SECTION SIX:

ANADROMOUS FISH HABITAT

6.1 GENERAL STATEMENT

This section describes the current status of aquatic habitat provided by La Honda Creek, in particular, habitat for anadromous salmonids. A summary of past habitat condition (including bed grain size distributions) is included for comparison, based upon historic Department of Fish and Game stream surveys. The general form, function, and behavior of the creek is also discussed, as it relates to its position along the Highway 84 corridor, water and sediment transport, and effects on aquatic biology and riparian ecology.

Many physical processes and conditions must be considered in determining the condition of aquatic habitat. This study specifically describes: channel morphology and slope, bank characteristics and riparian vegetation, sediment deposits, channel bed grain size characteristics, pools, and large woody debris pieces. These physical aspects are summarized as they pertain to salmonid spawning and salmonid rearing requirements. Finally, factors that are likely limiting the success of salmonids in La Honda Creek are identified.

6.2 PRIOR STREAM SURVEYS

Six stream surveys of La Honda Creek, conducted by California Department of Fish and Game (DFG) staff from the 1950's to 1997, describe the channel condition and fish habitat (Table 6-1, Appendix H). A single fish survey in 1978, and electrofishing as a part of the 1997 survey provide additional data on numbers of fish present. Each survey contains information on the flow condition, water temperature, substrate composition, habitat quality and quantity, and observed fish populations, illustrating how La Honda Creek has changed over time (Table 6-2). With the exception of the July 1985 survey, all documented continuous flow although flow measurements generally record slow moving water.

Most streams in the Bay Area experience low summertime flows, decreasing pool volumes and flow over riffles which stresses rearing and resident fish populations. La Honda Creek maintains at least some surface flow throughout the reaches downstream of Weeks Creek, with the exception of immediately downstream of Delay's bridge. Because only very few measures of past stream temperatures are available, no trend through time is apparent. However, water temperatures fluctuate with ambient air temperature and runoff, ranging from 10 to 19.4° C (50 to 67° F). Logging could have removed a significant amount of the stream shading vegetation, causing water temperatures to increase, possibly high enough to stress the salmonid population. However, stream temperatures for the survey time period have likely remained below stressing or lethal temperatures for salmonids, due to the re-growth of large trees and other shading vegetation.

Observations of substrate composition are the most consistent throughout the surveys (Figure 6-1). Most of the substrate descriptions are field estimates, and are not based upon repeatable clast measurements, nor are they reproducible, especially to percentages of 10 percent. Some of the variation through time is likely due to inconsistent estimates, but some represents actual changes in substrate composition. For example, the apparent change between the 1950's and 1964 probably represents different observation and reporting style, whereas the change from 1973 to 1985 probably represents an actual change in bed composition. The 1985 survey reports poor spawning gravels in most reaches, with large amounts of sand and silt in pools. The 1997 (work completed in 1995) survey also reports large amounts of silt and sand in pools. The fine sediment observed in these surveys was probably delivered to the channel in the form of landslides during the January 1982 and January 1995 storm events.

The 1964 survey reported many boulder and LWD jams in the upper portion of the watershed. At that the time, LWD jams were believed to prevent migration, and therefore, were detrimental to salmonid habitat. However, a paradigm shift has occurred since then; LWD is now seen as beneficial, providing shelter and channel complexity, while still allowing fish migration.

Observations of fish in the historic stream surveys are a good comparison with current observations. Although we were present throughout much of the 2002/2003 salmonid spawning season, only a single adult fish was observed. Shay Overton noted the fish between the La Honda Trailer Park and Memory Lane on March 14, 2003. The fish, likely an adult steelhead, was approximately 60-70 cm (24-27 in) long, and was visibly injured and fatigued. We know of no other sightings during this season. However, in previous years local residents and people familiar with the creek have seen fish. Local residents saw fish during the wet seasons of 1997-2002, Kris Vyverberg (DFG) saw a 0.3 m (1 ft) long adult in March 2002, local rancher Rudy Driscoll saw five steelhead smaller than 0.04 m (16 in) during the wet season of 2001/2002, and Julia Bott (San Mateo County Parks) saw a single adult in 1998. La Honda Creek historically and currently supports a population of steelhead trout (*Oncorhynchus mykiss*) (DFG stream surveys 1950s – 1997, personal communication with local residents, and personal observation). La Honda Creek may support, or supported in the past, a population of coho salmon (*Oncorhynchus kisutch*).

Table 6-1. Salmonid habitat and numbers in La Honda Creek from the 1950's to present.

Author	Year	Reaches	Perennial flow (m^3/s)	Water temperature (ºC)	Substrate / Habitat	Steelhead	
						Young of the Year	Adult
DFG	1950s	9.7 km (6 mi) of La Honda Creek	Yes 0.017 (0.6 cfs)	12.2 (54 ºF)	Gravel and silt.	Yes, some planted	Yes
DFG	1962	Approximately 8 km (5 mi)	Yes	-	Past logging in watershed is causing siltation. Less fishing pressure, but increased habitat destruction.	Yes, but decreasing	Yes, but decreasing
DFG	Aug. 3rd 1964	Entire length of La Honda Creek	Yes, throughout 0.014 (0.5 cfs) at the lower confluence	15.6 (60 ºF) headwaters 19.4 (67 ºF) lower confluence	Lower 4.8 km (4 mi) highly productive spawning and rearing habitat. Upper 6.4 km (3 mi) have boulder and LWD jams that act as migration barriers. Issues for success were thought to be barriers and silt from logging.	500 fish / 30.5 m (1000 ft) ranging in size from 13 – 127 mm (0.5 - 5 in)	
DFG	Sep. 27th. 1973	Entire length of La Honda Creek	Yes, throughout	11.7 - 15.0 (53 -59 ºF) warmer near the lower confluence	Good to excellent spawning habitat for steelhead and silver salmon, with an abundance of gravel and rubble in the lower 6.4 km (4 mi). Spawning materials were loose, without noticeable compaction, except in the areas where logging operations have destroyed the spawning and nursery habitats. Six diversions are observed, most being single small diameter pipes diverting for residential use, but also included diversions for agriculture, and an unused flashboard dam diversion for the Sky-L-Onda Mutual Water Company. Eleven barriers were described. Main issues were barriers, water diversion and human garbage.	Lowest 8.9 km (5.5 mi) of channel, numerous juveniles are observed, with schools of 15 to 20, ranging from 51 – 102 mm (2 – 4 in)in length in the middle reaches, and schools of 20 to 50, ranging from 51 – 102 mm (2 – 4 in) in length, with an occasional 152 –178 mm (6 – 7 in)trout in the lower reaches.	
DFG	Jan 17th 1978	Lower 3.2 km (2 mi)	Yes, 0.71 – 0.85 (25-30 cfs) at Entrada Road	11.6 (53 ºF) at 11am	Water is highly turbid.	No	
DFG	Jul. 19th –20th 1985	Entire length of La Honda Creek except the upper 0.4 km. (0.25 mi)	No, some dry sections 0.017 (0.6 cfs) at confluence	16.1 (61 ºF) at the lower confluence at 11am	Sand and silt in the pools, especially in the lower reaches. Overall spawning habitat as fair, with poor spawning gravels in most reaches and scattered areas of excellent gravels. The amount of spawning habitat available is enough to produce numbers of fish that will saturate the available rearing habitat. Rearing habitat is fair, with food availability (low flow over riffles) being the limiting factor. Abundant shelter consisting of undercut banks, logs, overhanging vegetation, boulders and water turbulence. Five diversions - only one is active (upstream from Weeks Creek).	Fish (likely steelhead) are observed in all reaches of the stream, from confluence to 3.2 km (2 mi) upstream from Weeks Creek. In deeper pools, steelhead up to 203 mm (8 in) in length are observed.	
DFG	Summer, fall, 1995 (written in 1997)	Lower 6.4 km (4 mi) measured from confluence	0.009 (0.33 cfs) Aug. 7th, 1995 at the downstream confluence 0.009 (0.33 cfs) Sep. 7th, 1995 downstream from Woodhams Creek	Water temperatures taken Sep. 5th - 14th, 1995 ranged from 10 - 16 °C (50 – 61 ºF)	Throughout the creek many springs observed and there was prolific algae growth in five separate locations. Five in-stream diversions were observed. Four in-stream cobble dams that limit low-flow migration of juvenile fish were observed. A partial logjam was noted at mile 3.8 (km 6.1), and 22 bank failures or landslides (Appendix H) are found to be contributing sediment to the creek. Issues for success include maintenance of perennial flow, natural and anthropogenic fine sediment supply, barriers to migration, maintenance of cover elements, and invasive non-native riparian species.	503 steelhead in total or 24 fish / 30.5 m (100 feet).	1-year-olds (61) 2-year-olds (2)

Table 6-2. Number and age distribution of steelhead and other fish species captured in La Honda Creek, 1995 (from DFG La Honda Creek Survey, 1997).

Age class	Survey Mile 1 (550 ft, 168 m)	Survey Mile 2 (518 ft, 158 m)	Survey Mile 3 (555 ft, 169 m)	Survey Mile 4 (507 ft, 155 m)
Young-of-year	179	61	75	188
1+	18	12	18	13
2+	0	1	1	0
Total Steelhead	197	74	94	201
Other species	11	9	4	24

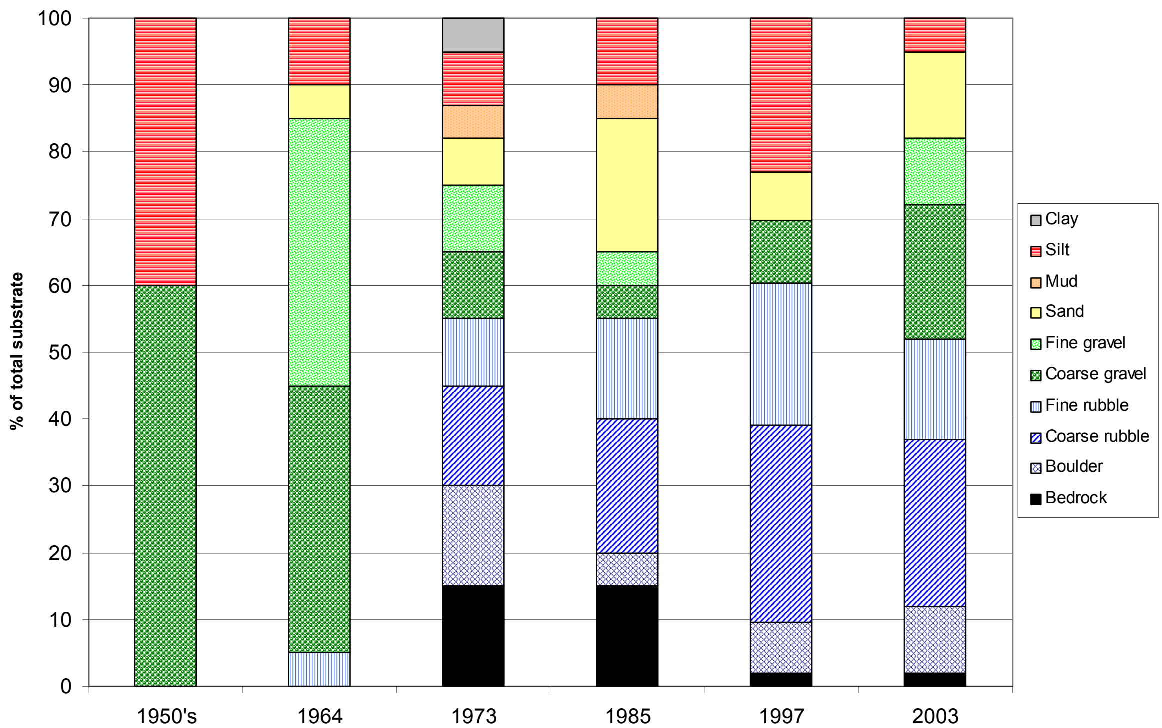

Figure 6-1. Visual estimates of grainsize distribution of the bed of La Honda Creek from DFG stream surveys, 1950's – 1997. Data from 2003 are measured distributions from this study.

6.3 SURVEY DESIGN

A field-based fluvial geomorphic survey of La Honda Creek was conducted to collect data for the salmonid habitat assessment. All fieldwork on La Honda Creek occurred in the fall and winter of 2002, and the spring of 2003. The survey's design and methods are based upon previous work conducted by SFEI (Collins and Collins, 1998; Collins, 2001; Pearce et al., 2002, Pearce et al., 2003a, Pearce et al., 2003b) and DFG. The use of standardized sampling protocols allows data collected in La Honda Creek to be compared to similarly sampled sites elsewhere in the state.

A longitudinal profile of La Honda Creek was plotted using the Woodside and La Honda USGS 7.5' topographic quadrangles (Figure 6-2, Appendix I). The longitudinal profile has three segments, based on their characteristic slopes. Because channel slope is known to be a good predictor of channel morphology (e.g. Montgomery and Buffington, 1997; Rosgen, 1996), the breaks in slope are used to divide the study area into three distinct segments. The segments are numbered I through III. Segment I, the furthest downstream, extends from the confluence with San Gregorio Creek to 134 m (440 ft) of elevation, just upstream of Woodhams Creek. Segment II extends from 134 m (440 ft) of elevation to 171 m (560 ft) of elevation, just downstream of Woodruff Creek. Segment III, the furthest upstream, extends from 171 m (560 ft) of elevation to the confluence of the Weeks Creek tributary.

