installation, repair, and/or replacement of road crossings over stream channels;

⁶⁶ At present, we estimated that average annual sediment delivery to channels associated with road-related erosion throughout the 135-mile road network is about 3200 cubic yards per year (to visualize, this is about 320 dump trucks full of sediment being delivered to the channel network each year, most of which is sand or finer in grain size).

- b) Installation and/or maintenance of trash racks (to catch stream transported debris and thereby prevent it from blocking flow) through road crossing;
- c) Installation and/or maintenance of ditch relief culverts and/or cross-drains (to reduce concentrated runoff from roads);
- d) Soil excavation of road-related landslide deposits (to prevent channel sediment delivery/transport);
- e) Construction of rolling dips, out-sloped road segments, and/or water bars on dirt roads to attenuate concentrated runoff;
- f) Sediment and/or vegetation removal to maintain conveyance capacity along the inboard ditch;
- g) Removal of road berms;
- h) Excavation and repaving of paved roads to repair and/or retrofit road drainage infrastructure, as needed to address significant sediment sources.; and/or
- i) Streambank stabilization to protect the roadway from erosion.

Over the vast majority of the length of roads within the project area, roads and related drainage does not overlap significantly with wetlands, and/or riparian areas. In most cases, stream crossings are the features where dirt and paved roads overlap most prominently with stream channels, riparian areas, and/or wetlands. Within the project area, paved public roads including Sir Francis Drake Boulevard (5.1 miles), Platform Bridge Road (2.4 miles), and the Point Reyes-Petaluma Road (3.1 miles) parallel the mainstem of Lagunitas Creek along most of its length. The horizontal distance between these paved roads and Lagunitas Creek varies from zero-to-several-hundred feet (in most cases it is 50 feet-or-more). Road drainage infrastructure including stream crossings (e.g., bridges and/or culverts), inboard ditches, cross-drains, and/or ditch relief culverts are the primary features, together with streambank stabilization projects, on paved roads within the project area that have the potential to effect stream, riparian, and/or wetland associated biological resources.

The proposed Basin Plan amendment does not define the specific actions that responsible parties would take to comply with requirements derived from the Basin Plan amendment. As discussed above, physical changes resulting from the Basin Plan amendment are foreseeable, but the attributes of specific implementation actions (e.g., location, extent, etc.) are unknown, pending responsible parties proposing actions to comply with Basin Plan amendment requirements. Therefore, this analysis considers the above-mentioned reasonably foreseeable methods of compliance with the Basin Plan amendment in general terms. In all cases, we have concluded that there will be no impact, or a less than significant impact with mitigation incorporation.

Specific compliance projects, when they are developed, will be subject to review and/or approval by the Water Board, which will, as part of administering its program responsibilities, likely either disapprove projects with significant and unacceptable environmental impacts (e.g.,

instream work with too many impacts) or require implementation of routine mitigation measures (e.g., best construction management practices) to ensure that environmental impacts remain at or are reduced to less-than-significant levels. Additionally, there are existing local and state agency performance standards (e.g., air standards and noise ordinances), and project components to avoid impacts including design requirements for large woody debris jams, and requirements for stormwater pollution prevention and the timing of construction projects to avoid potentially significant impacts to biological resources and/or to water quality and hydrology. An explanation for each box checked on the environmental checklist is provided below.

I. Aesthetics

- a-d) Physical changes to the aesthetic environment as a result of the Basin Plan amendment would be small/local and short-term (e.g., temporary construction access locally along the riparian corridor to facilitate installation/construction of engineered log jams). Also, because construction of engineered log jams will increase the land area adjacent to the channel that is regularly flooded and/or where alluvial sediment is regularly deposited, the extent of the riparian corridor will increase over time and the diversity of riparian patch types will also increase, resulting in net enhancement of aesthetic environment along Lagunitas Creek and its tributaries. The Basin Plan amendment would not substantially affect any scenic resource or vista, or degrade the existing visual character or quality of any site or its surroundings. It would not create any new source of light or glare.

II. Agriculture Resources

- a-c) Adoption of the Basin Plan amendment which includes projects to increase in the amount of large wood in channels, through management actions to increase natural recruitment and/or loading in channels and/or installation of engineered log jams, would result in some local expansion of the riparian corridor and floodplain along Lagunitas Creek and its tributaries. Such expansion would occur because in some cases engineering log jams would constitute significant obstructions to streamflow facilitating coarse sediment deposition in channels and more frequent inundation of adjacent valley flat.

A conservative estimate, erring on the side of over-estimation of the amount of land that could be converted from cattle pasture to riparian habitat, as a result of installation of engineered log jams and resultant inundation of the valley flat during the annual flood, is calculated as follows:

1. The only channel reach where installation of engineered or anchored log jams could substantially change the amount of land area that is regularly inundated, and where adjacent land also is used to provide forage for livestock, is in the Tocaloma Reach. For example in the San Geronimo Valley, the channel is too deeply incised for

engineered log jam installation to cause adjacent valley areas to be inundated during the annual flood.

2. In the Tocaloma Reach, from the confluence with Nicasio Creek upstream to approximately Jewel, a significant proportion of the valley flat area is inundated during the annual flood, riparian vegetation is established, and the valley flat is not utilized as pasture. The total area of the valley flat including the area covered by riparian vegetation in this reach is estimated to be ≤ 100 acres:

Length (approx. 16000 ft) x average Width (200 ft) = $3.2 \times 10^6 \text{ ft}^2 = 73.5$ acres

Since the vast majority of the ≤ 100 acre valley flat is currently covered by riparian vegetation, we estimate that the maximum loss of pasture in this reach as a result of engineered log jam installation and consequent frequent inundation of areas now in pasture, would ≤ 20 acres (a conservative estimate of the maximum area on the valley flat not currently covered by riparian vegetation). Approximately 32,000 acres are leased for agriculture within public lands located in Marin County, and there are a total of 169,000 acres of agricultural land in Marin County (Marin County, 2007, p. 2-151). None of the farmland in the reach from Jewel to Nicasio Creek, is designated as Prime Farmland, Unique Farmland, and/or Farmland of Statewide Importance (California Department of Conservation, 2012; Farmland Mapping and Monitoring Program: <http://maps.conservation.ca.gov/ciff/ciff.html>).

A loss of ≤ 20 acres of farmland would result from actions implemented to achieve the Basin Plan amendment, none of which has special designation. Therefore, we conclude there would be a less than significant conversion of farmland to other uses, no impact to farmlands with special designations (because of lack of overlap), and no conflict with existing agricultural zoning and/or an existing Williamson Act contract.

III. Air Quality

- a) Because the Basin Plan amendment would not cause any significant changes in population or employment, it would not generate ongoing traffic-related emissions. It would also not involve the construction of any permanent emissions sources. For these reasons, no permanent change in air emissions would occur, and the Basin Plan amendment would not conflict with applicable air quality plans.
- b) The Basin Plan amendment would not “violate any air quality standard or contribute substantially to an existing or project air quality standard.” Nor would it involve the construction of any permanent emissions sources or generate ongoing traffic-related

emissions. Construction that would occur as a result of Basin Plan amendment implementation such as earthmoving operations to reduce sediment discharges from eroding areas like roads would be of short-term duration and would likely involve discrete, small-scale projects as opposed to massive earthmoving activities. For example, there are 113 miles of roads where individual erosion sites could be treated. Based on review of completed road erosion inventories, where erosion site treatments were recommended over only 20-to-40 percent of the total road length (PWA, 2007 a, 2007b; Stetson Engineers, 2013), we estimate that erosion sites would be treated throughout ≤ 45 miles of road over a 20-year period associated with the TMDL implementation plan). Fine particulate matter (PM₁₀) is the pollutant of greatest concern with respect to construction. PM₁₀ emissions can result from a variety of construction activities, including excavation, grading, demolition, vehicle travel on paved and unpaved surfaces, and vehicle and equipment exhaust. Given the limited duration and scale of reasonably foreseeable construction activities to comply with the Basin Plan amendment, PM₁₀ standards, however, would not be “substantially” violated, if at all. Additionally, if specific construction projects were proposed to comply with requirements derived from the proposed Basin Plan amendment, such projects would have to comply with the Bay Area Air Quality Management District’s (BAAQMD) requirements with respect to the operation of portable equipment. Moreover, BAAQMD has identified readily available measures to control construction-related air quality emissions (BAAQMD 1999) that are routinely employed at most construction sites. These measures include watering active construction areas; covering trucks hauling soil; and applying water or applying soil stabilizers on unpaved areas. Therefore, in consideration of all of the foregoing, the Basin Plan amendment would not violate any air quality standard or contribute substantially to any air quality violation, and its temporary construction-related air quality impacts would be less-than-significant.

- c) Because the Basin Plan amendment would not generate ongoing traffic-related emissions or involve the construction of any permanent emissions sources, it would not result in a cumulatively considerable net increase of any pollutant for which the project region is non-attainment.
- d-e) Because the Basin Plan amendment would not involve the construction of any permanent emissions sources but rather involves short-term and discrete construction activities, it would not expose sensitive receptors to substantial pollutant concentrations or create objectionable odors affecting a substantial number of people.

IV. Biological Resources

- a) There are two types of reasonably foreseeable compliance actions: 1) projects to reduce sediment delivery from road-related erosion; and 2) projects to increase LWD loading in channels (including construction/installation of log jams). All of the log-jam construction projects would occur in stream channels that provide potential habitat for

coho salmon and/or steelhead. Therefore, permits to protect special status species would be required from:

- US Army Corps of Engineers (which regulates placement of all materials in waters of the US);
- NOAA Fisheries (which conditions US Army Corps permits to protect commercially important species, including steelhead and coho salmon, that are listed under the federal Endangered Species Act);
- Regional Water Quality Control Board (which reviews and conditions projects to ensure that water quality is protected);
- California Department of Fish and Wildlife (which reviews and conditions projects to protect all state-listed candidate, sensitive, threatened, and/or endangered species); and
- County of Marin (which would require a CEQA determination and a Biological Site Assessment to ensure that all species listed as rare, threatened, endangered, or of special concern under state or federal law are protected).

For all log jams constructed along Lagunitas Creek where most of the jams would be installed, since it also provides habitat for California Freshwater Shrimp, the US Fish and Wildlife Service would also prepare a permit to protect all non-commercial species listed under the federal Endangered Species Act (including California freshwater shrimp, California red-legged frog, Northern spotted owl, and several plant species).

The Basin Plan amendment also includes project components to avoid impacts to special status species including: a) limiting the construction period to August through October, and excluding use of heavy equipment within ¼ mile of a Northern Spotted Owl nesting site to avoid impacts to all special status bird species; and b) design requirements for constructed log jams, so that they do not fully span the channel, as needed to avoid blockage of movement by California freshwater shrimp, and to achieve consistency with the *California Freshwater Shrimp Recovery Plan* (USFWS, 1998).