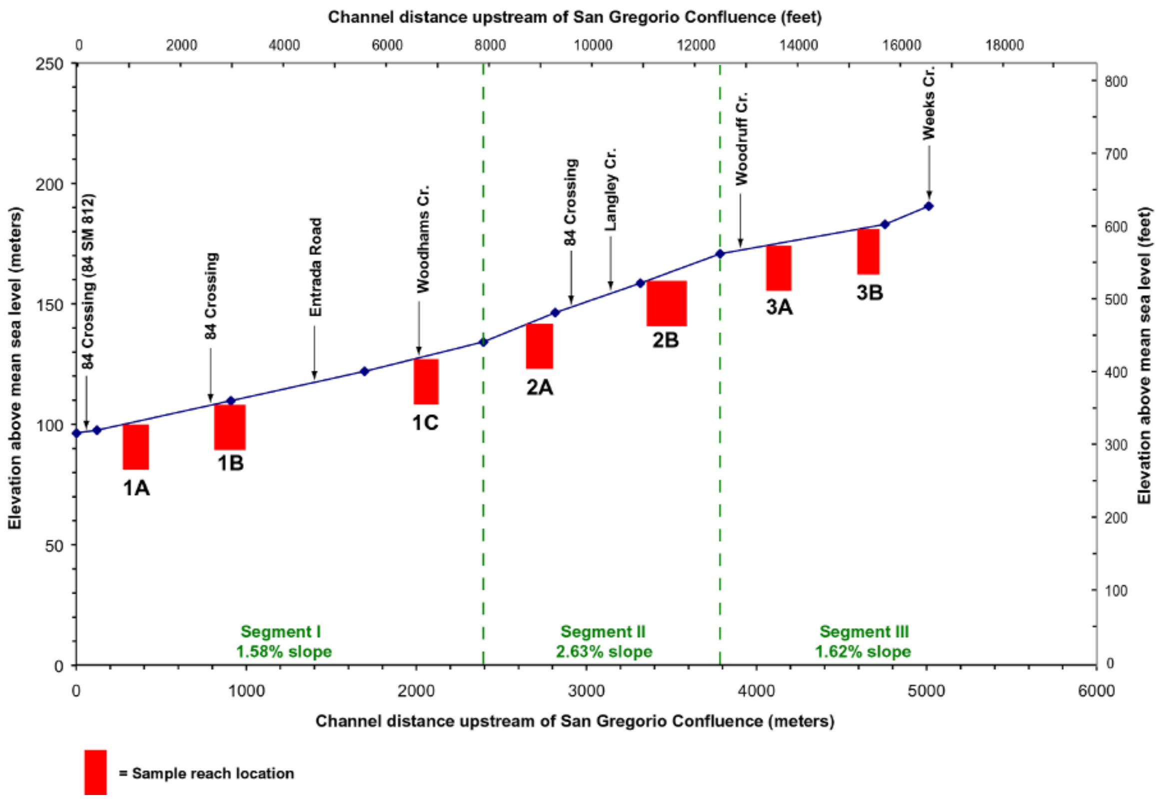

Figure 6-2. La Honda Creek longitudinal profile from the San Gregorio confluence to Weeks Creek. The channel profile is shown in the solid blue line, segment boundaries are shown in green dashed lines, and sample reach locations are represented by red bars.

Sample reaches were selected within each segment to characterize a representative portion of the larger segment. Segment I contains three sample reaches (1A, 1B, and 1C); Segment II contains two sample reaches (2A and 2B); and Segment III contains two sample reaches (3A and 3B); for a total of seven sample reaches. The general locations of these sample reaches were selected by taking into account 1) the longitudinal profile, 2) proximity to areas where the creek is or has the potential to destabilize the road, referred to herein as "pressure points", and 3) areas of property access (Figure 6-3). The exact location of each reach was selected using a random number. The process of random selection limits sampling bias towards a particular set of features. The distance to the start point was measured from a mapped benchmark location such as a bridge, a property boundary, or a tributary confluence allowing re-occupation in the future as necessary.

The length of each sample reach was 25 times the measured bankfull width. This length is necessary to capture in-channel features such as pool-riffle sequences, and an adequate sample of pools, which tend to have a spacing of 5 to 7 bankfull widths in meandering alluvial streams (Leopold et al., 1964; Dunne and Leopold, 1978). Bankfull flow is considered to be the flow equivalent to the 1.5- to 2-year recurrence interval flood, as opposed to the flow level that would fill the channel to the top of its banks.

At the randomly selected starting point for each sample reach, the bankfull width was measured using visual field indicators (e.g. Harrelson et al., 1994). Indicators of bankfull include, but are not limited to: the break in slope between the bank and the floodplain, a small break in slope of the bank, a change in vegetation type or density, the top of a bar surface, or the change from absence to presence of leaf litter. Flagging was then placed along the channel at intervals of five times the measured bankfull width until a total of 25 bankfull widths had been flagged. These intervals provided a systematic random sampling frame for selected field data. Longitudinal channel distances were measured using a metric HipChain (calibrated to 0.1m or 0.11 yds). Over a distance of 200 m (656 ft), the accuracy of the hip chain is +/- 2%.

Field data was collected in a manner that would characterize and quantify channel processes and conditions in the entire study reach. Based upon channel slope, seven sample reaches were chosen for intensive data collection. These sample reaches are intended to represent the entire creek, eliminating the need to collect intensive data for the entire study area.

Data was collected in 1150 m (3773 ft) of channel, comprising 23% of the study area length. The area sampled in this study is more than twice that in DFG basin-level habitat unit inventory protocol. This method states, “During basin-level habitat typing, full sampling of each habitat unit requires recording all characteristics of each habitat unit. After DFG analysis of over 200 stream habitat inventory data sets, it was determined that similar stream descriptive detail could be accomplished with a sampling level of approximately 10 percent” (Flosi et al., 1998). Based upon previous studies (Pearce et al., 2002, Pearce et al., 2003 a, 2003 b) and professional experience, this methodology has proven to accurately portray fish habitat conditions found throughout the study area. While data collection focused on the seven sample reaches, the entire channel length was walked several times, with observations and photos documenting the channel condition outside of the sample reaches playing an important role in understanding the entire study area.

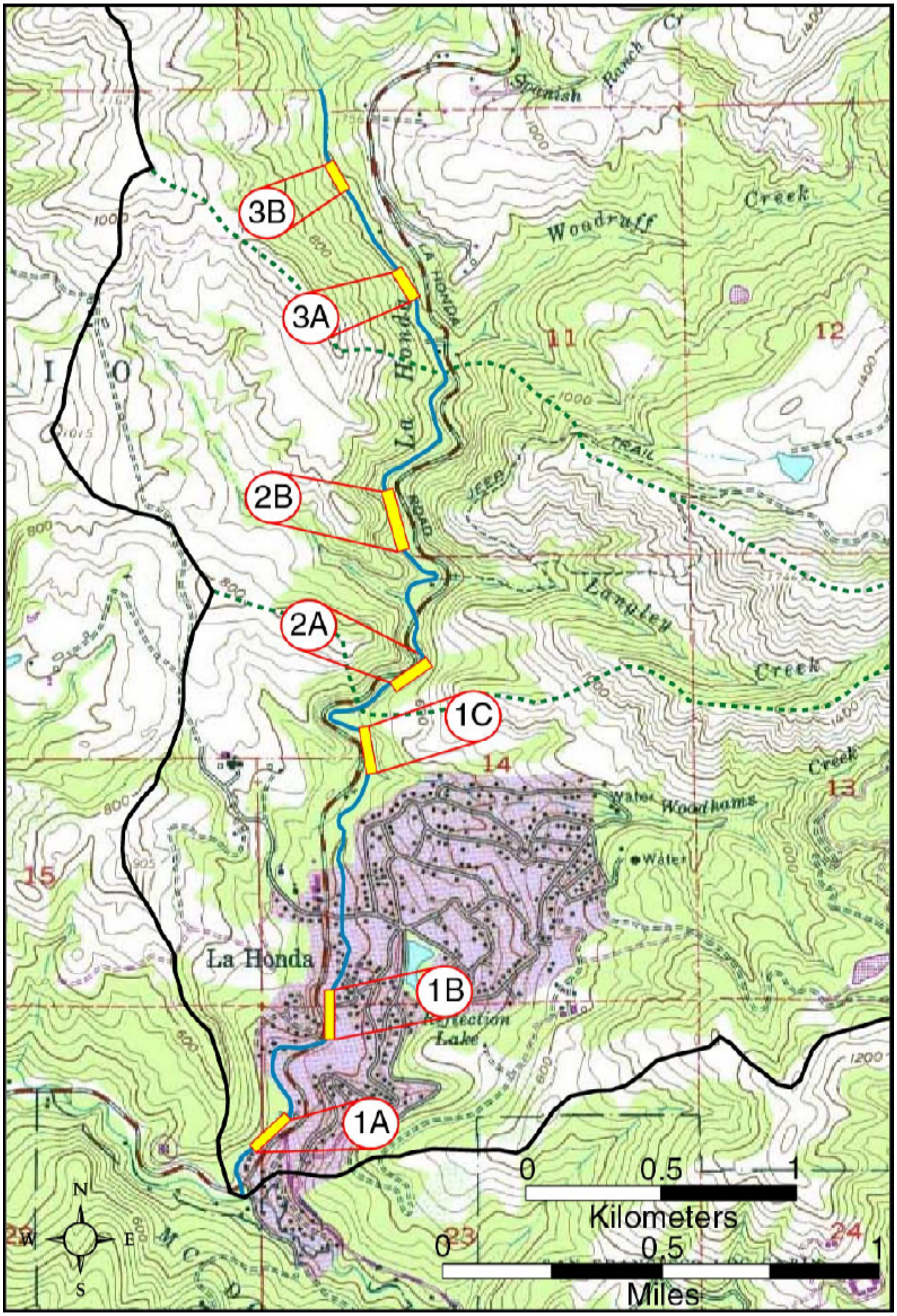

Figure 6-3. Topographic map of the lower portion of the La Honda Creek watershed. The watershed boundary is shown by a solid black line, the stream length in the study area is highlighted in blue, sample segments are shown in green dashed lines, and sample reach locations are shown in yellow.

6.4 SURVEY OF PHYSICAL CHARACTERISTICS

Channel Cross-sections

In each sample reach, three channel cross-sections were surveyed to determine the variability in channel geometry both along the sample reach, and between sample reaches. Cross-sections were surveyed at distances equal to 5, 15, and 25 times the bankfull width upstream from the start of the sample reach, using a Sokkia C3A optical level and a telescoping survey rod. Each cross-section is oriented perpendicular to the channel axis, and looking downstream. Field notes describe channel forms and the locations of visual indicators of bankfull width. Scale drawings of each cross-section, with the water level on the survey date and the field interpretation of bankfull flow, illustrate the variability of morphologies in La Honda Creek (Figures 6-4 through 6-6, Appendix J).

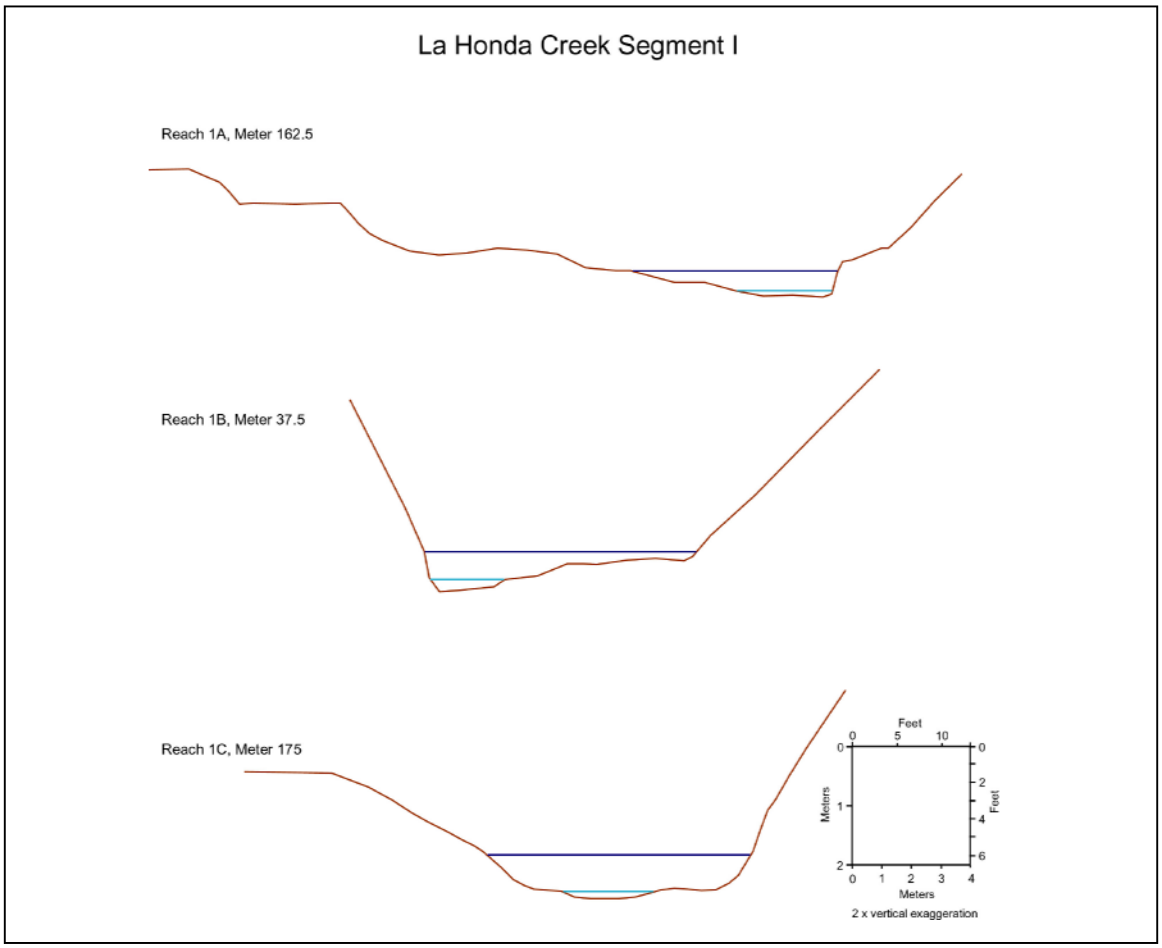

Figure 6-4. Example of three Segment I cross-sections. The lower blue line is the water elevation on the survey date, while the upper dark blue line is the water elevation at bankfull flow.

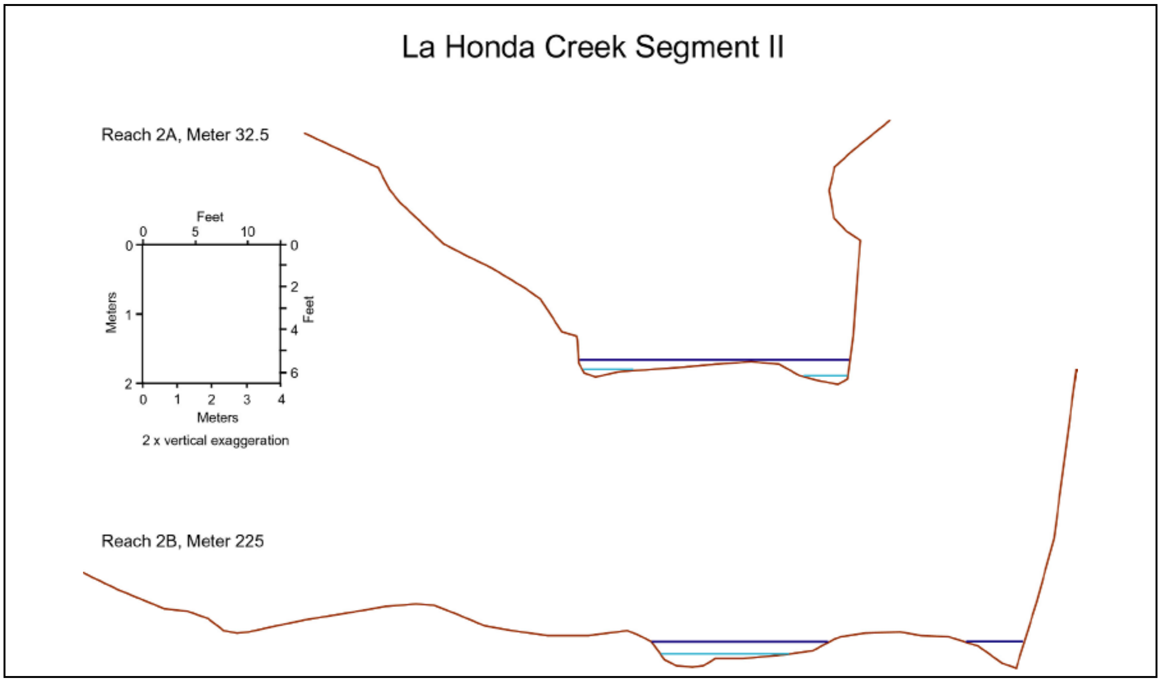

Figure 6-5. Examples of cross-sections in Segment II. The lower blue line is the water elevation on the survey date, while the upper dark blue line is the water elevation at bankfull flow.

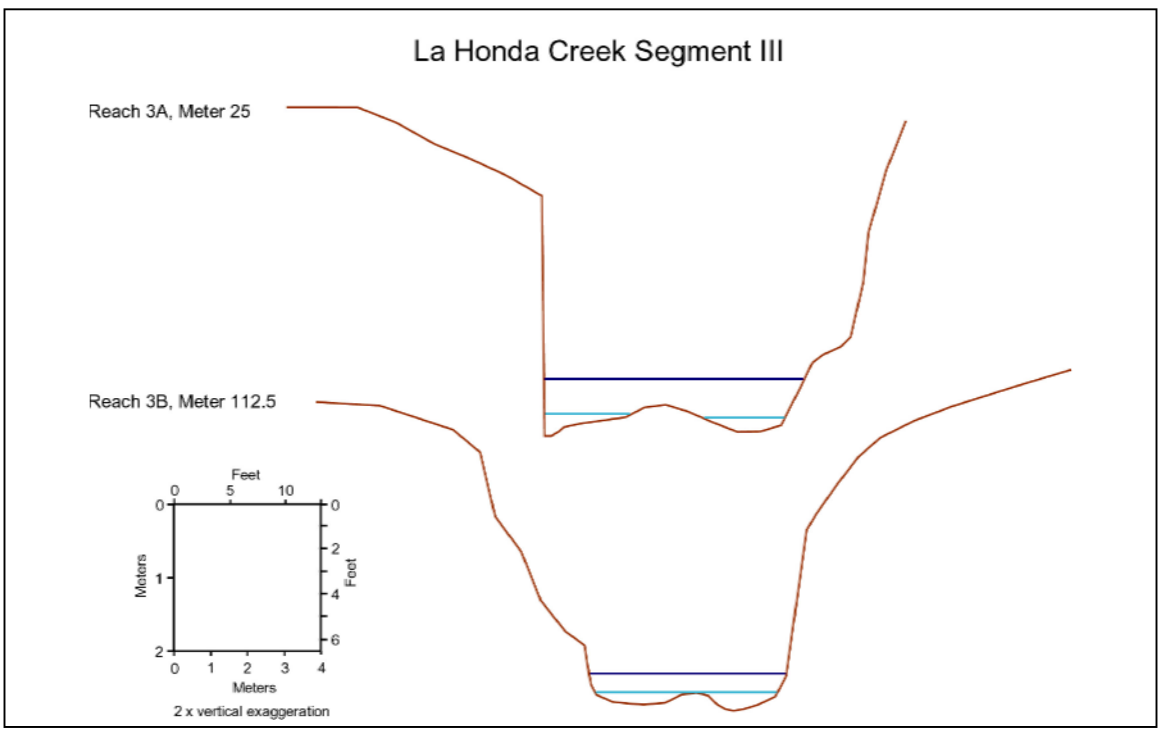

Figure 6-6. Examples of cross-sections in Segment III. The lower blue line is the water elevation on the survey date, while the upper dark blue line is the water elevation at bankfull flow.

The channel morphology in Segment I is typically slightly entrenched, with banks between two and four meters high (6.56 – 13.12 ft) (Reach 1B, Meter 37.5) (Figure 6-4). However, some reaches are slightly wider, allowing wide bars to be deposited, and small terraces to be preserved (Reach 1A, Meter 162.5). The channel morphology in Segment II is highly variable; generally, the channel downstream of the Highway 84 crossing (milepost 84 SM 9^{80}) is narrow and entrenched, with steep bedrock banks (Reach 2A, Meter 32.5) (Figure 6-5). Upstream of the crossing, the channel widens, depositing bars (including medial bars) and preserving some terraces (Reach 2B, Meter 225). Sample reach 2B is highly affected by large, shallow landslides, which contribute sediment and widen the valley. Reaches in Segment III are typically narrower and more entrenched than in sample reach 2B (Reach 3A, Meter 25 and Reach 3B, Meter 112.5) (Figure 6-6). The morphology of reaches in Segment III is highly controlled by large deep-seated landslides, and by the bank materials. Banks in Segment III are typically composed of bedrock, and older colluvium and fluvial deposits that keep the channel narrow.

At each cross-section location in the study area, and for Delay's bridge, average bankfull width and depth were recorded based on visual field indicators, providing an estimate of bankfull channel cross-sectional width throughout the watershed (Table 6-3, Appendix K).

Reach	Bankfull width		Bankfull depth		Bankfull cross-sectional area		Drainage basin area	
	(m)	(ft)	(m)	(ft)	(m2)	(ft2)	(km2)	(mi2)
1A	5.88	19.29	0.62	2.03	3.67	39.50	31.53	12.17
1B	10.37	34.02	0.58	1.90	5.98	64.37	29.81	11.51
1C	8	26.25	0.64	2.10	5.12	55.11	27.73	10.71
Delay's bridge	6.68	21.92	0.7	2.30	4.68	50.38	27.57	10.64
2A	5.98	19.62	0.47	1.54	2.79	30.03	26.84	10.36
2B	8.82	28.94	0.62	2.03	5.5	59.20	24.22	9.35
3A	6.66	21.85	0.9	2.95	6	64.59	14.99	5.79
3B	4.73	15.52	0.62	2.03	2.95	31.75	13.58	5.24

Table 6-3. Drainage basin area, and bankfull channel width, depth, and cross-sectional area based upon visual field indicators.

Channel Slope

Channel slope is generally regarded as an important control on channel morphology (Montgomery and Buffington, 1997). Although the slopes could be calculated from 7.5' topographic quadrangle maps, slope surveys in the field allow the stream energy and resultant channel morphology to be better understood.

Channel slope was surveyed for the entire length of each sample reach, with the relative height of the thalweg recorded every five bankfull widths. Measurements were made using a telescoping survey rod and a hand level (associated error +/- 0.03 m (1.2 in)). Slope was calculated as difference in elevation over the horizontal distance, and reported in percent. The average reach slope for each sample reach is the total elevation change divided by the total distance.

Reach average slopes range from 1.16% in reach 1A to 2.44% in reach 2B (Table 6-4, Appendix L). Reaches with lesser slopes tend to be areas of aggradation, because of reduced stream power. Sediment deposition can affect channel morphology by widening and shallowing the channel, or by filling of pools. Areas of lesser slope tend to accumulate fine sediment, which can be detrimental to the quality of fish habitat provided by the creek. Also, in areas where the valley width is greater and the gradient is lower, the channel's ability to migrate increases compared to a steeper, more confined channel. Migrating meander bends can become problematic if they encroach upon an existing structure or road. It is important to note that the entirety of La Honda Creek is not a typical alluvial channel whose bed and banks are composed of the material it transports. In most reaches, meandering is not caused solely by water and sediment transport processes, but instead, it reflects imposed channel conditions, such as bedrock outcrop, or large landslides.

Table 6-4. La Honda Creek reach average percent slope, standard error and coefficient of variation as measured in the field. Reach average percent slopes are compared with slopes calculated from USGS 7.5' topographic quadrangle maps.

Reach	Reach average % slope (field)	Standard error	Coefficient of variation	Reach average % slope (map)
1A	1.16	0.26	0.23	1.55
1B	1.20	0.18	0.15	1.55
1C	1.62	0.31	0.19	1.75
2A	1.78	0.53	0.30	2.88
2B	2.44	0.18	0.07	2.60
3A	1.42	0.06	0.04	1.26
3B	2.02	1.13	0.56	1.26

Bank Characteristics and Riparian Vegetation

Data were collected on the condition of the bank and terrace, the extent of riparian forest, and the type of plant species at every fifth bankfull width in each sample reach (Appendix M). The observations were limited to the area of the bank and terrace within half of a channel bankfull width on either side of the cross-section. In addition, the terrace and hillslope riparian vegetation, percent canopy cover, and adjacent landuse are reported (Appendix N).

These data were collected to understand how vegetation communities affect fluvial processes and morphology in La Honda Creek. The bank composition and the types and age of vegetation on the banks indicate the susceptibility to erosion: when bank vegetation is well rooted and established, the bank shear strength increases. Riparian vegetation is important in regulating water, sediment and nutrient inputs from the hillslopes to the channel, while also providing a source for the recruitment of large woody debris (LWD) to the channel. Riparian vegetation canopy cover shades the stream, reducing evaporation and maintaining cool water temperatures, and provides cover for salmonids that reduces predation.

Bank Stability and Composition

Previous studies have illustrated the effects of many species of vegetation upon bank stability, and types of bank failure processes. Bank erosion by fluvial entrainment is decreased by vegetation that increases flow resistance, whereas erosion by sliding and slumping decreases when a greater portion of the bank is reinforced by large roots (Abernethy and Rutherfurd, 1998). In a study by Simon and Collison (2002), tree roots increased soil strengths by 2 to 8 kPa (0.3 – 1.2 psi), while clump grass roots increased strength by 6 to 18 kPa (0.6 – 2.6 psi). They also note that most of the increased soil strength due to roots occurs in the upper 0.5 m (1.7 ft) of soil. Vegetation also has a significant control over water velocities, channel patterns and geometries. For example, vegetation provides a quantifiable control on channel pattern (Millar, 2000). However, contrasting conclusions have been drawn regarding the relationship between channel width and bank vegetation. Wooded and densely vegetated channels have been found to be two to three times narrower and more stable than equivalent non-vegetated channels (Hey and Thorne, 1986; Huang and Nanson, 1997), whereas other studies have found the vegetated channels to be wider than channels having non-forested riparian zones (Hession, et al., 2003).