Considering the statutory responsibilities of the local, state, and federal agencies that would permit all constructed log jams (including the California Department of Fish and Wildlife, the Water Board, NOAA Fisheries, US Fish and Wildlife Service, and the County of Marin), we conclude that impacts to special status species of log jam construction projects would be less than significant as a result of the permit conditions imposed by these agencies.

The other type of reasonably foreseeable actions to comply with the Basin Plan amendment, would relate to road-erosion control. For any road-erosion control project involving a stream crossing, and/or other jurisdictional wetlands, the same logic as presented above would apply, and we find that impacts to special status species of reasonably foreseeable actions would be less than significant.

For the remainder of road-erosion control actions/project types (e.g., cross drains and ditch relief culverts, excavation of road-related landslides, construction of rolling dips, out-sloping of road segments, installation of water bars, management of sediment and vegetation in inboard ditches; and/or removal of road berms), where roads are located on public land, impacts to upland animal and plant species would be less than significant because:

- The Marin Municipal Water District, Marin County Open Space District, SP Taylor State Park, and the Golden Gate National Recreation Area have completed vegetation surveys and rare plant inventories of their property's, and the County of Marin would require a Biological Site Assessment and CEQA determination for the road erosion control projects. Considering these surveys and inventories, and the required assessments and permits, impacts to special status species would be less than significant.
- 113 miles of roads would be subject to potential compliance actions resulting from adoption of the Basin Plan amendment, 108 miles of which are publically owned and hence subject to the protections described in a) above.

On the 5 miles of privately owned roads (4 miles of which are paved), almost all construction activity would be confined to the footprint of the existing roads, and for projects involving grading of 250 cubic yard-or-more, the County of Marin would require permits and a Biological Site Assessment, if the road overlapped with potential habitat for any special status species. Therefore, we conclude that impacts would be less than significant.

IV. Biological Resources (Cont.)

- b) Reasonably foreseeable compliance actions - management actions and construction of engineered log jams to increase large woody debris loading in channels, and road maintenance practices and erosion control projects – would result in an overall enhancement of riparian habitat conditions. This finding is based on the following logic. The number and frequency of key pieces of large woody debris (those large enough to remain in place in channels even during most large floods) in channel reaches that provide actual or potential spawning habitat for anadromous salmonids would be greatly increased, and as a result the complexity of channel habitat and connectivity to the floodplain would also be greatly enhanced (Collins et al., 2012; also see Chapter 5 of this report for additional details) with resultant enhancement of the extent and diversity of riparian habitats. Road erosion control actions will shift the particle size distribution of sediment supply closer to natural distribution enhancing sediment sorting and the diversity of substrate patch types in riparian habitats, which in turn would enhance the diversity of riparian habitats and communities.

There are other sensitive natural communities are located in upland habitats within the project area (including native grasslands and/or serpentine associated plant communities) that could overlap and be effected by road erosion control projects. However, 108-of-113 miles of the road network, where erosion control projects may occur, are publically owned and as described in a) above, vegetation surveys and rare plant inventories have been completed on the properties of these public agencies and the County of Marin would require a Biological Site Assessment and CEQA determination to identify and protect all sensitive natural communities. Also, as described in a) above, on the 5-miles of privately owned roads, since earth moving to implement the road erosion control projects would be greater than 250 cubic yards, the County of Marin would require permits and a Biological Site Assessment, if the road overlapped with any sensitive natural communities. Mitigation measures including minimization of the size of the construction area and/or avoidance to the maximum extent practicable the disturbance of all native vegetation cover, identification and flagging of the boundaries of the construction area with sensitive native communities, flagging to identify and avoid any State or Federal listed special-status plant species, and construction monitoring to ensure that the special-status plants are not disturbed. Therefore, we conclude that impacts of all road erosion control projects also would be less than significant to sensitive native communities with mitigation measures that are incorporated into the project.

- c) Basin Plan amendment-related implementation actions will involve channel habitat enhancement (large woody debris) and/or road-erosion control projects, a fraction of which would occur within and/or overlap with wetlands. The adverse impacts on

wetlands would not be substantial, however because under the Nationwide or individual permit programs administered by the US Army Corps of Engineers, there are general conditions that require that for projects that may adversely affect all wetlands, as defined under Section 404 of the Clean Water Act, responsible parties must demonstrate that avoidance, minimization, and mitigation has occurred to the maximum extent practicable to ensure that adverse impacts to the aquatic environment are minimal. Furthermore for all potential projects where wetland losses would exceed 0.1 acres, applicants are required to provide compensatory mitigation at a ratio that is greater than or equal to 1:1. For projects where wetland losses are less than 0.1 acre, on a case by case basis the District Engineer may require compensatory mitigation. If TMDL implementation projects are proposed that could have the potential to disturb wetlands, they also would be subject to the Water Board's review and approval under Section 401 of the Clean Water Act and the Porter-Cologne Water Quality Control Act, and the Water Board must, consistent with its Basin Plan, require mitigation measures to avoid, minimize, and mitigate impacts to less-than-significant levels. As specified in the Basin Plan, the San Francisco Bay Regional Board uses the USEPA Section 404(b)(1) Guidelines for dredge and fill material in determining the circumstances under which the filling of wetlands may be permitted. This policy requires that avoidance and minimization be emphasized and demonstrated prior to consideration of mitigation. Furthermore, the California Wetland Protection Policy also is incorporated into the Basin Plan. The goals of this policy include ensuring that "no overall net loss" and "long-term net gains in the quantity, quality, and permanence of wetland acreage and values ..." (Governor's Executive Order W-59-93). Wetlands not subject to protection under Sections 404 and 401 of the Clean Water Act are still subject to regulation, and protection under the California Water Code. Please also see discussion in part b) above relating to sensitive natural communities, some of which are wetland types.

- d) The Basin Plan amendment would not substantially interfere with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites. To avoid potential impacts of engineered log jams on movement of California freshwater shrimp, the Basin Plan amendment project includes as a mitigation measure, the requirement that all constructed log jams not fully span the channel. Furthermore, none of the reasonably foreseeable compliance actions has the potential to substantially interfere with wildlife movement. Therefore we conclude that the impact is less than significant with mitigation incorporated.

- e-f) The Basin Plan amendment itself does not conflict with any local policies or ordinances protecting biological resources such as trees, or with any adopted Habitat Conservation Plan, Natural Community Plan, or other approved local, regional or state habitat conservation plan. There is no evidence to suggest that projects proposed to comply with Basin Plan amendment requirements would conflict with these plans.

V. Cultural Resources

- a-b) With regard to road-erosion control projects implemented to comply with the Basin Plan amendment, all earth moving would occur in already disturbed areas, within the footprint and/or right-of-way of existing roads. No roads would need to be relocated in order to comply with the Basin Plan amendment. Therefore, we conclude that potential impacts of road-erosion control projects implemented to comply with the Basin Plan amendment are less than significant.

With regard to log jams construction projects implemented to comply with the Basin Plan amendment, earth moving and vegetation disturbance would be minor, to provide construction site access, and/or to key large woody debris pieces into the streambed and/or banks. No log jams will be constructed where they might adversely impact Historical Resources including the Pioneer Paper Mill and related dam site (California Historical Landmark No. 552). No other significant Historical Resources, as defined in Section 15064.5 of the CEQA guidelines, including historic buildings, are known along reaches of Lagunitas and/or San Geronimo creeks where log jams would be constructed. In order to obtain a Clean Water Act Section 401 permit, prior to starting construction of any log jam project, the Regional Board also would require a copy of the CEQA determination for the project including documentation of the analyses performed to determine whether the project site overlaps with known or potential archeological sites (as determined through review of the County's Archeological Sensitivity Map. To avoid impacts to archeological resources, for sites that may overlap with archeological resources, prior to constructing any engineered log jam project that would involve earth moving, the Water Board would require as mitigation measures that: 1) a field survey be performed by a qualified archeologist, who would provide recommendations and/or procedures to further investigate and/or mitigate adverse impacts; and 2) if cultural resources are discovered during field survey or subsequent construction activities, all earth moving would cease until a qualified archeologist assesses the potential resources and their significance, and then develops recommendations or procedures to mitigate any impacts.

- c) There are no unique paleontological resources known in the project area. Sites that may qualify as unique geologic features including "The Ink Wells" and "Spirit Rock" will not be adversely impacted by any reasonably foreseeable actions because both sites are composed of hard bedrock that is resistant to erosion, none of the anticipated types of road erosion control projects would result in any alteration of a unique geologic feature,

and log jams would not be constructed where they would alter or obscure a unique geologic feature.

- d) There are no known cemeteries and/or known historical Native American communities within the project area. However, if human remains are disturbed at a construction site, work would be stopped, and the County Coroner would be contacted immediately. If the remains are determined to be pre-historic and possibly of Native American origin, the coroner would contact the Native Heritage Commission within 24 hours. The Native Heritage Commission would then identify the person(s) it believes to be the most likely descendants, and they would be responsible for making recommendations for the disposition and treatment of the remains.

VI. Geology and Soils

- a) The Basin Plan amendment would not involve the construction of habitable structures. Therefore, it would not involve any human safety risks related to fault rupture, seismic ground-shaking, ground failure, or landslides.
- b) Specific projects involving earthmoving or construction activities to comply with requirements derived from the proposed Basin Plan amendment are reasonably foreseeable. Such activities would not result in substantial soil erosion or the loss of topsoil. The purpose of the Basin Plan amendment is to reduce erosion, not increase it. To meet the proposed Basin Plan amendment targets, construction would be designed to reduce overall soil erosion associated with erosion. However, temporary earthmoving operations could result in short-term, limited erosion. These specific compliance projects would be subject to the review and-approval of the Water Board, which requires implementation of routine and standard erosion control best management practices and proper construction site management. In addition, construction projects over one acre in size would require a general construction National Pollutant Discharge Elimination System permit and implementation of a stormwater pollution prevention plan to control pollutant runoff such as sediment. Therefore, the Basin Plan amendment would not result in substantial soil erosion, and its impacts would be less-than-significant.
- c-d) All Basin Plan amendment construction activities including road-erosion control actions and/or construction of engineered log jams would be designed and conducted under the supervision of a certified Professional Geologist licensed in California. Construction activities would be designed to minimize any potential for landslides, lateral spreading, subsidence, liquefaction, or collapse. Therefore, the Basin Plan amendment would not create safety or property risks due to unstable or expansive soils.

- e) The Basin Plan amendment would not require wastewater disposal systems; therefore, affected soils need not be capable of supporting the use of septic tanks or alternative wastewater disposal systems.

VII. Greenhouse Gas Emissions

- a-b) The project would not generate greenhouse gas emissions that would have a significant impact on the environment or conflict with any plan, policy, or regulation adopted for the purpose of reducing greenhouse gas emissions. Instead, it is reasonable to conclude that the project will contribute to a significant, but not quantified, reduction in greenhouse gas emissions by reducing the total sediment supply to Lagunitas Creek by approximately 50 percent, and by reducing fine sediment supply by a larger amount. In addition, construction of engineered log jams will increase the residence time of large woody debris in channels, substantially enhancing the growth of riparian tree species and the total area of riparian habitat, contributing to additional carbon sequestration.