Bank composition and vegetation vary greatly throughout the sample reaches. Common bank compositions include: highly plastic, silty, terrace deposits; cobble fluvial deposits; plastic, silt-to-sand, colluvial deposits and associated soils; weathered bedrock; and intact bedrock. Bank vegetation also depends upon the bank composition. For example, banks composed of colluvium usually support hardwood and redwood roots, as well as ferns, grasses, sedge and small shrubs. Bank strength greatly affects channel morphology: banks composed of bedrock are more resistant than those composed of fluvial or colluvial deposits. Vegetation, especially tree roots, is more important for low-strength banks; without vegetation, these banks are much more susceptible to erosion.

Riparian Vegetation

Riparian vegetation assemblages are more consistent than bank vegetation assemblages between sample reaches, consisting dominantly of redwood canopy, with a smaller number of assorted hardwoods (bay, maple, willow, oak). Understory is related to the openness of the canopy, but often contains some combination of ferns, grasses, blackberry, nettle, moss, fleshy vines, woody shrubs, equisetum, ivy, and other plant types. Typically, at least 50% of the channel is shaded from the mid-day sun by the riparian canopy. Only a few locations have less than 50% shading: for example, one is due to human activity on the adjacent terrace, while another is associated with riparian removal due to the proximity of Highway 84. Typically, locations having less than 50% shading were caused by landslides that removed the canopy vegetation from the banks and adjacent slopes, bringing it into the channel along with the slide debris.

The majority of the La Honda corridor contains a continuous riparian canopy. Bank and riparian vegetation is generally similar throughout most of the study reach. La Honda Creek appears to be affected more by bedrock outcrop and landslide locations rather than vegetation.

Sediment Bars and Other Deposits

The volume and mobility of active sediment deposits within a drainage system influences the stability of the banks, controls the formation of desirable habitat features, influences the longevity of different habitat features and influences of the stability of structures built by humans such as bank revetments and bridges. Measurements of the deposit's volume are somewhat subjective because their precise area and depth are difficult to determine. Mobility is estimated based on clast size, position relative to bankfull, and age of vegetation growing on the bar surface. "Active" is subjectively defined as the portion of the streambed ordinarily entrained as bedload, and that can be routed through the entire channel network in a period of decades. Despite these issues, when a systematic methodology is used, meaningful comparisons between reaches or between watersheds can be made.

<u>Survey Methods</u>

Bars and sediment deposits in La Honda Creek were categorized as: alternate, forced, point, medial, and lateral bars; active channel deposits; pool deposits; and secondary channel deposits. This classification is similar to that used in the *Stream Channel Assessment of the Washington DNR Watershed Analysis Methodology* (Washington Forest Practices Board, 1997). Along the entire length of each sample reach (25 bankfull widths), data were collected on the type and volume of bars and other deposits of mobile sediment (Appendix O). The average width, depth, and length of individual bars and sediment deposits were measured to the nearest 0.1 m (0.33 ft).

Although the width and length can be measured directly, the depth is estimated using field evidence of likely depth of scour. The depth of larger, rectangular bars is typically determined from measuring the difference between the maximum bar height and the thalweg elevation adjacent to the bar and/or in adjacent pools. However, a shape factor is typically used to adjust the deposit depth when the bar has a triangular cross-sectional geometry. For example, for a smoothly sloping bar, the maximum bar height and the thalweg depth define the hypotenuse of a right triangle, making the shape factor 0.5, and the deposit depth one-half of the maximum bar height above the thalweg. The shape factor aids in accurately portraying the true thickness of a deposit, and is adjusted on a case-by-case basis to best represent more complex bar geometries in order to estimate sediment volume.

The depth of fine-textured deposits was estimated either by probing with a metal rod, or by digging with the heel of a boot. The depth of fine-grained pool deposits is measured using water depth in the pool; water depth over the deposit plus the depth of deposit equals the total maximum water depth in the pool. The detailed method described by Lisle and Hilton (1999) is more accurate, but requires more time than was feasible for this more generalized study.

In segments with a coarse-textured bed and relatively shallow and uniform depth, the typical depth of scour determines the depth of the active layer during peak flows. The scour depth is thought to be controlled by the size of the larger sediment clasts on the bed. DeVries et al., (2001) suggested that the D_{84} (the diameter for which 84% of sediment is finer) is an approximate predictor of the depth of scour in ordinary peak flow events in cobble-dominated reaches. In the more coarse-grained reaches of La Honda Creek, the estimated depth of the active bed for purposes of estimating active sediment storage rarely exceeds 0.2 m (0.7 ft). Based upon surface grain size distributions, the surface D_{84} ranges from 49 to 84 mm (1.9 – 3.3 ft), and based upon bulk sediment samples, the D_{84} ranges from 34 to 155 mm (1.3 – 6.1 in), both measures agree with the 0.2 m (7.9 in) maximum assumed scour depth.

A bar must be at least 1 m (0.33 ft) in length or width to be included in the survey. Although a wide range of bars were measured, calculations show that the larger bars contain most of the total volume of stored sediment, and thus, including bars near the nominal 1 m (0.33 ft) threshold will not significantly increase the total estimated sediment storage. Hence, in this investigation, the overall interpretation of data is not very sensitive to the minimum bar size measured.

Throughout La Honda Creek, a small, but notable portion of the mobile sediment consists of coarse sand and fine gravel deposited in small pockets in the relatively immobile cobble-boulder bed. For purposes of measurement, these active channel deposits were often aggregated over channel lengths larger than individual gravel bars. The stability of the different bar and sediment deposit types were estimated based upon the age of vegetation growing on the deposit, the type of deposit, as well as the dominant grain size. The approximate age was estimated in class intervals of: < 1 yr, 1-5 yrs, 6-19 yrs, and > 20 yrs.

Sediment Volume

The total volume of active sediment measured for all seven sample reaches is 7,750 m^3 (10,136 yd^3). Together, point, forced, and lateral bars comprise 6,409 m^3 (8,382 yd^3) or 82% of the total sediment storage (Figure 6-7). Pool deposits, although representing only 3% of the total, can significantly affect the quality and quantity of salmonid habitat. The number of deposits measured in each sample reach ranges from 29 in reach 2B to 13 in reach 3B (Figure 6-8). Each reach contained every deposit type, with the following exceptions: secondary channel deposits are absent from all reaches, alternate bars were present only in reach 1B, and medial bars were present only in reaches 1C, 2B and 3A. Reach 2B stores the greatest proportion of sediment (30 %), followed by reaches 1B (25%) and 1A (14%) (Figure 6-9). Reaches 3A and 3B store low amounts of sediment, reflecting the smaller channel width and depth. Most sediment in reach 2B is being stored in eight individual bars: forced, medial, point and lateral. The valley width is larger in this reach, allowing flow to disperse and sediment to deposit in a few large bars. In addition, this reach receives a large sediment supply from local landslides. Reach 1B is storing most of its sediment in ten point, forced and lateral bars, and a fairly significant active channel deposit.

The volume of sediment stored in each sample reach depends on the length of the sample reach. In order to compare the reaches of differing lengths, sediment storage was normalized, producing the sediment volume per unit channel length (m^3/m) (Figure 6-10).

This further confirmed that reaches 1A and 2B presently store the most sediment and reaches 3A and 3B store the least.

The largest volume of sediment is stored in bars, particularly in a few reaches that are wider and directly receive sediment from landslides. Pool deposits comprise only a minor percentage of the total volume.

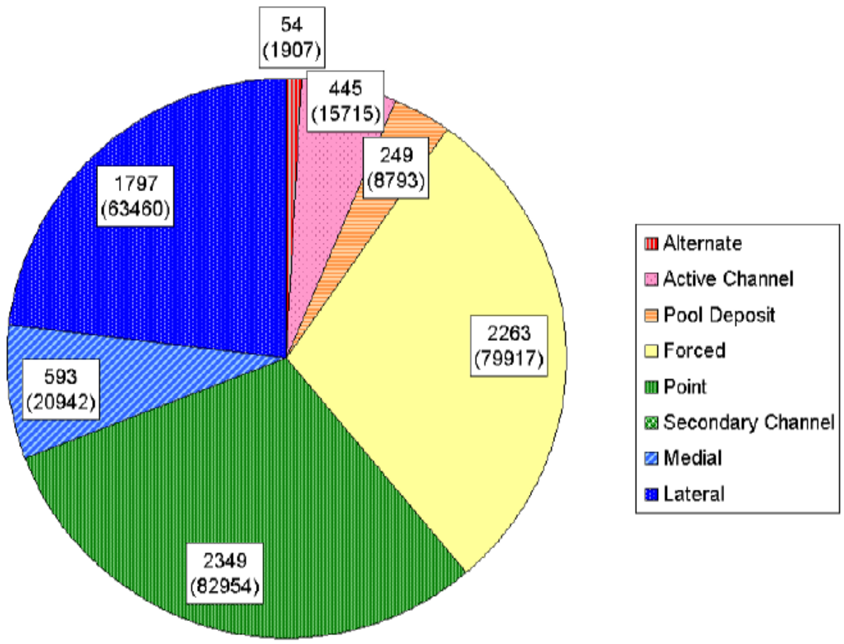

Figure 6-7. Volume (m^3) and type of sediment deposits measured in all seven sample reaches.

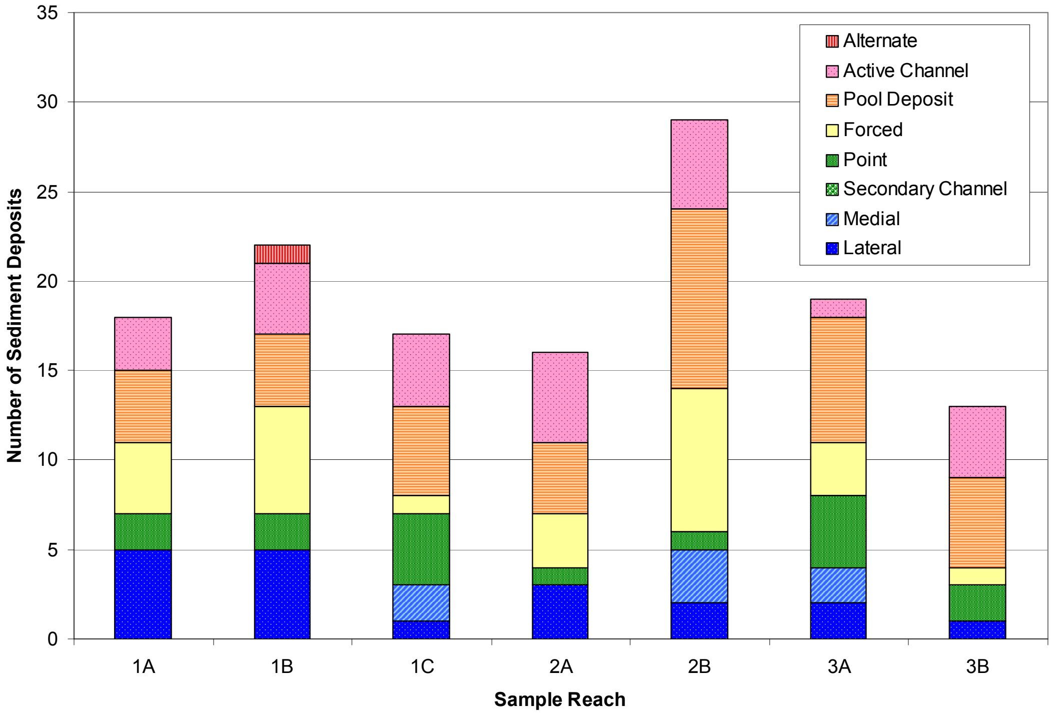

Figure 6-8. Number and type of sediment deposits in each sample reach.

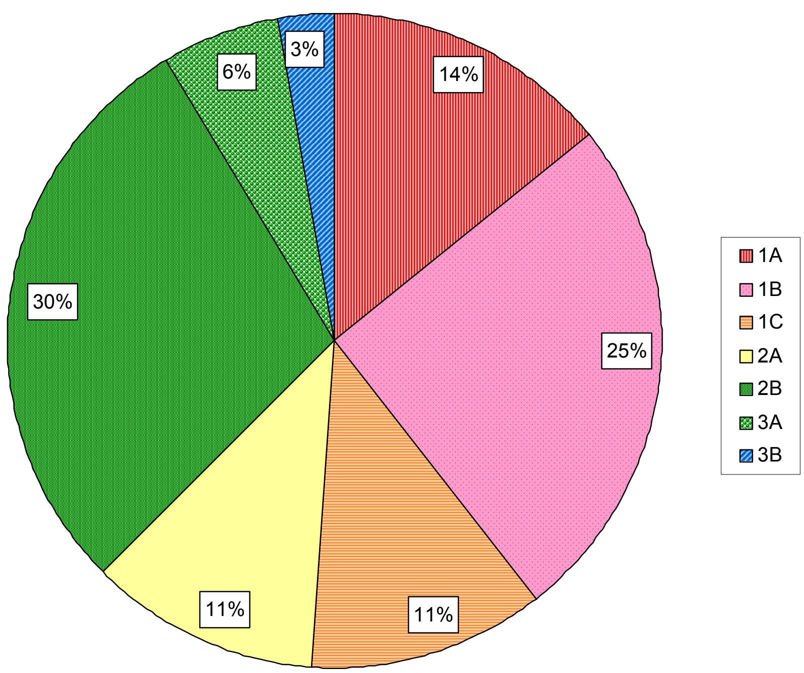

Figure 6-9. Volumetric contribution of each sample reach to the total volume of measured sediment deposits in all sample reaches.

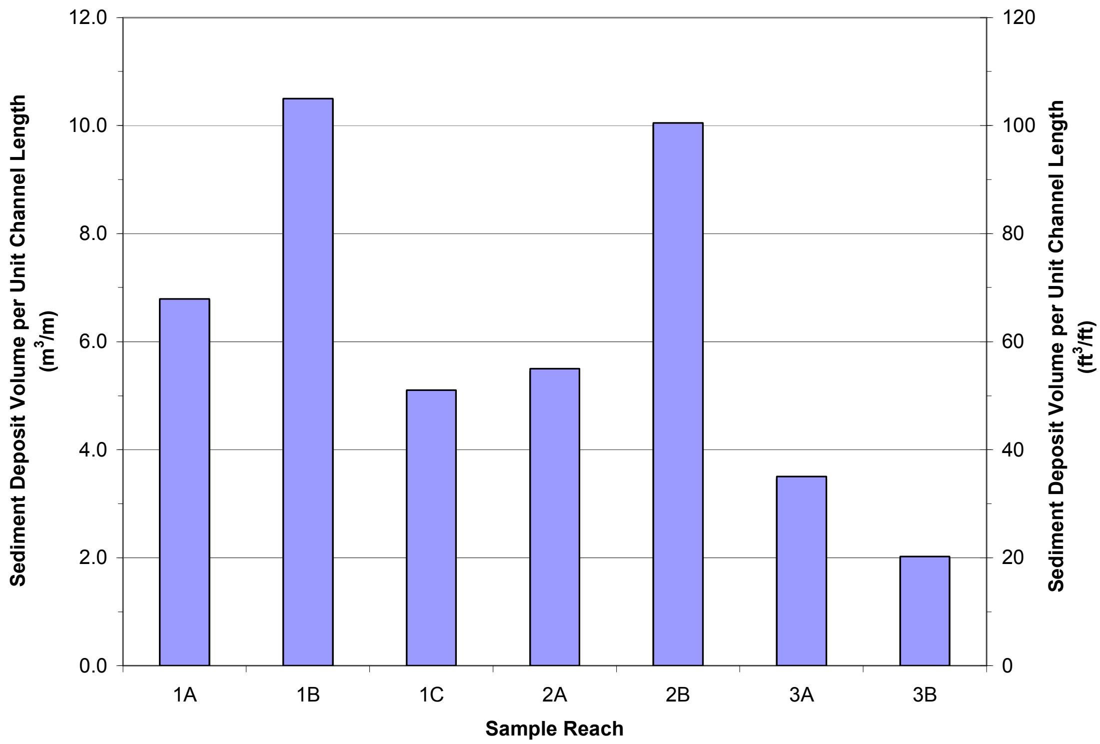

Figure 6-10. Sediment deposit volume per unit channel length in each sample reach.

Deposit Stability

The stability of bars and sediment deposits affects the availability of sediment for transport, reworking, and salmonid spawning. The age class of sediment deposits was estimated in the field based on the deposit's position in the bankfull channel, the size distribution of the deposit, and the approximate age of vegetation on the deposit, if any. The <1 year age class represents fine-grained deposits (typically < 8 mm or 0.31 in) in pools and in the active channel that would be entrained in high-frequency flow events. The 1-5 year class represents deposits having coarser surface textures (approximately 11 to 90 mm or 0.43 – 3.5 in), often with upper surfaces above the active channel, and young shrubs, seedlings and herbaceous vegetation on the deposit surface. The 6-19 year class and the >20 year class represent coarse deposits at elevations above the bankfull channel, but lower than adjacent terraces, that often have older vegetation and trees colonizing the surface. These relative age classes do not imply the frequency of occurrence; for example, a bar in the 1-5 year age class will not necessarily form every 1 to 5 years. Instead, the age classes represent the age of the current set of bars and deposits in the channel.

In La Honda Creek, 57% of all deposits are in the <1 year age class, 39% are in the 1-5 year class, 1% in the 6-19 year class, and 3% in the >20 year class (Figure 6-11). The majority of 1-5 year deposits probably formed during the recent high magnitude, low frequency floods of 1995 and 1997, whereas the > 20 year age class deposits probably formed during the events of 1982 and 1983. The large number of low-stability deposits indicates that even during low magnitude events that occur annually, La Honda Creek transports a large volume of sediment. Qualitative observations during a field reconnaissance after the December 2002 floods (~1:3 year return, highest discharge measured at Delay's bridge was 10 m^3/s (353 cfs), Table 4-5 and Figure 4-5) suggested some major morphological changes. For example, many riffles had changed length and some pools had been completely filled, sizable LWD pieces had moved and new pieces had entered the channel, and there were new pro-graded deposits on the downstream edge of bars. These observations suggest that La Honda Creek may be capable of modifying channel features and transporting larger grain sizes than expected at relatively low discharges. It appears that even modest flow events are capable of scour, transporting and depositing the relatively large grain sizes observed on many bars throughout the creek.

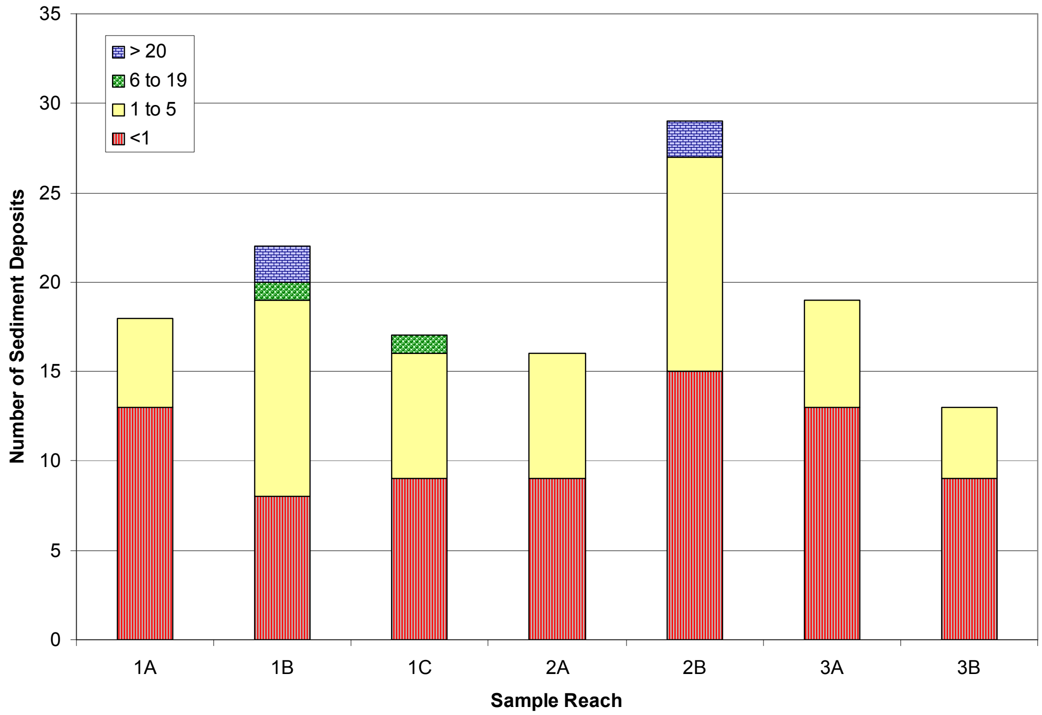

Figure 6-11. Distribution of estimated age (years) of sediment deposits measured in each sample reach.

When the total volume of sediment in each reach is normalized to the reach surface area (sediment volume in m^3 per unit channel surface area in m^2) a simple measure of sediment storage, depth in meters, allows the reaches to be compared (Figure 6-12). Sediment deposits are grouped into three general categories: pool deposits, active channel deposits, and bars, with reach average depth of sediment storage shown for each. Most of the sediment in La Honda Creek is stored in bars, however in some reaches, pool deposits and active channel deposits comprise a noteworthy proportion of the total sediment storage. For example, pool and active channel deposits are 26% of the total in reach 3B and 17% of the total in reach 1C. Reaches 3A and 3B have the largest percentage of total sediment storage in pool deposits, with 10% and 14%, respectively. These data, especially sediment storage in pools, have implications for salmonid spawning and rearing. Pool deposits can decrease the total volume of pools available for rearing, while active channel deposits supply most of the gravels appropriate for spawning. Although precise measures of pool volume and infilling (V*, Hilton and Lisle, 1993) were not conducted, our measurements of pool residual depth and sediment deposit volume suggest that as a whole, the pools in La Honda Creek are not being excessively in-filled. While some pools do have substantial deposits, the sediment appears to be relatively mobile, especially over a period of many years. While a single pool may filled with sediment in any particular year, scour mechanisms may excavate the sediment, transporting it downstream, where it may temporarily be stored in a different deposit or pool. Thus, pools acceptable for salmonid rearing should always exist, although any single pool may change its volume filled with sediment, and quality of habitat provided, from year to year.

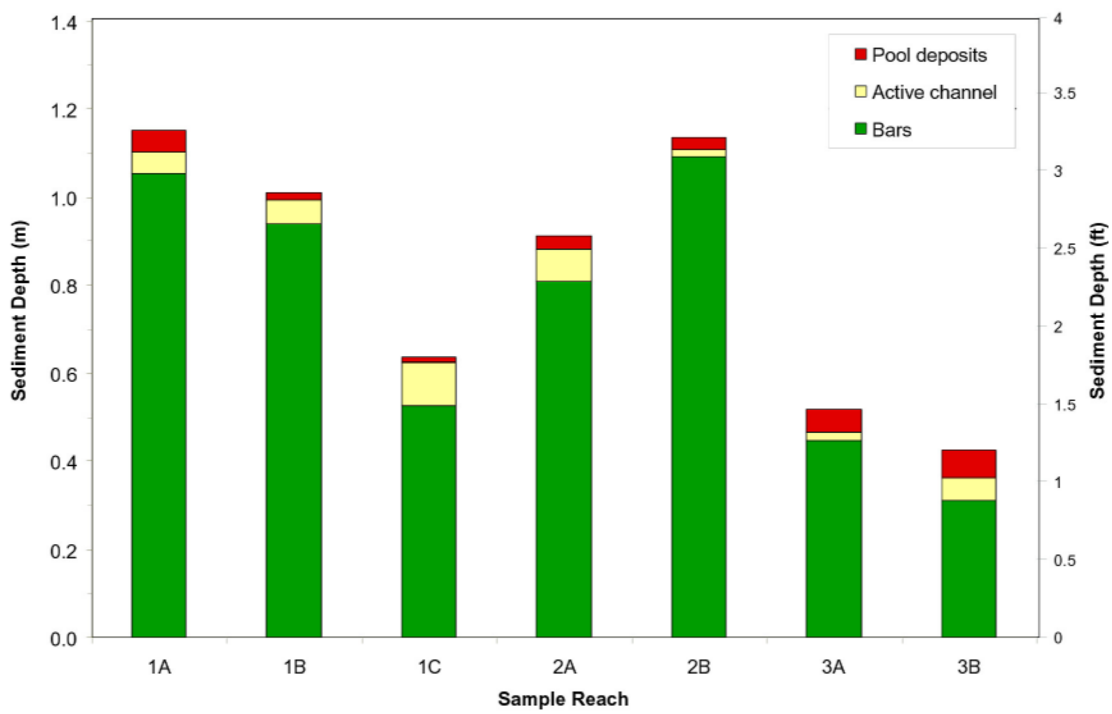

Figure 6-12. Normalized sediment depth of pool deposits, active channel deposits, and all types of bars measured in each sample reach.

Sediment Grain Size Analysis

Surface Sediment Analysis

We characterized the surface grain size distribution in each sample reach, by performing pebble counts at five locations corresponding to every fifth bankfull width, according to methods in Bunte and Abt (2001). A systematic random sampling approach was used wherein 100 clasts were measured in a grid pattern scaled to the local bankfull width and maximum particle size, and centered on the five cross-section locations in each sample reach. A total of 500 clasts per sample reach were measured producing a statistically robust estimate of surface sediment size distribution for the sample reach. In most cases, a grid spacing of 0.25 to 0.5 m (0.8 – 1.6 ft) was adequate to avoid double counting a single clast. However, if a single clast was large enough to be counted twice, one measurement and one “no count” was recorded.