VIII. Hazards and Hazardous Materials

- a-d) At a small fraction of sites, hazardous materials or substances may be discovered during project activities associated with erosion control and/or habitat enhancement. Required remediation actions would include the proper disposal and transport of contaminated soils, but such waste is expected to be of small volume. Proper handling in accordance with relevant laws and regulations would minimize hazards to the public or the environment, and the potential for accidents or upsets. Therefore, hazardous waste transport and disposal would not create a significant public or environmental hazard, and would be a less-than-significant impacts.
- e-f) The project would not require actions in the vicinity of airports or airstrips.
- g) Hazardous waste management activities resulting from the Basin Plan amendment would not interfere with any emergency response plans or emergency evacuation plans.
- h) The Basin Plan amendment would not affect the potential for wild-land fires.

IX. Hydrology and Water Quality

- a) The project would amend the Basin Plan, which articulates applicable water quality standards; therefore, it would not violate standards or waste discharge requirements.
- b) The Basin Plan amendment would not decrease groundwater supplies or interfere with groundwater recharge. Large woody debris construction projects to reduce sediment delivery from channel incision could result in local increases in groundwater recharge in the Tocaloma and/or State Park channel reaches.

- c) Specific projects involving earthmoving or construction activities to comply with requirements derived from the proposed Basin Plan amendment are reasonably foreseeable including road-erosion control and/or large woody debris jam construction projects. Such projects could affect existing drainage patterns. However, to meet proposed Basin Plan amendment allocations, they would be designed to reduce overall soil erosion, not increase it. Additionally, project components include: a) the requirement to prepare hydrologic and geomorphic analyses to support design and construction of engineered log jams, as needed to avoid erosion and flooding impacts; and b) limiting the project construction period to the dry season and requiring that all basin plan amendment construction projects include preparation of a stormwater pollution prevent plan to control erosion and protect water quality. Nevertheless, temporary earthmoving operations could result in short-term, limited erosion. These specific compliance projects also would be subject to the review and approval of the Water Board, which requires implementation of routine and standard erosion control best management practices and proper construction site management. Therefore, the Basin Plan amendment would not result in substantial erosion, and its impacts would be less-than-significant.
- d) Reasonably foreseeable actions to comply with the Basin Plan amendment will involve earthmoving that could affect existing drainage patterns, and construction of engineered log jams that will contribute to increases in the amount of riparian vegetation and/or large woody debris in stream channels. Road-erosion control projects will reduce storm runoff from roads, and engineered log jams will provide additional floodplain water storage in public park reaches, where additional inundation would not threaten structure or human safety. Also, the project includes as a mitigation measure, the requirement to prepare hydrologic and geomorphic analyses to avoid significant increases in erosion and/or flooding. These required studies will be prepared by a Certified Professional Geologist and/or a Registered Civil Engineer that is licensed to practice in the State of California, who has expertise in fluvial geomorphology, hydrology, and river restoration. All construction projects will require use permits from the County of Marin, and be subject to review under the California Environmental Quality Act. Therefore, we conclude that the impact of the Basin Plan amendment on increases in runoff and/or flooding is less than significant with mitigation incorporated.
- e) Basin Plan amendment-related activities are, by design, intended to decrease peak runoff rates from roads, as needed to reduce fine sediment input to channels and channel erosion. Therefore, the Basin Plan amendment would not increase the rate or amount of runoff, exceed the capacity of storm water drainage systems, or degrade water quality, and the impact is less than significant with mitigation incorporation (i.e., including the above-mentioned performance standard as part of the project).
- f) The purpose of the Basin Plan amendment is to attain and maintain all water quality objectives. Reasonably foreseeable compliance actions would not otherwise adversely affect water quality.

- g-i) Basin Plan amendment-related construction will not include housing, and with the mitigation measures incorporated, as described above in d), that will govern design and construction of engineered log jams within channels, we conclude that impacts are less than significant with mitigation incorporated.
- j) Basin Plan amendment-related construction would not be subject to substantial risks due to inundation by seiche, tsunami, or mudflow.

X. Land Use and Planning

- a) Basin Plan amendment-related construction would be too small in scale to divide any established community.
- b-c) Reasonably foreseeable actions to comply with the Basin Plan amendment would not conflict with the policies and implementing programs of the Marin County General Plan, and/or plan and policies of other state and federal agencies responsible for management of public lands and/or any state or federal agencies with regulatory authority over compliance actions. The Basin Plan amendment is consistent with the objectives and will contribute to recovery of the Lagunitas Creek populations of coho salmon and California freshwater shrimp.

XI. Mineral Resources

- a-b) Basin Plan amendment-related excavation and construction would be relatively small in scale and would not result in the loss of availability of any known mineral resources.

XII. Noise

- a-b) Earthmoving and construction activities for engineered log jams and/or road erosion control projects could temporarily generate noise. These reasonably foreseeable compliance actions would be required to be consistent with Sections 6.70.030(5) and 6.70.040 of the Marin County Code, which establishes allowable hours of operation for construction-related activities, and also that construction projects be consistent with the standards established in the Noise Element of the Marin County General Plan, including Implementing Program NO-1.i, which requires development and implementation of a project noise reduction plan to control significant construction noise.
- c) The Basin Plan amendment would not cause any permanent increase in ambient noise levels. Any noise would be short-term in nature.

- d) To comply with requirements derived from the Basin Plan amendment, specific projects involving earthmoving or construction, which could result in temporary noise impacts, are reasonably foreseeable. Noise-generating operations would, however, have to comply with local noise ordinances to keep levels to less-than-significant levels. Therefore, the Basin Plan amendment would not result in substantial noise impacts, and its impacts would be less-than-significant.
- e-f) The Basin Plan amendment would not cause any permanent increase in ambient noise levels, including aircraft noise. Therefore, it would not expose people living within an area subject to an airport land use plan or in the vicinity of a private airstrip to excessive noise.

XIII. Population and Housing

- a-c) The Basin Plan amendment would not affect the population of the Bay Area, or Marin County. It would not induce growth through such means as constructing new housing or businesses, or by extending roads or infrastructure. The Basin Plan amendment would also not displace any existing housing or any people that would need replacement housing.

XIV. Public Services

- a) The Basin Plan amendment would not affect populations or involve construction of substantial new government facilities. The Basin Plan amendment would not affect service ratios, response times, or other performance objectives for any public services, including fire protection, police protection, schools, or parks.

XV. Recreation

- a-b) Although the Basin Plan amendment would not affect population levels, potential enhancement of fisheries habitat and stream aesthetics has the potential to contribute to an increase in river-focused recreational activities (e.g., kayaking, rafting, fishing, swimming, wading, birding, etc.). Increases in these activities are expected to cause less than significant impacts on the environment. No recreational facilities would need to be constructed or expanded.

XVI. Transportation / Traffic

- a-b) Because the Basin Plan amendment would not increase population or provide employment, it would not generate any ongoing motor vehicle trips. Earthmoving and construction would be temporary, and related traffic would be of short-term duration. Therefore, the Basin Plan amendment would not substantially increase traffic in relation to existing conditions. Levels of service would be unchanged.
- c) The Basin Plan amendment would not affect air traffic.
- d) Reductions in road-related erosion called for by the Basin Plan amendment would not require implementation of hazardous design features or incompatible uses in order to meet the TMDL.
- e) Minor construction and earthmoving operations to reduce road-related erosion that would occur as a result of adoption of the Basin Plan amendment is not expected to restrict emergency access. Local agencies would confirm that specific proposals would not restrict emergency access through their environmental reviews.
- f) Because the Basin Plan amendment would not increase population or provide employment, it would not affect parking demand or supply.
- g) Because the Basin Plan amendment would not generate ongoing motor vehicle trips, it would not conflict with adopted policies, plans, or programs supporting alternative transportation.

XVII. Utilities and Service Systems

- a) The project would amend the Basin Plan, which is the basis for wastewater treatment requirements to improve water quality and the environment in the Bay Area; therefore, the Basin Plan amendment would be consistent with such requirements.
- b) Although the Basin Plan amendment proposes planning and regulatory efforts to facilitate enhancement of baseflow in streams, since no specific actions are proposed or required at this time, it would be speculative to evaluate possible physical changes to the environment at this time. Should local agencies propose specific projects at a future date, those would be subject to environmental review, and mitigation as needed.

- c) New or expanded stormwater drainage facilities are not called for under the proposed Basin Plan amendment.
- d-e) Because the Basin Plan amendment would not increase population or provide employment, it would not require an ongoing water supply. It would also not require ongoing wastewater treatment services.
- f-g) Basin Plan amendment implementation would not substantially affect municipal solid waste generation or landfill capacities.

XVIII. Mandatory Findings of Significance

- a) Reasonably foreseeable actions to comply with the Basin Plan amendment will benefit native fish and wildlife species including rare and endangered species by decreasing fine sediment supply and enhancing stream-riparian habitat conditions in Lagunitas Creek and its tributaries such that fish and wildlife species and their populations in and near waters of the state thrive. Reasonably foreseeable compliance actions in all cases would have to be permitted by the Water Board, the California Department of Fish and Wildlife, the US Fish and Wildlife Service, NOAA Fisheries, and the County of Marin (which would require a CEQA determination, and as applicable, a Biological Assessment). As described earlier in the explanation of checklist responses for Biological Resources and Cultural Resources (pp. 117-122 of this report), we conclude that compliance actions would not threatened any plant or animal community, and/or reduce the number or restrict the range of a rare or endangered plant or animal species. Also, as described in the explanation for the checklist response for Cultural Resources, there are no significant impacts to Cultural Resources.
- c) *Discussion of Cumulatively Considerable Impacts.* Project-specific impacts in all resource categories are less than significant. The project incorporates design and construction requirements to avoid potential impacts of constructed large woody debris jams on California freshwater shrimp and all special status bird species; and to avoid potentially significant impacts to cultural resources and to flooding and erosion. Some special status plant species (including those associated with native grasslands and/or serpentine geology) may overlap with the right-of-way for roads where erosion control projects would be implemented to comply with the Basin Plan amendment. These plant communities would be protected however because all would be permitted by the

California Department of Fish and Wildlife through required permit conditions, and/or through conditions resulting from a required by the County of Marin which requires a Biological Assessment, as applicable, where special status species may overlap or be adversely affected by a project that requires a permit by the county.

The only other project we are aware of where there is a direct overlap and/or where impacts to resources may be additive is the Sir Francis Drake Road Widening Project. However, that project incorporates a suite of mitigation measures to result in less than significant impacts with mitigation incorporated. Construction activities associated with both projects although each individually causing a less than significant impact on noise could through interaction result in cumulative effects. However, the Sir Francis Widening project is expected to be completed prior to the expected dates of approval by the State Water Resources Control Board and the USEPA of the Basin Plan amendment, which would be no earlier than December 2014. Therefore, we conclude that the project does not contribute to any cumulatively considerable impacts

- c) The Basin Plan amendment would not cause any substantial adverse effects to human beings, either directly or indirectly. The Basin Plan amendment is intended to benefit human beings through implementation of actions predicted to enhance fish populations, aesthetic attributes, recreational opportunities, and contribute to a reduction in property damage in and/or nearby to stream channels in the Napa River watershed.

7.3 Alternatives

In defining and presenting reasonable alternatives to the proposed Basin Plan amendment, we discuss how each alternative could affect foreseeable environmental outcomes, and the extent to which each alternative would achieve the goals and objectives of the proposed amendment. The objectives of the Lagunitas Creek Sediment Reduction and Habitat Enhancement Plan (Project) are substantially enhance channel substrate quality and complexity, and floodplain connections in the freshwater reaches of Lagunitas Creek and its tributaries, as needed to support conservation and/or recovery of watershed populations of coho salmon, steelhead, Pacific lamprey, and California freshwater shrimp. To do so, the implementation plan for Basin Plan amendment calls for management actions and erosion control projects to reduce the rate of fine sediment delivery to channels that is generated from road-related erosion, and management actions and construction of engineered log jams to substantially increase the amount of large woody debris in channels, as needed to address impacts of channel incision on fine sediment delivery and habitat complexity/connectivity.

Our analysis includes the following alternatives:

1. ***Proposed Project*** – establishes a total maximum daily load for sediment in Lagunitas Creek at 125 percent-or-less of the natural background, and related stream-riparian

habitat enhancement plan that emphasizes a 100-percent-or-greater increase in the amount of large woody debris in channels. Primary actions include: a) erosion control projects to reduce sediment delivery from roads (road-related erosion constitutes one-fifth-or-more of the current total sediment supply and this source is comprised primarily of sand and finer grain sizes); and b) construction and installation of engineered log jams (and related management actions to restore natural recruitment rates) in order to address impacts of channel incision on total sediment delivery and habitat complexity in channel reaches located downstream of municipal reservoirs in the Lagunitas Creek watershed. Under the proposed Basin Plan amendment, sediment reduction and habitat enhancement objectives would be achieved by 2034.

2. ***Proposed Basin Plan amendment plus floodplain restoration***- identical to the proposed Basin Plan amendment, except this alternative also includes a water quality target to double the floodplain area. As a result, in addition to the engineered log jams that are part of the proposed Basin Plan amendment (some of which will increase floodplain area locally in backwaters of jams), there also would be large-scale floodplain restoration projects (e.g., 500 meters-or-greater in length) constructed adjacent to channels located in public parklands. Floodplain restoration involves actions to increase the elevation of the streambed and/or to decrease the elevation of the adjacent valley flat, in order to increase the frequency, area, and/or duration of inundation on the valley flat. As a result, stream and riparian habitat connectivity and complexity is enhanced including: a) formation of side channels and alcoves (that provide essential habitat for coho salmon and other native species); b) establishment of diverse vegetation and substrate patch types; c) enhanced recruitment and loading of large woody debris; d) a substantial increase in fine sediment storage on floodplains; and e) a reduction in shear stress (elevated rates of streambed mobility) in the channel during large storms (because a greater proportion of discharge is conveyed on the floodplain). As compared to the proposed Basin Plan amendment, this alternative would involve a much greater amount of earth moving and construction in/around stream channels, and potentially significant short-term impact to impacts to biological resources (with medium- and long-term benefits), and potentially significant impact to cultural resources.
3. ***Alluvial fan and channel restoration*** – Under natural reference conditions, it is likely that some tributaries to Lagunitas Creek were naturally disconnected. As a result, all of the sand and coarser sediment and some of the finer sediment generated from these watershed areas went into long-term storage in alluvial fans and/or adjacent flood basins, and was not delivered to Lagunitas Creek. Large naturally disconnected tributaries may have been most common in the San Geronimo and Nicasio valleys,

which are very broad and where channels typically are unconfined. To facilitate agricultural and residential development, it is likely that Euro-American settlers, ditched (connected) many of the naturally disconnected channels, greatly increasing sediment supply and peak flow in Lagunitas, Nicasio, and San Geronimo creeks. Under this alternative: a) some of the naturally disconnected channels would be restored (disconnected) to reduce upland sediment delivery and peak flow discharge to channels; and b) identical to the proposed Basin Plan amendment, the amount of large woody debris in channels would be increased by 100-percent-or-more. However, road erosion control projects would not need to be implemented in order to achieve the sediment TMDL established at 125 percent of natural background. Timeframe for implementation also is through 2034.

4. *Fish passage through Nicasio Reservoir and Kent Lake* – this alternative would involve operation/construction of facilities to restore passage by coho salmon and steelhead through Nicasio Reservoir and Kent Lake, the result of which would be to restore access to much of the spawning and rearing habitat available prior to dam construction. While this alternative may be effective in achieving the underlying objective of the Basin Plan amendment to greatly increase the watershed carrying capacity for coho salmon and steelhead (by a significant increase in access to potentially suitable habitat), it does not address the current water quality impairment, which relates to sedimentation and habitat simplification in the habitat along Lagunitas Creek and/or in its tributaries that remain accessible to salmonids.
5. *No Action/No Basin Plan amendment* – No sediment TMDL and/or no habitat enhancement plan would be adopted by the Water Board.

Alternative 1: Proposed Basin Plan amendment

The proposed Basin Plan amendment is based on the technical analyses presented in Chapters 2 through 6 of this Staff Report. Reasonably foreseeable actions to comply with the Basin Plan amendment are in two primary categories: 1) retrofits and/or maintenance actions to control road-related erosion; and 2) management actions and projects to increase the amount of large woody debris in channels.

Up to 45 miles of roads in the watershed may require construction projects and/or retrofits to existing road drainage facilities to address potentially significant sources of sediment delivery. These road-erosion control projects would be completed over a 20-year period. No road reaches are proposed for relocation, and reasonably foreseeable actions to reduce sediment delivery from roads in almost all cases would be contained within the current footprint of the existing roads.

As an example, to visualize how many additional large fallen trees would be in the channel given attainment of the LWD target that is part of the proposed Basin Plan amendment, we estimate that in Lagunitas Creek within SP Taylor State Park, there would be at least 20 additional bar-apex jams, at least 10 additional flow-deflector jams, and at least 3 additional meander jams throughout the approximately 4-mile long reach, or on average about one engineered log jam every 200 meters (see, Figures 6.2 and 6.3 for examples of these debris jam types⁶⁷).

To avoid potentially significant impacts to biological resources and/or hydrology and water quality, the project also incorporates the following components:

- g) Design requirements for engineered log jams, so that they do not fully span the channel, as needed to avoid blockage of movement by California freshwater shrimp, as need to achieve consistency with the *California Freshwater Shrimp Recovery Plan* (USFWS, 1998);
- h) Requirements for hydrologic and geomorphic analyses, consistent with Abbe (2003b), and the Marin County General Plan, (Goal EH-3 and Implementing Program, EH-3.f, Marin County, 2007) to support design of engineered log jams, including avoidance of significant increases in flooding or erosion, for all structures installed in channel reaches with adjacent residential, commercial, and/or for public facility uses; and
- i) Implementation of stormwater pollution prevention plans (approved by the Water Board) for all road-erosion control and/or engineered log jam construction projects, and as needed, limiting the construction period for compliance projects to the August through October period avoiding potentially significant impacts to nesting birds, and/or water quality.

Based on the environmental analysis, presented earlier in this chapter, we conclude there are no potentially significant impacts resulting from reasonably foreseeable actions to comply with the proposed Basin Plan amendment.

Alternative 2: Proposed Basin Plan amendment plus a doubling of floodplain area

This alternative is identical to the proposed Basin Plan amendment except it also includes a target to double floodplain area within fifteen years of adoption of the Basin Plan amendment. For the floodplain, we use the definition of Dunne and Leopold (1978):

“The floodplain is the flat area adjoining a river channel constructed by the river in the present climate and overflowed at times of high discharge. It is inundated on the average once every one or two years (p. 600).”

⁶⁷ We infer these were the most common types of debris jams along Lagunitas Creek under natural reference conditions in what is now SP Taylor State Park; see pp. 79-84 of this document for additional details.

The geomorphic and biological objectives associated with the floodplain area target are listed in Table 7.2. As compared to the proposed Basin Plan amendment, this alternative would involve a much greater amount of earth moving and construction in/around stream channels, and potentially significant short-term impact to impacts to biological resources (with significant positive medium- and long-term benefits).

Table 7.2: Goals for Floodplain Reconnection

1. To increase side channel plus alcove area, wetted during winter baseflow and higher flows, by 100 percent-or-more. Side channels and alcoves should be accessible, nearby or adjacent to debris jams and/or undercut banks in the main channel, and/or tributary junctions.
2. To establish diverse vegetation and substrate patch types that are dynamically established, evolve, and deform through time: a complex and dynamic mosaic of stream-riparian habitats.
3. To store a substantial fraction of the fine sediment supply on the floodplain: 20 percent-or-more of the total sediment supply to a given channel reach.
4. To achieve the streambed mobility and redd scour targets in all reaches where floodplains are reconnected to channels.
5. To increase gravel storage volume and average residence time, and to increase the variability in the thalweg profile in SP Taylor State Park, Tocaloma, and Lower Lagunitas reaches.
6. To restore natural rates of recruitment of large woody debris from riparian areas of channels located on public lands.
7. To achieve or exceed targets for large woody debris loading as specified in Table 1 within 10 years of Basin Plan amendment adoption.
8. To convert one-third-or-more of the plane bed habitat in channel reaches accessible to anadromous salmonids to forced pool-riffle habitat.
9. To expand the reach length occupied by California freshwater shrimp by two kilometers-or-more.
10. To produce 10,000-or-more coho salmon smolts, and 6,000-or-more steelhead smolts, on average, each year.