Clasts located at each grid node were measured using an aluminum gravel template (US SAH-97TM Hand-held Size Analyzer) and reported as the phi sieve mesh on which the particle was caught (2 mm or 0.08 in, 4 mm or 0.16 in, 5.6 mm or 0.22 in , 8 mm or 0.31 in, 11 mm or 0.43 in, 16 mm or 0.63 in, 22 mm or 0.87 in, 32 mm or 1.26 in, 45 mm or 1.77 in, 64 mm or 2.52 in, 90 mm or 3.54 in, 128 mm or 5.04 in and 180 mm or 7.09 in). Clasts finer than 2 mm (0.7 in) were reported as < 2 mm (<0.7); clasts larger than 180 mm (7.09 in) were measured with a ruler and placed in the appropriate phi size class. This method provides high quality data for grain sizes larger than 8 mm (0.31 in), however, quality decreases at <8 mm (< 0.31 in) because it is difficult to select a single clast from the bed by hand. Also, surface pebble counts tend to overestimate coarse clasts, while underestimating the grain sizes that are sand and finer.

The median grain size (D_{50}) ranges from 10 mm (0.4 in) in reaches 3A and 3B to 26 mm (1.02 in) in reach 1A (Table 6-5, Figure 6-13, Appendix P). Grain size in La Honda Creek reflects the underlying bedrock lithology rather than fining downstream as normally occurs (Figure 6-14). Reaches 3A and 3B have a fine grain size distribution because they are underlain by Lambert Shale and San Lorenzo Formation (Tls), which are primarily composed of mudstones. The mudstone lithology is much more friable than the basalt, and will decrepitate upon wetting and drying (Figure 6-15). The relatively fine grain size distribution in the upper reaches of the study area is maintained by a continual supply of small clasts formed by this process. Reaches 2A, 2B and part of 1C are underlain by Mindego Basalt (Tmb), which is more resistant to erosion and supplies coarser clasts to the creek. Reaches 1A, 1B and part of 1C are underlain by the Tahana Member of the Purisima Formation (Tpt), primarily consisting of sandstone and siltstone. These units supply finer grain sizes than the basalt. The short channel length and modest change in valley physiography and stream slope of the study area is another reason for the lack of a fining downstream trend. At least locally, grainsize distribution in La Honda Creek appears to be more influenced by underlying and upstream lithology and less by changes in stream slope.

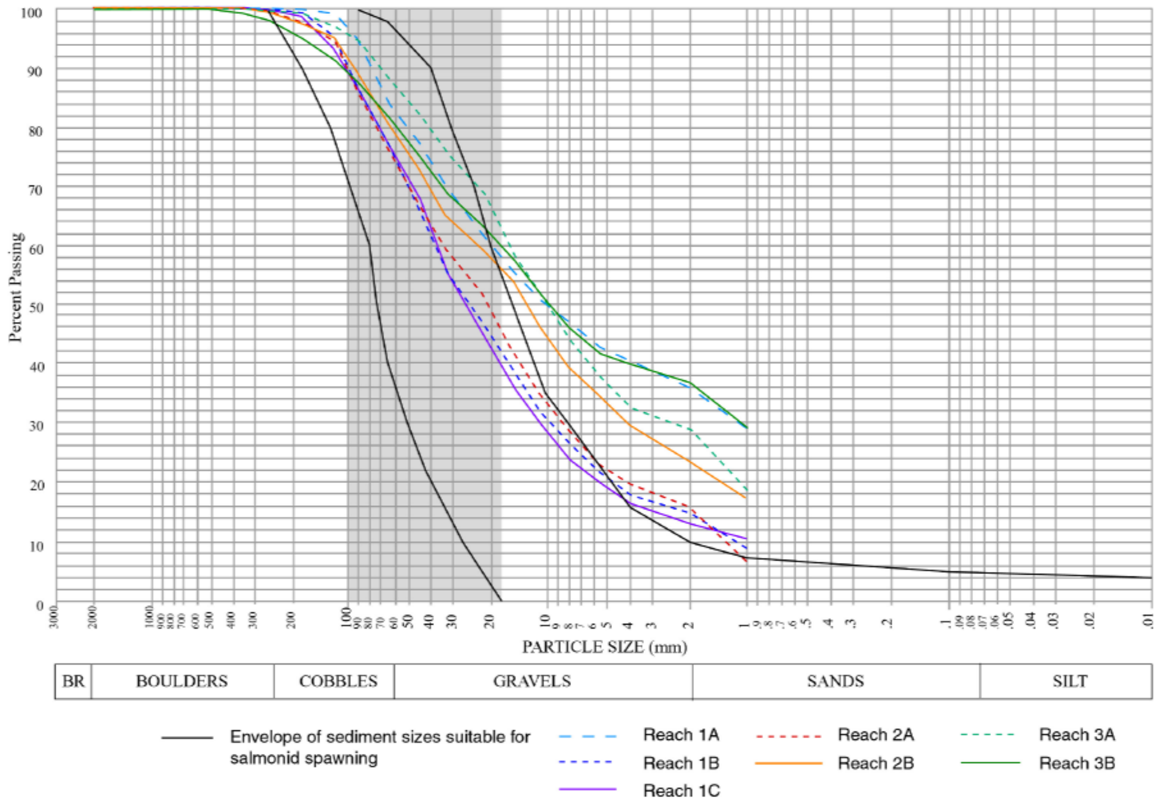

Figure 6-13. Surface particle size distribution curves of samples in all three study Segments. Shaded area highlights framework grain sizes utilized by steelhead for spawning (Kondolf and Wolman, 1993). Envelope of sediment sizes suitable for salmonid spawning is shown in black (Bjorn and Reiser, 1991; Kondolf 2000; Shirazi and Siem, 1979). BR = bedrock.

Table 6-5. Surface grain size data for each sample reach.

Reach	% <2mm	% <8mm	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	% Bedrock
1A	28.5	42.2	<2	11	64	0
1B	9.4	21.5	2.7	25	82	2.2
1C	10.3	19.7	3.8	26	82	0
2A	6.6	22.7	2.1	21	84	1.9
2B	17.2	34.3	<2	14	72	0
3A	19.3	37.9	<2	10	49	5.6
3B	29.1	41.8	<2	10	72	4.7

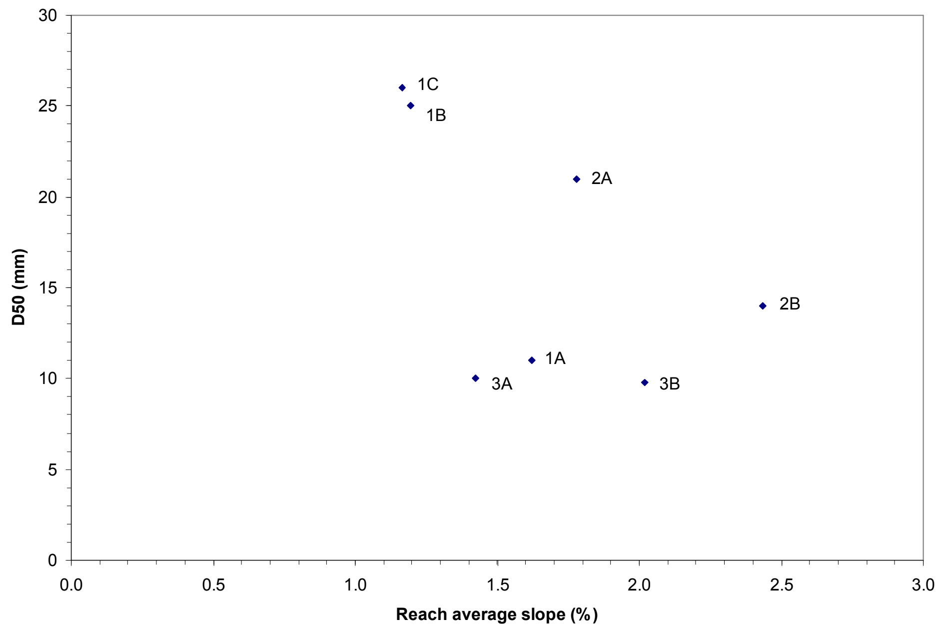

Figure 6-14. Reach average slope versus mean sediment grain size (D_{50}) for each sample reach.

Figure 6-15. Photographs of a clast of mudstone from the bed, commonly found in parts of Segment III. Upon wetting and drying, these rocks readily decrepitate into smaller fragments.

Subsurface Sediment Analysis

For spawning success salmonids require an adequate size distribution of gravels at pool tail-out locations. The salmonids must be able to readily excavate their nests (redds) and water must flow through the gravels, delivering oxygen to the developing eggs. Ideal spawning gravels should have low embeddedness and a low percentage of fine grains in order to maximize the through-flow of oxygenated waters and to reduce the effort required by the adult to build the redd.

Although surface grainsize information provides an indication of the subsurface, it is best to sample the subsurface sediment to help determine whether it is of appropriate size for spawning. Five bulk sediment samples were taken, one from each sample reach (1A, 1B, 1C, 2B, and 3B). Samples were collected from the location having the best spawning gravels, as determined by visual estimate, appropriate hydraulic flow into the riffle crest, and location relative to other channel features. This determination was largely based upon professional judgment and past experience with salmonid spawning locations.

Sample methodologies followed those used by DFG and described in Vyverberg et al. (1997). At each sample site, a square plot 0.75 m (2.5 ft) on each side was defined in the center of the pool-tail out location. Sediment from within the plot was carefully excavated using shovels and trowels (Figure 6-16) and divided into "surface" and "subsurface" subsets. The embedded depth of the largest surface clast was measured before excavation; above this depth, sediment is considered "surface", and below it "subsurface". Surface and subsurface sediment was removed from this plot until at least 250 kg (550 lbs) was excavated, typically corresponding to a final depth of ~25 cm (~10 in) below the bed surface, and similar to the average depth of excavation during salmonid redd construction in a stream of this size. Segregated surface and subsurface sediment was sieved in the field through a set of Gilson brand, 30-cm (11.8 in), square-mesh, rocker sieves (8 mm or 0.31 in, 16 mm or 0.63 in, 22 mm or 0.87 in, 32 mm or 1.26 in, 45 mm or 1.77 in, 64 mm or 2.52 in, 90 mm or 3.54 in) (Figure 6-17). Each size class was weighed in the field using a Pesola MacroLine spring scale (50 kg or 110 lbs capacity, 0.1 kg or 0.22 lb sensitivity) assuming the mass associated with moisture on the particles was negligible (Figure 6-18). Sediment finer than 8 mm (0.31 in) was set aside, allowed to drain, homogenized, weighed, and quartered before a subset was taken for lab analysis. Except for sediment suspended in the water, all sediment was collected, measured and weighed.

Samples ranged from 261 kg (575 lb) to 402 kg (886 lb); bulk density of samples averaged about 2.2 t/m^3 (140 lb/ft^3) (Table 6-6). The weight of the largest clast in each sample ranged from 1.1% to 7.6% of the total sample. Ideally, samples would be sufficiently large to reduce the weight of the largest clast to not more than 1% of the sample mass (Church et al., 1987). The largest clast encountered during bulk sediment sampling weighed 20.0 kg (44 lbs) (subsurface of reach 1C), requiring 2,000 kg (4409 lbs) of sediment to be sieved based upon the methods suggested by Church et al. (1987). Because it is unreasonable to sieve that amount of sediment, we increased the percentage allowed for a single clast to 5%.

Lab analysis of the sediment finer than 8 mm (3.3 in) was conducted by Sarah Pearce in the civil engineering sediment lab at California State University, Fresno. Samples were oven dried and mechanically sieved using a Rotap shaker through 203 mm (8-in) diameter brass sieves: 4.75 mm 0.19 in, 2.0 mm 0.08 in, 0.84 mm or 0.3 in, 0.5 mm or 0.02 in, 0.25 mm or 0.01 in, 0.125 mm or 0.005 in, 0.075 mm or 0.003 in, and 0.0625 mm or 0.0025 in) (US Standard sieve mesh sizes 4, 10, 20, 35, 60, 120, 200, and 230) (Table 6-7). Sediment in each size class was weighed to the nearest tenth of a gram on a Fisher Scientific Model 720 brand scale (accuracy of 0.1 gram or 0.0035 oz).

Figure 6-16. An excavated bulk sediment sample site. Wood stakes define the boundary of excavation.

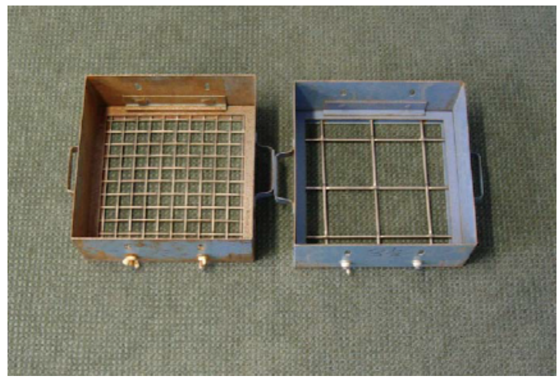

Figure 6-17. Two of the eight Gilson metal sieves used in the field for bulk sediment sampling.

Figure 6-18. Field sieving in action with the tripod and Pesola MacroLine spring scale in the foreground.

Table 6-6. Bulk sediment sample characteristics.

Sample location	Total weight (kg)	Total weight (lb)	Portion of total weight comprised by largest clast (%)
1A	274.4	604.9	1.1
1B	402.3	886.9	1.9
1C	264.2	582.5	7.6
2B	266.3	587.1	4.8
3B	261.5	576.5	2.3

Table 6-7. Sieve and square template sizes used for mechanical analysis of bulk gravel samples (0.065 mm to 256 mm), and pebble count sample (8 mm to 256 mm).