This alternative matches an earlier draft of the proposed Basin Plan amendment that was submitted for peer review. In response to peer review, and based on additional consideration, the floodplain target was removed from the current version of the Basin Plan amendment because:

- a) Although there has been a tremendous reduction in floodplain area during the historical period (e.g., we conclude that there were extensive floodplains along San Geronimo and Nicasio creeks, and also along Lagunitas Creek downstream of its confluence with Nicasio Creek), and floodplains provide essential geomorphic, hydrologic, and ecological functions, available information is not sufficient to develop an accurate map/estimate (e.g., within 30 percent of the actual value) of the current floodplain area, the vast majority of which is located in the Tocaloma Reach. At best, we can only estimate the current area of floodplain within a factor-of-two of the actual value introducing considerable uncertainty into our analysis of the potential effects of doubling floodplain habitat area. Developing an accurate estimate of the present-day floodplain area is challenging because there is considerable variation in channel cross-section area, streambed slope, and roughness (because of a large amount of variability in the amount of large woody debris and vegetation in the main channel and also on the floodplain and other parts of the valley flat) in the Tocaloma Reach. These variables exert a significant influence on streamflow conveyance capacity in the main channel, and depth and area of inundation on the valley flat, during the annual flood and/or more common or rare flood events. Because the Water Board does not have sufficient resources available in the near-term (current fiscal year) to support preparation of a fairly complete and accurate map to estimate the present-day floodplain area, analysis of potential environmental effects of doubling floodplain area, even at a programmatic level, becomes highly uncertain.
- b) Also, the proposed target to double total floodplain area is premised in part on the hypothesis that overall doubling of the total floodplain area, would lead to an approximate doubling-or-greater of the areas/lengths of side channel and/or alcove habitats that are part of the floodplain, this hypothesis has not been confirmed through mapping of present-day floodplain area and delineation of the active side channels and alcoves within, and analysis of process-form relationships and dynamics. It is likely that the proportion of the valley flat that is a present-day floodplain, may be best explained by one or more of the following attributes: the difference in elevation of the thalweg and the top of the stream banks in the main channel; the frequency of (naturally formed) channel spanning log jams; valley width; channel slope; and/or the amount of roughness

associated with riparian vegetation that is rooted within the bankfull channel. Therefore, achieving a doubling-or-greater of side channel and alcove habitat areas, may actually involve much more or much less of an increase than called for under the floodplain target.

- c) Depending upon the specific attributes of a given incised channel reach, where little or none of the adjacent valley flat is a floodplain at present, different techniques and/or approaches for reconnecting the floodplain would be called for. These techniques likely vary considerably with regard to amount of potential short-term disturbance (in particular) to existing biological resources.

Therefore, we conclude that a more detailed understanding of the opportunities and constraints and of the potential benefits of floodplain reconnection is warranted before implementing large-scale floodplain reconnection projects, in order to optimize potential environmental benefits. This alternative is not preferred.

Alternative 3: Alluvial fan and channel restoration

This alternative was suggested as part of the public comment on the scope of the Basin Plan amendment project. In order for this alternative to result in a significant reduction in total sediment supply to Lagunitas Creek, as needed to achieve the TMDL equal to 125 percent of natural background, implementation would have to be focused in the San Geronimo Valley, where we infer there were naturally disconnected tributary channels, and where at present-day much of the watershed sediment supply is generated. Therefore, complimentary construction of large runoff detention basins and/or high flow bypass channels would also be required to avoid a significant increase in flooding and related impacts to residential, commercial, and public facilities uses in the San Geronimo Valley. As a result, substantial additional funding would be needed for land purchase, and construction of flood management facilities, in addition to the cost of restoring the alluvial fans and naturally disconnected channels. Also, it is likely that there would be higher frequency of avulsion (a sudden shifting and relocation during high flow) of the restored/re-aggraded alluvial fan channels, as compared to the current dynamics in incised channel reaches (which typically are not subject to frequent avulsion, except locally near natural or human-made constrictions, such as bridge crossings). This change in channel dynamics could contribute to a greater risk of flooding and property damage as compared to the environmental baseline, and/or might require an increase in the footprint of detention basins (so that during an avulsion the new channel would still flow into the basin), which would in turn lead to additional potential impacts to the environment. Also, if a significant fraction of the gravel supply to San Geronimo Creek was deposited on the restored/re-aggraded fans, which is reasonable to hypothesize, then further alluvial stripping (greater bedrock exposure and fewer riffles and smaller gravel bars) could occur in San

Geronimo and Lagunitas Creek, and potentially the Tocaloma channel reach (where the channel is well connected to its floodplain) could be incised.

Based on initial review, this alternative appears to have the potential for much greater impacts than the proposed Basin Plan amendment, and therefore, it is not preferred.

Alternative 4: Fish passage through Nicasio Reservoir and Kent Lake

This alternative was suggested during public comment on the scope of the proposed Basin Plan amendment project. Although building facilities to restore passage by coho salmon and steelhead through Nicasio Reservoir and Kent Lake has the potential to significantly increase watershed populations of these species, it does not address the current water quality impairment: excessive fine sediment deposition and habitat simplification along Lagunitas Creek and/or in its tributaries that remain accessible to salmonids. As such this alternative, although complimentary to the proposed Basin Plan amendment, would not resolve the water quality impairment listing, that the Water Board is legally required to address. Also, detailed evaluation of salmonid passage through Nicasio Reservoir and Kent Lake would require substantial effort and technical expertise that are not available to the Water Board in the near-term (current fiscal year). Also, we should emphasize that Water Board does not have previous experience undertaking such a large-scale and technically complex fish passage analysis, and other trustee agencies including NOAA Fisheries and the California Department of Fish and Wildlife would be better suited to lead such an analysis considering their staff expertise, regulatory authority, and the focus and priorities of these agencies. Because this alternative does not resolve the current water quality impairment, it is not preferred.

Alternative 5: No Action/No Basin Plan amendment

If the Water Board does not adopt the Lagunitas Creek sediment TMDL, the U.S. Environmental Protection Agency (USEPA) will be required to do so, pursuant to the Clean Water Act Section 303(d) listing of Lagunitas Creek as impaired by sediment. USEPA would likely rely, at least in part on analyses completed to date. Within legal constraints the agency would be free to develop a TMDL in any manner they deem appropriate. Subsequently, the Water Board would be required to prepare a plan specifying actions to resolve the impairment, as needed to attain and maintain the numeric targets and sediment allocations approved by USEPA. Absent USEPA completion of an alternative TMDL, it would be speculative to evaluate whether or not reasonable foreseeable actions needed to achieve the alternative TMDL would reduce or increase environmental impacts (as compared to the proposed Basin Plan amendment).

Analysis of the Preferred Alternative

The *No Action* alternative is not realistic because there is a legal requirement under the Clean Water Act to adopt a TMDL, and not preferred because there is a higher potential for disconnects between the TMDL and implementation plan, when these two parts are developed by different agencies. In addition, it would delay adoption and subsequent implementation and waste public monies as significant amount of public funds have already gone into the development of the proposed Basin Plan amendment. Furthermore by delaying TMDL implementation, the duration of the sediment impairment could be extended, lengthening the duration of a significant environmental impact (e.g., sediment impairment).

The *Proposed Basin Plan amendment plus a doubling of floodplain area* is not preferred because available information is not sufficient to accurately evaluate potential impacts, and/or to optimize benefits. The *Alluvial fan and channel restoration alternative* is not preferred because it

appears that it could result in much greater impacts to the environment than the Proposed Basin Plan amendment. *The Fish passage through Nicasio Reservoir and Kent lake alternative* is not preferred because it does not resolve the current water quality impairment, which is a fundamental objective of the proposed project. The *Proposed Basin Plan amendment* alternative is preferred. It addresses the sediment and habitat impairment listing, and reasonably foreseeable compliance actions would not result in any significant environmental effects.

7.4 Government Code §57004: Peer Review

Independent peer review of the Basin Plan amendment and staff report was provided by two scientists: 1) Dr. John G. Williams, an Environmental Consultant with a Ph.D. in Geography, who has expertise in salmonid biology; and 2) Dr. Benjamin R. Hayes, a Professor of Earth Sciences at Bucknell University and the Director of the Susquehanna River Initiative, who has expertise in fluvial geomorphology and aquatic habitat restoration.

Dr. Williams raised significant concerns regarding the adequacy of description of the study area and the accuracy of the natural channel reference model. Specifically, he commented that we may be over-emphasizing the role of large woody debris in shaping habitat conditions and sediment dynamics, and that the sediment budget for the watershed covers too short a period. He also questioned our interpretation of the nature of valley fills along Lagunitas Creek (primarily in the State Park Reach), where we have inferred they are floodplains formed by the river that later isolated as a result of channel incision. He hypothesized instead that the stream terraces could be: a) the product of debris flows; and/or b) if river-formed floodplains, that they may be formed primarily by deposition during infrequent large floods, which could explain why they are elevated high above the channel.

To address Dr. Williams' concerns we prepared a detailed description of the study area that is now included as an appendix to the public review draft of the staff report. We also provided additional citations to published literature and evidence from data collected in the watershed to support the channel reference model. With these changes, we believe that all of the significant concerns that Dr. Williams raised have been addressed.

In contrast to the review by Dr. Williams, Dr. Hayes expressed very strong support for our plan, and found the staff report and Basin Plan amendment to be founded on sound scientific knowledge, methods, and practices. In his summary, he stated that:

“It (the *Lagunitas Creek Watershed Sediment Reduction and Habitat Enhancement Plan*) identifies regulatory programs that will greatly reduce human-caused sediment impacts to Lagunitas creek and voluntary programs which will enhance the channel habitat complexity and connection to the floodplain. ... I am confident that given sufficient time, your proposed measures will help to provide aquatic habitat improvements necessary to sustain viable coho salmon, steelhead, and California [freshwater] shrimp populations (Hayes, 2013).”

7.5 Economic Considerations

Introduction

The California Environmental Quality Act requires that whenever one of California's nine Regional Water Quality Control Boards, such as the San Francisco Bay Regional Water Quality Control Board (Water Board), adopts a rule that requires the installation of pollution control equipment or establishes a performance standard or treatment requirement, it must conduct an environmental analysis for reasonably foreseeable methods of compliance (Public Resource Code 2759 [a][3][c]). This analysis must take into account a reasonable range of factors, including economics. Furthermore, if the rule includes an agricultural control plan, then the total cost of the program must be estimated and potential sources of funding must be identified (Water Code 13141).

The proposed *Lagunitas creek Watershed Sediment Reduction and Habitat Enhancement Plan* includes performance standards (i.e., targets and allocations), and therefore requires the consideration of economic factors. The Total Maximum Daily Load (TMDL) implementation plan also proposes activities for agriculture, and therefore, the total cost of the implementation effort is estimated.

In amending the Basin Plan, the Water Board must analyze the reasonably foreseeable methods of compliance with proposed performance standards and treatment requirements (Pub. Resources Code §21000 et seq.). This analysis must include economic factors, but does not require a cost-benefit analysis.

Additionally, in accordance with the Porter-Cologne Water Quality Control Act, it is the policy of the state to protect the quality of all waters of the state. Waters of the state include "any surface water or groundwater, including saline waters, within the boundaries of the state" (CWC §13050). When adopting the Porter-Cologne Act, the Legislature declared that all values of the water should be considered, but then went on to provide only broad, non-specific direction for considering economics in the regulation of water quality.

"The Legislature further finds and declares that activities and factors which may affect the quality of the waters of the state shall be regulated to attain the highest water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved, beneficial and detrimental, economic and social, tangible and intangible" (CWC §13000).

The Porter-Cologne Act directed regulatory agencies to pursue the highest water quality that is reasonable, and *one* of the factors used to determine what is reasonable is economics. It is clear, though, that economic factors cannot be used to justify a result that would be inconsistent with the federal Clean Water Act or the Porter-Cologne Act. The Water Board is obligated to restore and protect water quality and beneficial uses.

Cost Estimates

We present cost estimates for sediment control actions by source category (e.g., actions to control channel incision/enhance habitat complexity and floodplain connection, and road-related erosion). These cost estimates include all costs for control of sediment discharges. We then estimate proportion of total costs associated with agricultural sources (e.g., Agricultural Water Quality Control Program Costs).

Wood and Floodplain Restoration Costs (\$13-to-\$33 million)

In estimating costs to rehabilitate channel habitat complexity and control future incision, we rely on data compiled by Thompson and Pinkerton (2008) and/or by Evergreen (2003).

Along San Geronimo Creek and its tributaries, there is about 8 miles of habitat for anadromous salmonids (Stillwater Sciences, 2009, Figure 3-17, p. 3-61). We think it may be safe and feasible to install large woody debris structures and/or engineered log jams over about 2 miles of this habitat, primarily in reaches where homes and roads are not close to channels, and where landowners are willing to participate voluntarily in stewardship projects. Most large woody debris structures and/or engineered log jams would be designed to force pool-bar units to form in reaches that are scoured to bedrock and/or where a paucity of large woody debris has caused the channel to become simple and flat. Also, upstream of the Dickson Weir, along the North Fork of San Geronimo Creek, we think it may be feasible using engineered log jams to re-connect the channel to its historical floodplain, creating a substantial amount of high quality winter rearing habitat for coho salmon and steelhead throughout a 0.5-mile long reach. This project would require permission and support of property owners on both sides of the creek.

Within the 4.5-mile long State Park Reach, as needed to achieve the large woody debris target and rehabilitate channel habitat complexity, it may be necessary to double-to-triple the amount of large wood in channels. To double-to-triple wood loading, we estimate that 20-to-50 engineered log jams need to be installed (see Environmental Analysis for additional details). Considering channel drainage area and valley type, we infer that bank input jams, bar-apex jams, bank-deflection jams, and meander jams were common in this reach prior to disturbance (See Chapter 6 of this report).

Over most of the Tocaloma Reach, wood loading already appears to be very high, stream habitat is complex, and the channel is connected to its floodplain. Therefore, additional engineered log jams and/or floodplain restoration projects aren't needed in this reach to achieve the TMDL, and/or numeric targets for wood. As such, we don't estimate costs for this reach⁶⁸.

⁶⁸ Some sub-reaches of Tocaloma are simple and disconnected from the floodplain. In these locations, well designed projects could further enhance habitat conditions. Therefore, we support the efforts by MMWD to design and construct engineered log jams in this reach, as part of a recently awarded grant from the California Department of Fish and Wildlife

In the Lower Lagunitas Reach, in advance of proposed studies to identify opportunities for floodplain restoration, it is difficult to develop a reliable estimate of the potential cost of a large-scale channel restoration project. However, to provide an initial basis for evaluation of the relative magnitude of costs, we outline an approach involving gravel supplementation and construction of channel spanning debris jams to re-aggrade Lower Lagunitas Creek and reconnect it to its floodplain from Highway 1 upstream to Nicasio Creek confluence, and/or over about $\frac{3}{4}$ of the reach. **A conservative estimate of the total cost for projects to enhance habitat complexity and connectivity is \$13-to-\$33 million (Table 7.3).**

Table 7.3. Cost Estimates to Enhance Habitat Complexity and Connectivity

Action	Parties	Items	Low Cost (\$million)	High Cost (\$million)
Develop and implement wood projects in San Geronimo Creek and its tributaries	Landowners in partnership with local government agencies	• Design and environmental review • Construction • Maintenance and monitoring	0.1 0.5 0.1	0.4 1.0 0.2
Develop and implement wood projects in SP Taylor State Park	MMWD in lead partnering with State Parks	• Design and environmental review • Construction • Maintenance and monitoring	0.2 1.0 0.2	0.4 4.0 0.4
Develop and implement a large-scale stream-riparian restoration project in the Lower Lagunitas Reach	MMWD in lead partnering with GGNRA	• Design and environmental review • Construction • Maintenance and monitoring	0.5 10.0 0.2	1.0 25.0 1.0
All required actions		Total	13	33

Key assumptions and information (for Lower Lagunitas Creek Restoration):

1. The approach would involve channel spanning debris dams, local grading to widen the channel and inject gravel in lower Nicasio Creek and/or Lower Lagunitas Creek over a 10-20 yr period.
2. We use the following data to estimate the volume of gravel that would be dumped at sites along lower Nicasio Creek and/or Lower Lagunitas Creek: bed-elevation is raised by 15' on average; average channel width is 65', and the project is implemented over 14,000'-to-20,000'.
3. Thompson and Pinkerton (2008) cite an average cost of \$20-to-\$40 per cubic yard (\$26-to-\$52 per cubic meter) for sorted gravel. We assume an average cost of \$25-to-\$45 per cubic yard for gravel and sand, supplied from dredging Nicasio Reservoir and/or other local sources.
4. We infer at least ½ of the necessary gravel-sand volume, about 175,000 cubic meters has been deposited in Nicasio Reservoir since closure in 1961.
5. We also factor in \$1-to-\$2 million for grading, rock work, and large woody debris at sites where we would locally widen the channel and install channel-spanning debris dams to build-up streambed elevation and fully maintain fish passage.

Key assumptions and information (for wood projects in SP Taylor State Park):

1. 20-to-50 engineered log jams would be constructed. Most will be bank-deflection or bar-apex jams. To avoid potential impacts to roads and bridges, detailed hydraulic and geomorphic analyses will guide design. Key pieces need to be large (diameter ≥ 1 m, intact root-wads and ≥ 15 m in length). Other factors influencing cost are channel size (med.) and high wood density. Consistent with Evergreen (2003), cost is \$50-to-\$80,000 per jam.
2. We also assume limited amounts of local grading to key logs into the channel bed and/or banks.

Key assumptions and information (for wood projects in San Geronimo Creek watershed):

1. We consider construction of five channel-spanning and/or valley jams along North Fork of San Geronimo Creek, at a cost of \$80,000 per jam. In most other locations, bank input jams and log-steps would be installed. In a few locations, bankfull-bench jams would be installed.
2. As compared to Evergreen Consultants (2003), we assume costs in the San Geronimo Creek watershed will be ≥ the highest values cited therein. We also assume very high costs for design and permitting, considering the close proximity of many houses and roadways.

Road Sediment-Source Control Project Costs (\$2.7 million)

There are 134 miles of roads within the project area: a) 109-miles of publically owned roads (62-miles unpaved, and 47-miles paved); and b) 25-miles of privately owned roads (21-miles unpaved, and 4-mile paved) (Lynx technologies, 2007). To achieve TMDL load allocations and road sediment delivery performance standards, on average, we estimate that potential sediment delivery to channels from unpaved roads, need to be reduced by about 350 cubic yards per mile, and by ≤ 150 cubic yards per mile from paved roads.⁶⁹ At least 27-miles of unpaved publically-owned roads (under the jurisdiction of the Marin County Open Space District) already have been treated to control sediment delivery to channel reaches that provide habitat for anadromous fish; so these roads are not included in our estimate of the potential cost of road-erosion control projects that would be implemented to achieve the TMDL.

Calculations are as follows:

1. **Cost to reduce sediment delivery from unpaved publically-owned roads:**
(62 miles total – 27 miles already treated) = [35 miles that need to be treated $\times$ (350 cubic yards per mile sediment savings) $\times$ (\$50 per cubic yard of sediment savings)] $\times$ 1.2 (to account for the cost of environmental review and permitting) = **approximately \$750,000.**
2. **Cost to reduce sediment delivery from paved publically-owned roads:**
[47 miles that need to be treated $\times$ (150 cubic yards per mile sediment savings) $\times$ (\$150 per cubic yard of sediment savings)] $\times$ 1.2 (to account for the cost of environmental review and permitting) + (\$50,000 to perform a road erosion inventory) = **approximately \$1.3 million**⁷⁰.
3. **Cost to reduce sediment delivery from unpaved privately-owned roads:**
[(21miles, all but one-mile of which are located on ranch properties) $\times$ (350 cubic yards per mile sediment savings) $\times$ (\$50 per cubic yard of sediment savings)] $\times$ 1.2 (to account for the cost of environmental review and permitting) = **approximately \$450,000.**

⁶⁹ Sediment source inventories for roads estimate future potential delivery to channels from both chronic sources associated with sheetwash processes (surface erosion) along the road prism and cutbank, and also the potential for episodic sediment delivery from gully erosion and landslides associated with the road drainage system and/or road cuts and fills. Typically, as a result of the inventory, future potential sediment delivery to channels is estimated for a 20-year period (to account for the episodic processes). Also, costs to control surface erosion in road reaches that could deliver to channels are estimated, as are costs to avoid or control sediment delivery to channels from actual or potential gully and/or landslide erosion sites. Typical costs per cubic yard of sediment prevented from being delivered to a channel, for an unpaved road is $\leq$ \$50 per cubic yard (PWA 2007a, 2007b, 2010; and Stetson Engineers, 2013). Cost per cubic yard of sediment savings from paved roads are much higher (PWA 2003). We estimate that the potential cost per cubic yard of sediment savings from paved roads could be as high as \$150 per cubic yard; twice as high as estimated in PWA (2003).

⁷⁰ It is possible that the paved roads already are meeting the road sediment delivery performance standard or much closer to it than we have assumed in our conservative estimates of total cost. If so, the actual cost for erosion control on paved public roads could be very much lower.

4. **Cost to reduce sediment delivery from paved privately-owned roads:**

[4 miles that need to be treated x (150 cubic yards per mile sediment savings) x (\$150 per cubic yard of sediment savings)] x 1.2 (to account for the cost of inventory, environmental review, and permitting) = **approximately \$100,000**.

Adding these estimated costs, the total cost of control of road-related sediment delivery to channels is **≤ 2.7 million** (and the actual cost could be about half as much, see footnotes above).

Agricultural Water Quality Program Costs

Implementation measures located on grazing lands constitute an agricultural water quality control program and therefore, consistent with California Water Code requirements (Section 13141), the cost of this program is estimated herein. This cost estimate includes the cost of implementing all road-related sediment control measures specified in the implementation plan, and is based on costs associated with technical assistance, project design, and implementation of actions needed to achieve the TMDL. Agricultural Water Quality Program Costs are for treatment of 20-miles of unpaved roads, located on privately owned ranches. The total estimated cost is 20-miles x 350 cubic yards of sediment savings per mile x \$50 per cubic yard of sediment savings x 1.2 (to account for the costs of environmental review and permitting) = **\$420,000** over the 20-year period associated with implementation actions to achieve the sediment TMDL (on average about \$21,000 per year)⁷¹. There are no other costs to farmers or ranchers associated with actions to enhance channel habitat complexity and floodplain connection, because participation by private landowners is voluntary, and almost all of the cost of these projects is expected to be paid for from grants by public agencies and/or non-profits.