	Size Classes [1/]	Sieve Designations	
		ISO Standard 565 or Tyler numbering System	ASTM/US Standard Numbering system (ASTM E-11 equivalent)
Field Sieves & Templates[2/]	small boulder (≥256 mm)	256 mm	10"
	large cobble (≥128 mm)	180 mm	7"
		128 mm	5"
	small cobble (≥64 mm)	90 mm	31/2"
		64 mm	2½"
	very coarse gravel (≥32 mm)	45 mm	13/4"
		32 mm	11/4"
	coarse gravel (≥16 mm)	22 mm	7/8"
		16 mm	5/8"
	medium gravel (≥8 mm)	8 mm	5/16"
	fine gravel (≥4 mm)	4.75 mm	#4
Lab Sieves[3/]	very fine gravel (≥2 mm)	2 mm	#10
	very coarse sand (≥1 mm)	0.84 mm	#20
	coarse sand (≥0.5 mm)	0.5 mm	#35
	medium sand (≥0.250 mm)	0.250 mm	#60
	fine sand (≥0.125 mm)	0.125 mm	#120
	very fine sand (≥0.065 mm)	0.075 mm	#200
		0.065 mm	#230

1/ Wentworth (1922) grain size classification
2/ Field sieves and templates: size of sieve openings
3/ Lab sieves: sieve mesh number equals the number of mesh openings per inch.

A correction for moisture content of each laboratory sample was made. The weight of the dried, sieved sediment in each size class was extrapolated to determine percent by weight passing each sieve for the entire weight of fines sampled in the field. The lab data were combined with the results of field sieving to calculate the total percent by weight of sediment in each size class for the entire bulk sediment sample, and plotted as weight percent on a semi-logarithmic scale (Table 6-8, Figure 6-19, Appendix Q).

The median grain size (D_{50}) ranged from a low of 14 mm (0.55 in) in reach 3B to a maximum of 90 mm (3.5 in) in reach 2B. Although D_{50}, and the D_{16} and D_{84} (the diameters at one standard deviation from the median) are adequate for describing the size distribution of the gravel, other parameters such as geometric mean, geometric sorting index, and skewness provide additional information (Table 6-9). The following description of these parameters is from Vyverberg et al., (1997). Because the grain size analysis was completed for habitat rather than engineering purposes, these parameters rather than those of the USCS are used herein.

The geometric sorting index (sg), geometric mean (dg), and the skewness (sk) are computed as follows:

$$sg = (D_{84}/D_{16})^{0.5}$$
$$dg = (D_{16}*D_{84})^{0.5}$$
$$sk = \log(dg/D_{50}) / \log(sg)$$

The geometric sorting index (sg) reflects how well fluvial processes have concentrated particles of similar sizes. If a deposit has a small range of grain sizes, it is “well-sorted” and has a low sg value; if the range of grain sizes is large, the deposit is "poorly-sorted" and has a high sg value. A perfectly sorted (all one size) sediment has a value of 1. A sg of less than 2.5 indicates a well-sorted sediment, about 3 is considered normal, and above 4.5 is poorly sorted.

The geometric mean particle size (dg) indicates stream bed material permeability. In general, permeability increases with increasing dg. However, for a given mean particle size, more poorly sorted samples will have decreased permeabilities.

Skewness (sk) measures the asymmetry of the particle size distribution. If the distribution is not symmetric around the mean, then extreme values will pull the mean toward one tail of the distribution. Gravels of the size typically used by salmon for spawning are usually negatively skewed; that is, their size distributions are not perfectly lognormal but are characterized by tails that extend into the fine sediment sizes (Kondolf, 1988). This is also reflected in the tendency for D_{50} to exceed dg.

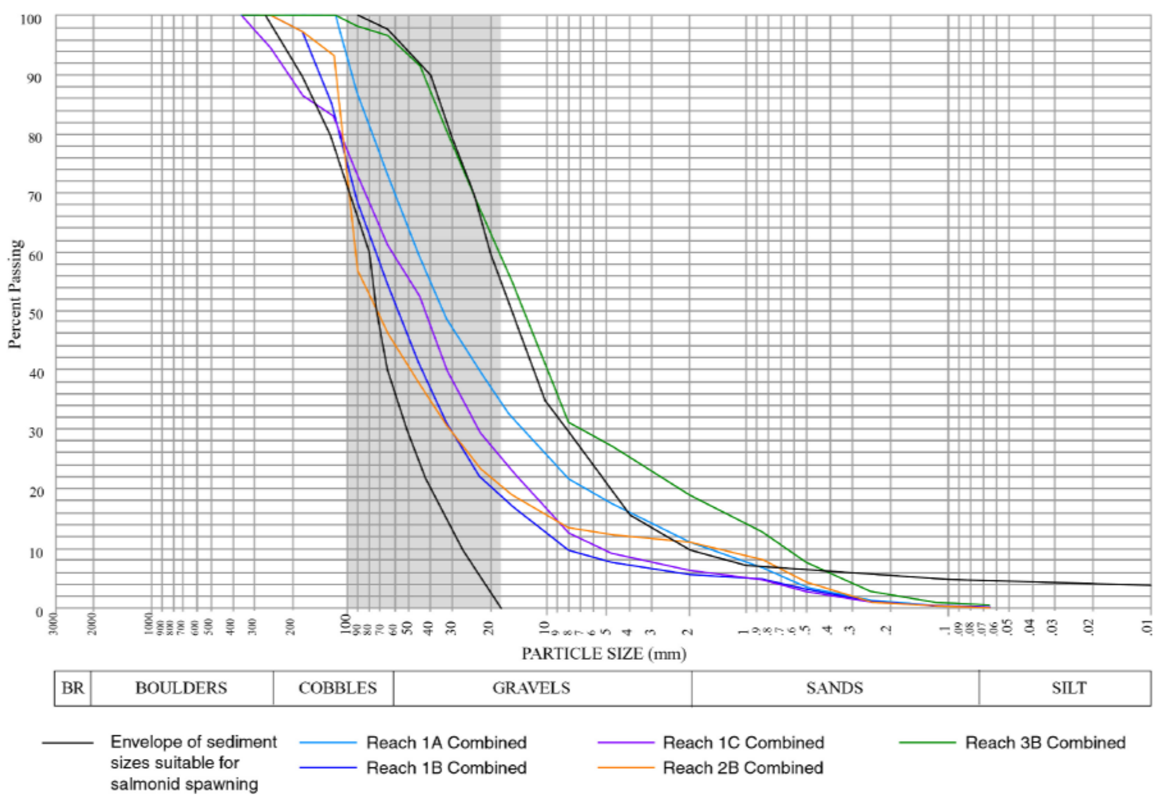

Figure 6-19. Particle size distribution curves of combined (surface and subsurface) bulk sediment samples in sample reaches in all three study segments. Shaded area highlights framework grain sizes utilized by steelhead for spawning (Kondolf and Wolman, 1993). Envelope of sediment sizes suitable for salmonid spawning is shown in black (Bjorn and Reiser, 1991; Kondolf 2000; Shirazi and Siem, 1979). BR = bedrock.

Table 6-8. Grain size distribution for bulk sediment samples.

Sample location	% < 1mm (0.04 in)	% < 6.35 mm (0.25 in)	D_{16} (mm)	D_{16} (in)	D_{50} (mm)	D_{50} (in)	D_{84} (mm)	D_{84} (in)
1A surface	6.0	16.5	5.9	0.0	43	1.7	92	3.6
1A subsurface	9.8	23.5	2.7	0.1	26	1.0	73	2.9
1B surface	1.5	2.9	25	1.1	69	2.7	140	5.5
1B subsurface	8.8	15.0	7.5	10.4	47	1.9	105	4.1
1C surface	3.4	9.0	11	0.1	38	1.5	96	3.8
1C subsurface	7.0	13.0	8.7	0.0	55	2.2	155	6.1
2B surface	4.2	8.2	16	0.8	59	2.3	105	4.1
2B subsurface	12.5	19.0	1.9	0.0	90	3.5	115	4.5
3B surface	12.5	28.2	1.8	0.0	15	0.6	34	1.3
3B subsurface	16.2	30.1	0.95	0.1	14	0.6	36	1.4

Table 6-9. Bulk sediment descriptive analysis.

Sample location	Geometric sorting index	Geometric mean [mm (in)]	Skewness
1A surface	3.9	23.3 (0.92 in)	-0.4
1A subsurface	5.2	14.0 (0.55 in)	-0.4
1B surface	2.4	59.2 (2.33 in)	-0.2
1B subsurface	3.7	28.1 (1.11 in)	-0.4
1C surface	3.0	32.5 (1.28 in)	-0.1
1C subsurface	4.2	36.7 (1.45 in)	-0.3
2B surface	2.6	41.0 (1.61 in)	-0.4
2B subsurface	7.8	14.8 (0.58 in)	-0.9
3B surface	4.3	7.8 (0.31 in)	-0.4
3B subsurface	6.2	5.8 (0.23 in)	-0.5

By plotting the grain size distribution curves from both the surface pebble counts and the combined bulk sediment samples, the results of two separate methods can be compared (Figure 6-20). This comparison is valuable because studies rarely collect both types of data, and typically estimate both surface and subsurface grain size distributions based upon a single data type. This study provides a measure of both surface and subsurface sampled distributions, as well as comparing the observed distributions to those in the literature. In all samples, the pebble count method overestimated the percentage of fines in the bed. The average overestimation is 11%, ranging from 4% to 21% in the five locations sampled. The overestimation of fines from the pebble count method is surprising because pebble counts typically under-represent the amount of fine grain sizes due to the limitations of selecting a single fine grain with one's fingertip. The overestimation of fines in this study is likely due to the method chosen. Following the method outlined in Bunte and Abt (2001) pebbles were selected from 10 transects per sample location across the bankfull width of the channel. Pebble counts were performed in all channel unit types, including pools, runs and riffles and sediment size distribution changed significantly between different channel unit types. Because the pebble counts were not limited to a single grain size facies/patch type (e.g., only riffle locations) it is not surprising that the distribution overestimates the percentage of fines compared to the bulk samples taken only at riffle tail-out locations. Future grain size distribution analyses in La Honda Creek should utilize description of surface distributions in each individual channel unit type or patch, or alternatively, should utilize bulk sediment sample methods in combination with surface pebble counts focusing on the same discrete channel unit type or patch.

A large volume of sediment is stored in all sample reaches, however reaches 1A and 2B currently store the largest volume. Bars comprise the largest volume of storage, while pool deposits only comprise a minor percentage. The stability of deposits suggests that La Honda Creek is capable of transporting large volumes of sediment, even in annual low-magnitude events. Sediment transport is effective, transporting large grain sizes at relatively low discharges. Grainsize distributions reflect lithology rather than channel slope. Surface pebble counts in La Honda Creek tend to overestimate the percentage of fines, compared to bulk sediment sampling methodologies. Overall, the grain size distribution of gravels appears adequate for salmonid spawning.

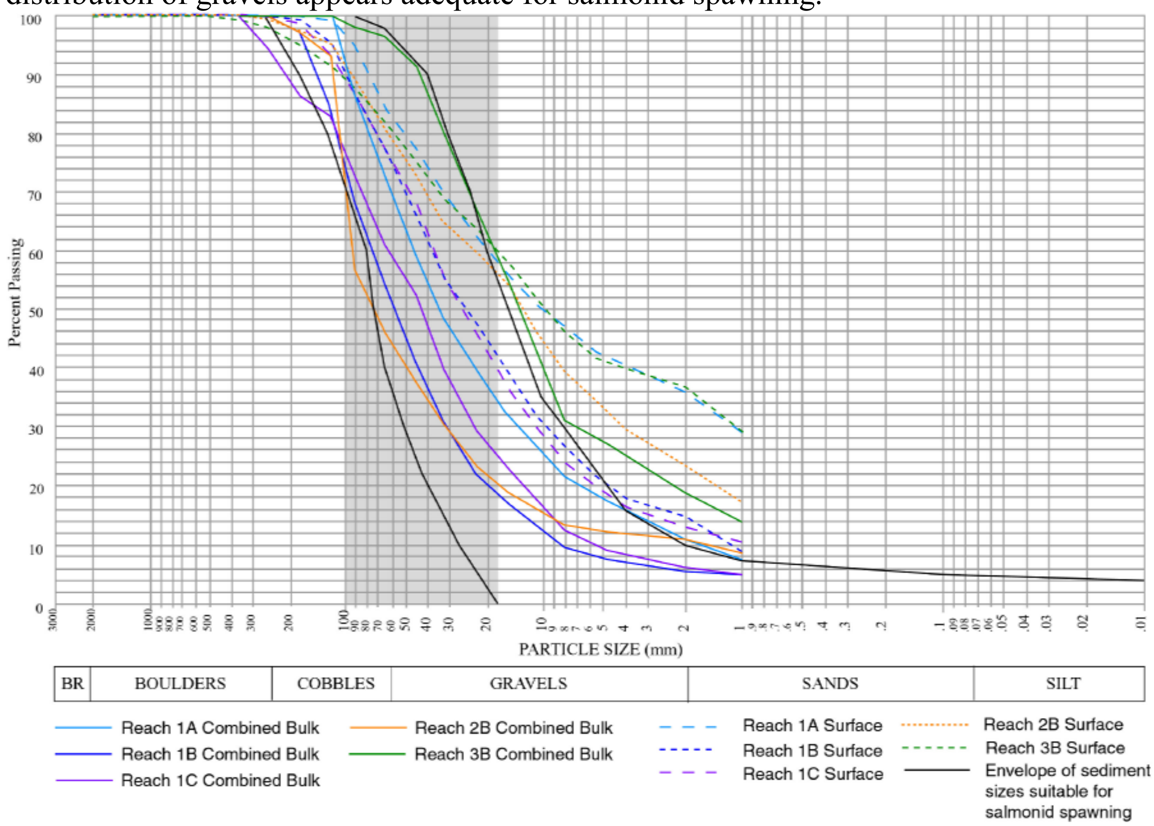

Figure 6-20. Comparison of grain size distribution curves. Surface = surface pebble counts. Combined Bulk = weighted bulk samples (surface and subsurface) combined. Shaded area highlights framework grain sizes utilized by steelhead for spawning (Kondolf and Wolman, 1993). Envelope of sediment sizes suitable for salmonid spawning is shown in black (Bjorn and Reiser, 1991; Kondolf 2000; Shirazi and Siem, 1979). BR = bedrock.