⁷¹ Arguably these may not actually be new agricultural water quality program costs because these ranch properties already are regulated under the Water Board's pollutant control program for grazing operations in the Tomales Bay watershed (Order R2-2013-0039), which specifies that access and ranch roads be maintained and operated to minimize erosion. Because the Basin Plan amendment further establishes quantitative performance standards for road sediment delivery, we have included these costs herein.

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Appendix I:

Detailed Description of Study Area

San Geronimo Creek and its watershed

San Geronimo Creek drains a 24 square kilometer (9.4 square mile) watershed (Map 1). Almost all of the residents within the TMDL project area live in the San Geronimo Creek watershed⁷². As of 2013, the San Geronimo Creek watershed had a population of approximately 3,500 (San Francisco Association of Realtors, 2013). Many homes are located close to the top of the banks of channels along: a) Woodacre Creek (its largest tributary) and/or tributaries to Woodacre Creek; b) near San Geronimo Creek in its lower reach (downstream of Roy's Pools); and/or c) along tributaries to lower San Geronimo Creek including Montezuma Creek, Cintura Creek, and Arroyo Creek. Although there is significant rural residential and commercial development in the San Geronimo Valley, most of the watershed remains in open space or ranch uses. Total impervious surface area averages approximately 5 percent in the San Geronimo Creek watershed varying from about 2 percent within the watershed of the North Fork of San Geronimo Creek to about 9 percent in the Woodacre Creek watershed (Stillwater Sciences, 2009). There are about 116 kilometers (72 miles) of roads in the San Geronimo Creek about half are paved, and half are dirt or gravel-surfaced (Lynx Technologies, 2007).

The San Geronimo Creek watershed is underlain by the *mélange* unit of the Franciscan Complex, except in its headwaters which is underlain by the inter-bedded sandstone and shale unit of the Franciscan Complex. San Geronimo Valley is comprised of sand, gravel, and finer sediment deposited by streams in their channels and/or on floodplains and alluvial fans, as indicated from examination of stream bank exposures (Table A-1.1, Stillwater Sciences, 2009). The fine-grained ocean-floor rock types that form the bulk of the *mélange* have been sheared, and they comprise a mechanically incompetent matrix that engulfs occasional large pieces of hard rock referred to as blocks. The Franciscan *mélange* is renowned for its high to extreme rates of erosion (Brown and Ritter, 1971; Kelsey, 1980; and Lehre, 1982). Its associated clay-rich soils on hillslopes are sensitive to compaction and resultant amplification of storm runoff. Since at least the 1840s and continuing through recent decades, much of the watershed has been managed to provide forage for livestock (sheep and cattle earlier on, and then predominantly cattle).

Prior to European-American settlement, it appears that the riparian forest along at least part of San Geronimo and Woodacre creeks was composed of an over-story of coast

⁷² There are only a few other homes in the project area, primarily on ranches in or near the Golden Gate National Recreation Area in the Tocaloma and Lower Lagunitas channel reaches.

redwood with a mid- and lower-canopies of big leaf maple and California bay laurel⁷³ (Stillwater Sciences, 2010). Before nineteenth century logging, many of the old-growth redwood trees along San Geronimo Creek were huge as indicated by the size of the stumps (Oral History Project of the Marin County Free Library, Interview with Melville and Fred Dickson, 1976).

Where redwood forests grew along the channels, based on comparison to similar undisturbed channels studied in Redwood National Park (Keller et al., 1995) and the Pacific Northwest (Abbe and Montgomery, 2003), we hypothesize that when large trees fell into the channel, they would have formed debris jams (that created complex habitat), and that upstream of the debris jams, the channel would have filled in rapidly with gravel and sand, and been shallow, such that the adjacent valley flat (now an infrequently flooded terrace) would have been flooded several times during the wet season in most years. Such channels, where they traverse broad alluvial valleys, often are anastomosing, comprised of main and side channels; where debris jams are deposited, immediately upstream the channel fills rapidly, and then shifts its course and cuts a new channel, with the older channel becoming a side channel (Abbe and Montgomery, 2003).

San Geronimo Creek is the largest remaining undammed tributary to Lagunitas Creek, and therefore, it is its primary source of fine and coarse sediment supply (Balance Hydrologics, 2010). San Geronimo Creek, along almost all of its length, is a fairly straight and deeply incised⁷⁴ gravel-bedded channel with significant bedrock exposure

⁷³ A remnant of this forest type occurs along the North Fork of San Geronimo Creek upstream of the Dickson Weir, where the channel is not as deeply incised (4-to-5 feet) as further downstream, and some of its tributaries are naturally disconnected, fostering a very moist environment for plant growth.

⁷⁴ The bed of the channel is 8-to-17 feet below the valley flat (Stillwater Sciences, 2009, Appendix A-1, Table A1-1). During the water year 1983 through 2008 sediment budget period, along most of San Geronimo Creek and in its tributaries, the streambed elevation lowered on average by about 1 foot (0.3 meters) (Stillwater Sciences, 2010, Table 3-18, p.46). In some locations, along San Geronimo Creek, a narrow inset floodplain has formed that typically is about 1.5-to-2.5 feet above the channel bed indicating that all but extremely large floods (e.g., floods with recurrence intervals of 50-years-or-more) are contained within the incised channel in most locations.

Although no formal analysis has been conducted to evaluate the history of channel incision along San Geronimo Creek, considering the age of a grade control structure (a chute built prior to WW II) on the North Fork of San Geronimo Creek, that is located immediately upstream of a 10-foot high knickpoint, it is clear that incision has been active there since at least the 1940s (and we suspect since the mid-to-late nineteenth century). Further upstream, where the channel is not as deeply incised, the valley floor remains a seasonal wetland today (Stillwater Sciences, 2009, pp. 4-1 and 4-2). The bankfull channel is 20-to-40 feet wide at the elevation of the inset floodplain, and 40-to-100 feet wide at the elevation of the

that alternates between pool-riffle and plane-bed morphologies (streambed slope is typically 0.5-to-1 percent). Considering the exposure of competent bedrock in the channel bed, significant additional lowering (incision) of the channel bed is unlikely. However, as a consequence of incision, and the substantial increase shear stress, bedrock exposure may continue to increase as alluvial streambed deposits are scoured and transported out of the watershed. Also, there is a paucity of large woody debris in the channel under current conditions (also contributing to scour/export of alluvial deposits), which likely is related to historical and recent disturbances (e.g., nineteenth century logging of redwoods, regular removal of debris jams from channels, channel incision which makes it more likely for fallen trees to remain perched above the channel, etc.). With more large fallen trees in the channel, as was the case under natural reference conditions, the simple plane-bedded channel reaches with shallow pools would be converted into pool-riffle channels with good cover, and the depth and extent of alluvial deposits would increase. Similarly, the frequency of pools and their depth and cover would be enhanced in pool-riffle reaches, if there were more large fallen trees in the channel.

In the upper reach of San Geronimo Creek, which is about 1.6 kilometers (1 mile) long, beginning at the confluence of the North Fork of San Geronimo Creek with Woodacre Creek and continuing downstream to Roy's Pools (a short distance downstream of Deer Camp Creek), the valley is very wide, typically about 1000 feet (Map 1). There, broad alluvial fans extend from most of the north-side tributaries and the channel hugs the southern margin of the valley. Tributaries that join San Geronimo Creek on the north side traverse the alluvial fans and the valley floor in their lower reaches. Therefore, the north side tributaries throughout most of their length have moderate slopes (< 1-to-2 percent) and they are gravel-bedded channels with plane-bed or pool-riffle morphology. In contrast, tributaries that join from the south side are much steeper cobble-bedded channels that typically alternate between step-pool or cascade bedforms. Much of the cobble and boulder sized material deposited in San Geronimo Creek likely is derived from debris flows deposited at/near the confluences of these steep south-side tributaries, and/or from widespread mobilization and re-arrangement of the streambed in the steep tributaries during large flood events (with recurrence intervals $\geq$ 50-years) (Grant et al., 1990).

In the lower reach of San Geronimo Creek, about 5.3 kilometers (3.3 miles) in length, its valley narrows significantly in the downstream direction. Between Larsen and Arroyo creeks, typically the valley is 300-to-600 feet wide (Map 1). Prior to historical incision,

valley flat (which we infer was a floodplain during the historical period, and now is an infrequently flooded terrace).

in this sub-reach, the channel would have been unconfined and able to migrate back and forth across the valley. Downstream of the confluence with Arroyo Creek to the mouth of San Geronimo Creek (adjacent to the “Ink Wells”), the valley narrows considerably to an average width of 200 feet or less. In this sub-reach, the channel prior to incision was moderately confined or confined between adjacent hillslopes. Prior to disturbance, the channel would have been single threaded and more-or-less locked in-place; large fallen redwoods (from the adjacent riparian forest) would have created forced pool-riffle and step-pool bedforms.

The State Park Reach of Lagunitas Creek

The State Park Reach of Lagunitas Creek begins at the confluence of San Geronimo Creek with Upper Lagunitas Creek, at Shafter Bridge, and it continues downstream for approximately 5-miles to about the half-way point between Cheda and McIsaac creeks (i.e., 0.5 miles upstream of the Tocaloma Bridge)⁷⁵ (Map 2). At the upstream boundary of the State Park Reach, approximately 70 percent of its watershed drains into Kent Lake or other reservoirs located further upstream. Kent Lake/Peters Dam was constructed in 1954, and its height was raised in 1982 doubling its storage capacity from 16,000-to- 32,000 acre-ft. Kent Lake and upstream reservoirs trap all of the sediment and wood delivered to upstream channels, and a significant fraction of total runoff. As such, following dam construction the supply of fine and coarse sediment and wood to the State Park Reach, and the flood magnitude for a given recurrence interval, have been greatly reduced as compared to the historical period⁷⁶.

⁷⁵ Reach boundaries and names are as defined by Bratovich and Kelley (1988).

⁷⁶ Kent Lake/Peters Dam and/or upstream reservoirs trap all of the sediment and large wood delivered from upstream channels, and this has been the case since Peters Dam was constructed in 1954. In 1983, following construction to double the capacity of Kent Lake, the effect of Kent Lake and upstream reservoirs on peak flows in the State Park Reach of Lagunitas Creek has been significant (and much greater than it was prior to expansion of this reservoir). For example, in wet years and/or during very large storms (e.g., January 4-5, 1982; water year 1998; December 31, 2005), flood peaks in the State Park Reach are only modestly attenuated by the reservoirs. However, in dry years or during a wet year that is preceded by one-or-more dry years, most of the storm runoff (typically 70% or more) is generated from the San Geronimo Creek watershed, with a drainage area equal to only about 30 percent of the total for Lagunitas Creek at SP Taylor State Park. As such, we hypothesize that the potential impact of dams on channel incision in the State Park Reach, would have been greatest in the period following initial construction of Kent Lake, and that it would be less significant at present because following doubling of Kent Lake storage, although coarse sediment supply has not been further altered, stream power has been significantly diminished. We also note that the earlier mill pond dam built on Lagunitas Creek in the State Park Reach (near its confluence with Barnaby Creek that remained in place between 1856 and 1886) may have caused significant upstream aggradation and significant downstream incision while it was in place, and subsequent incision upstream of the former dam site after its removal.

The State Park Reach is a deeply incised gravel-bedded channel with significant bedrock exposure (i.e., in many locations the gravel deposits are not very thick). Throughout most of the reach, the bed of the channel is 12-to-15 feet below the elevation of the valley flat⁷⁷. The channel alternates between plane-bed and pool-riffle morphology. In the State Park Reach, the riffles typically are very short as compared to the length of the pools, where bedrock exposure is significant. Large woody debris loading is quite low as compared to similar channels draining redwood forests (see Section 4.4 of this report), and hence, under current conditions does not exert a significant influence on channel form.

Typically, the streambed slope is between 0.25-and-0.5 percent, with locally steeper sub-reaches approaching 1 percent (e.g., between Deadman Gulch and Devils Gulch). Throughout most of the State Park Reach, Lagunitas Creek is moderately confined within a narrow northwest trending valley (i.e., a 150-to-300 feet wide valley in most locations, that is equal to about 2-to-4 times the width of the channel during the annual flood) that is bordered by steep slopes downstream approximately to its confluence with Barnabe Creek⁷⁸. At least part of the valley floor in most locations is a stream terrace that is infrequently flooded (i.e., not flooded during floods with recurrence intervals ≥ 25 years). A mature second-growth coast redwood forest covers the valley floor and north facing slopes creating a well shaded channel reach. Based on interpretation of exposures at sites of active bank erosion, the valley floor deposits are comprised predominantly of floodplain deposits (Stillwater Sciences, 2010, p.40).

⁷⁷ During the period characterized by the sediment budget, water years 1983 through 2008, the average lowering of the streambed throughout the upper State Park Reach (i.e., upstream of the Big Bend) was approximately 0.7 feet (0.2 meters). Considering the significant exposure of hard bedrock on the channel bed, we think it is unlikely that the channel bed elevation will become much lower. However, as indicated for San Geronimo Creek, the likely response would be for the area in riffles and bars to decrease and for bedrock exposure to increase (which for example, would reduce food supply and habitat complexity for salmonids).

⁷⁸ The steep canyon-like slopes in the upper part of the State Park Reach are underlain by hard meta-volcanic rocks. Downstream of Barnabe Creek, hillslopes adjacent to the valley become gentler and the valley floor begins to widen, where Lagunitas Creek is underlain by soft Franciscan *mélange* bedrock. The short and steep north facing tributaries that join Lagunitas downstream of Deadman Gulch are underlain primarily by more coherent and harder bedrock (as compared to the *mélange*) that is comprised of inter-bedded sandstones and shales of the Franciscan Complex. Devils Gulch watershed is underlain primarily by the hard meta-volcanic bedrock. The watersheds of Cheda and McIsaac creeks are underlain mostly by the soft and highly erosive *mélange*. Hence, in their lower reaches, Cheda and McIsaac creeks have slopes of less than 2 percent and the channels have plane-bed and/or pool-riffle morphology, as compared to tributaries underlain by the harder bedrock units (the meta-volcanic and sandstone bedrock) that include step-pool and cascade bedforms in their lower reaches.

In the State Park Reach, although the lower reaches of many tributaries are steep enough to transport debris flows (they have slopes ≥ 3 percent), such debris flows are deposited in the tributaries and/or at or near their confluences with Lagunitas Creek, because Lagunitas Creek (slope = 0.25-to-1 percent) is not steep enough for the debris flows to remain entrained along its channel⁷⁹. Therefore, debris flows are not significant in shaping Lagunitas Creek and/or its valley except at/near its confluences with steep tributaries.

With the goal of enhancing habitat diversity in the State Park Reach (i.e., forcing pool-bar sequences to form and increasing the diversity of substrate patch types), between 1998 and 2006, Marin Municipal Water District installed 38 anchored large woody debris structures in the State Park Reach. Even though these large woody debris structures were anchored into the bed and/or banks, 17 of the structures collapsed or were damaged in the New Year's Eve 2005 storm or during smaller floods that occurred in water years 1998 through 2006. That so many structures were damaged or collapsed, likely is due to the fact that the New Year's Eve 2005 flood was a very large flood (recurrence interval ≥ 25 years), and also because shear stresses are much greater in incised channels (as compared to those that are connected to floodplains).

The Tocaloma Reach of Lagunitas Creek

The 2.1-mile long Tocaloma Reach of Lagunitas Creek begins about 0.5 miles upstream of Platform Bridge, about half-way between Cheda and McIsaac creeks and continues downstream to Nicasio Creek. The valley widens significantly here, and the riparian vegetation changes abruptly from a coast redwood to a hardwood forest, dominated by alder and willow species, with lesser amounts of ash, maple, and an occasional redwood. The streambed slope averages 0.2 percent, the channel is gravel-bedded (with some sand patches), and typically it has a pool-riffle morphology. Channel deposits are much thicker here than in upstream reaches, and hence, bedrock exposure is uncommon.

Over most of the Tocaloma Reach, the channel is topographically complex and well connected to an active floodplain, except for in part of the sub-reach between Nicasio

⁷⁹ Debris flows are deposited commonly at slopes of 3-to-10 percent in channels with watershed areas between 1 and 10 km² (Stock and Dietrich, 2006). Lagunitas Creek in the State Park Reach has a much more gentle slope (less than 1 percent) and a much larger drainage area ≥ 80 km², and hence, any debris flows that continue in transport through the tributaries and into Lagunitas Creek would be deposited immediately at/near the tributary confluence (e.g., see description of debris flow deposition and channel changes described in Balance Hydrologics, 2010, Appendix C). In the State Park reach, at/near the confluences of Lagunitas Creek with its steep tributaries, debris flows likely are important sources of coarse sediment and large woody debris delivery, and agents for shaping complex habitat.

and Fence Line creeks, where the channel oscillates between a simple deeply incised channel (bordered by an adjacent terrace that is infrequently inundated) and a complex channel that is well connected to an active floodplain. In the complex/well connected sub-reaches, characteristic of most of the Tocaloma Reach, debris jams are common with large/mature hardwood trees acting as key pieces that facilitate formation of debris jams⁸⁰, which cause pool-riffle units to form. Where debris jams block most of width of the main channel, debris jams also cause channel avulsions and formation of side channels that are well connected to the adjacent valley flat, which functions as an active floodplain. Many of the side channels are inundated during winter baseflow and/or during small/frequent runoff events with peak flows ≤ 500 cfs (less than one-third of magnitude of the annual flood). In the complex sub-reaches, the channel appears to be actively aggrading (see for example, Balance Hydrologics, 2010, Appendix B, and Bratovich and Kelley, 1988, p.11).

Devils Gulch (located about 1-mile upstream of the Tocaloma Reach), Cheda Creek, McIsaac Creek, and Fence Line Creek all appear to be significant sources of coarse sediment supply to the Tocaloma Reach (Devils Gulch is the second largest undammed tributary to Lagunitas; Cheda, McIsaac, and Fence Line creeks all are medium sized tributaries draining watersheds underlain by the *mélange*, which has a very high natural sediment supply). Some of the smaller/steep tributaries also occasionally provide significant inputs of coarse sediment to Lagunitas Creek. For example, debris flows travelling down two of the small tributaries that join Lagunitas in the lower part of the State Park Reach at the Big Bend, contributing thousands of tons of gravel to Lagunitas Creek in the late 1990s and also during the New Year's Eve 2005 storm.

The Lower Lagunitas Reach

The Lower Lagunitas Reach begins at its confluence with Nicasio Creek and extends downstream to the Highway 1 Bridge, a distance of about 3.8 miles. This reach is the most deeply incised reach of Lagunitas Creek. Based on a partial field reconnaissance of this reach completed during the summer of 2013, and review of notes and survey results for the long profile (Graham Mathews & Associates, 2010), it appears that downstream of Nicasio Creek for about 1.1 miles, the channel typically is characterized by long deep lake-like pools that alternate with short infrequent riffles, and an adjacent stream terrace that is greatly elevated above the channel (also this morphology is dominant for about 2000 feet upstream of Nicasio Creek). Further downstream, where the channel is wider (and bank erosion rates have been higher), there are alternating pool-riffle sequences and in a few locations there is a narrow inset floodplain (although

⁸⁰ In some cases, living hardwood trees in growth position (on channel banks and/or the floodplain) buttress large fallen trees that are in the channel, contributing to the stability of the debris jam.

the channel also is deeply incised below the valley flat in the wider and more complex sub-reaches).

Valley width increases substantially, to between 300-and-600 feet, beginning in the first bend downstream of Nicasio Creek. Most of the Lower Lagunitas Reach is gravel-bedded, however, finer mixed gravel-sand or gravel-silt patches and bedrock also are common (Graham Mathews & Associates, 2010). In the early 1980s, Bratovich and Kelley (1988) described the channel bed in the Lower Lagunitas Reach as sand-bedded, which if their description was accurate, would suggest that the bed of the channel has armored/coarsened since that time (perhaps in response to additional down-cutting). Greater depth of incision in the Lower Lagunitas Reach, as compared to Lagunitas Creek further upstream, may be explained at least in part by truncation of the coarse sediment supply from Nicasio Creek following construction of Seegar Dam in 1961. Prior to dam construction (now all of the sediment generated in the Nicasio Creek watershed is trapped in the Reservoir), Nicasio Creek was the largest natural tributary source of gravel to Lagunitas Creek. Also, during the historical period there was a gravel mining operation on Lagunitas Creek immediately downstream of its confluence with Nicasio Creek. If gravel mining rates were higher than re-supply from Nicasio, the gravel mining operation also would have contributed to incision.

Immediately upstream of the current location of the MMWD smolt trap on the Gallagher Ranch, the roots of mature alders are perched, extending out of the ground in growth position, approximately 2-meters above the current elevation of the channel bed suggesting that there has been 2-meters-or-more of lowering of the channel bed over the life span of these trees⁸¹ (which based on their size, appear to be at least 30 years old).

In the Lower Lagunitas Reach, there are several well-defined and perched historical side channels. Because the valley flat is much wider in the Lower Lagunitas Reach, than it is further upstream, if the channel could be re-aggraded (as part of a channel restoration program), it appears that the total area of side channel and alcoves habitats and active floodplain along Lagunitas Creek could be more than doubled.

⁸¹ Alders are a good indicator of channel reaches with perennial flow. They grow between the flood and low flow elevations with their roots in saturated substrate. Therefore, we infer that prior to incision that the perched roots were growing at the elevation of the groundwater table during the dry season, which would have corresponded approximately to the elevation of the channel bed.