Pools

Pools are important channel features that provide habitat for biota including salmonids. In intermittent streams pools may be the only place where aquatic life can survive the summer months. The best habitat is in large and deep pools, and in those shaded by riparian plants because they remain cooler and take longer to dry up.

Quantifying the occurrence and formative mechanisms of pools is an important step in managing habitat for salmonids.

Survey Methods

The surface dimensions (average length and width) and residual depth (maximum pool depth minus tail-out depth) were measured to the nearest 0.1 m (0.33 ft) (Lisle, 1999). Minimum pool dimensions were at least 1 m (3.3 ft) or larger than ¼ of the bankfull width, and had residual depths of at least 0.2 m (0.66 ft). The length and width measurements were adjusted for fluctuating water elevations so that data were comparable. An index of pool volume was computed as the product of pool length, width and residual depth. Pool class is based on the apparent mechanism of formation and less so on descriptive morphology. Pools were classified and grouped into either step-pool, plunge pool, dammed pool, main channel/bedrock trench pool, or lateral scour pool (Table 6-10) using a modified version of fish habitat inventory methods (Flosi et al., 1998). To better understand the formative mechanism, lateral scour pools were further subdivided into pools associated with large woody debris (LWD), bedrock, or other/unapparent.

Table 6-10. DFG Level III and Level IV Habitat Types, 1998.

La Honda Creek Pool Classes	Cal. Dept. of Fish and Game Classifications 1998 (name, abbreviation, Level IV classification number)
Step-pool	Step pool (STP) [4.4]
Plunge pool	Plunge pool (PLP) [5.6]
Dammed pool	Dammed pool (DPL) [6.5]
Main channel/Bedrock trench pool	Mid-Channel pool (MCP) [4.2], and Trench pool (TRP) [4.1]
Lateral scour pool	Level III, Scour pool. Includes: (LSL) [5.2], (LSR) [5.3], (LSBk) [5.4], (LSBo) [5.5]

Pool Type and Spacing

A total of 46 pools were measured and classified in each of the seven sample reaches of La Honda Creek (Figure 6-21, Appendix R). Each reach contains many different pool classes, but lateral scour pools dominate, comprising 92% of all pools measured (Figure 6-22). While all three types of lateral scour pool are present in all sample reaches, main channel/bedrock trench pools were noted only in reaches 2B and 3B, and plunge pools were present only in reaches 2B and 3A. Both of the two measured plunge pools were associated with LWD, and were more than 1 m (3.3 ft) deep.

In every reach, pools are spaced less than five bankfull widths apart, and commonly they are spaced less than three bankfull widths apart (Table 6-11). The average pool spacing in La Honda Creek is less than the typical pool spacing of five to seven bankfull widths for alluvial channels discussed by Leopold (1964) and Dunne and Leopold (1978). Spacing is less in La Honda Creek because of the abundance of elements such as bedrock banks, other hard banks, LWD pieces, and boulders that form step, plunge and dammed pools, and that induce scour for main channel and lateral scour pools.

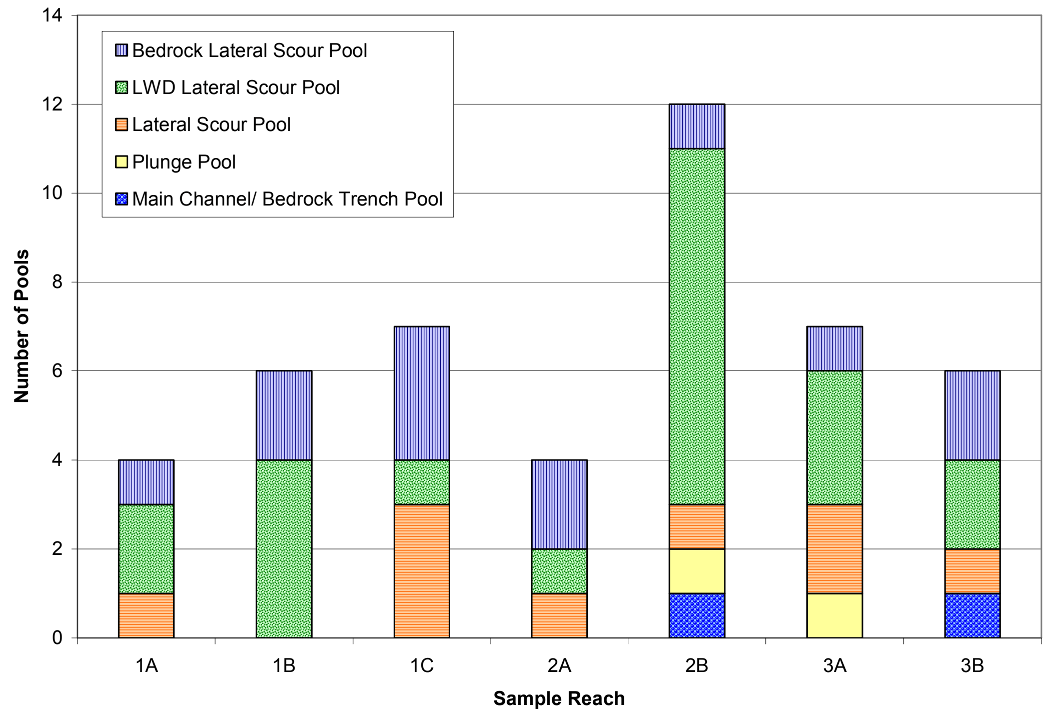

Figure 6-21. Number and class of pools in each sample reach.

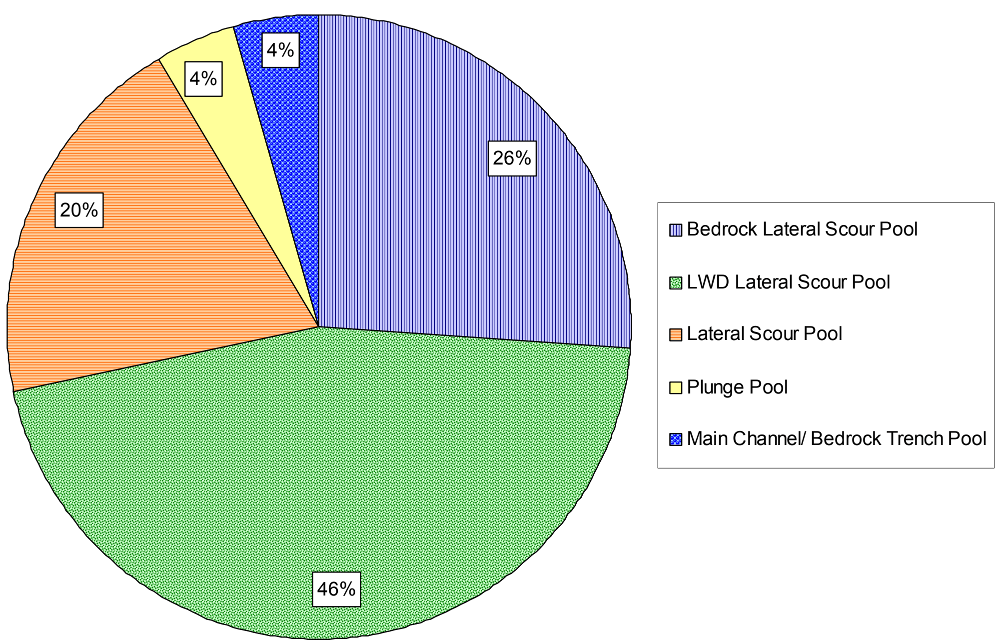

Figure 6-22. Number of pools in each class measured in the seven sample reaches combined.

Table 6-11. Average pool spacing in La Honda Creek.

Reach	Reach length [m (ft)]	Number of pools	Average pool spacing (in bankfull widths)
1A	162.5 (533 ft)	4	4.3
1B	187.5 (615 ft)	6	1.0
1C	175 (574 ft)	7	2.0
2A	162.5 (533 ft)	4	3.8
2B	225 (738 ft)	12	0.6
3A	125 (410 ft)	7	1.5
3B	112.5 (369 ft)	6	2.5
Total	1150 (3,773 ft)	46	2.2

Nearly three-quarters of all pools measured in La Honda Creek are formed by or are associated with LWD (Figure 6-23). A pool that is associated with LWD may or may not have formed primarily due to its presence, but the piece shades, covers, or adds complexity increasing the habitat quality. In all sample reaches combined, 50% of pools measured are directly formed by LWD, and 22% are associated with LWD.

Pool Depth

Pools in La Honda Creek were classified based on their residual depths, ranging from 0.2-0.4 m (0.66 – 1.3 ft) up to >1.0 m (>1.3 ft) (Figure 6-24). A relationship between pool depth and location in the watershed is not evident. The deepest pools tend to be either plunge pools or LWD lateral scour pools, while the shallowest tend to be main channel/bedrock trench pools. This relationship reflects the influence of bankfull cross-sectional area and pool-forming agents upon pool residual depth. Typically, as channel slope decreases, residual depth and range of depths increase, reflecting the greater ability to scour deeper pools in the lower reaches of the channel. Because slopes in the sampled reaches of La Honda Creek are fairly gentle, pools of all depth classes should be expected. But, pool depth in La Honda Creek appears to be fairly independent of slope, probably because slope does not vary much (1.16% to 2.44%) in the project area. Pools in all depth classes are present in all seven sample reaches of La Honda Creek (Figure 6-25). Because La Honda Creek is overall not an entirely alluvial channel, agents that form the pools (large boulders, bedrock outcrops, LWD pieces and jams) appear to be more important than slope in governing a pool's residual depth.

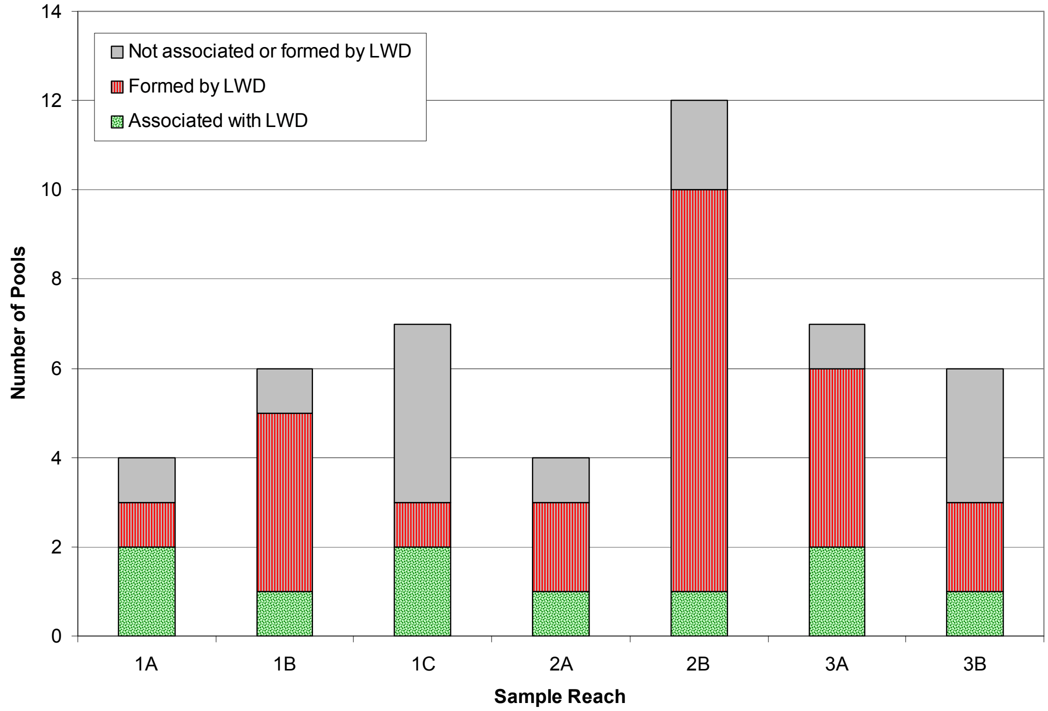

Figure 6-23. Number of pools formed or associated with LWD in each sample reach.

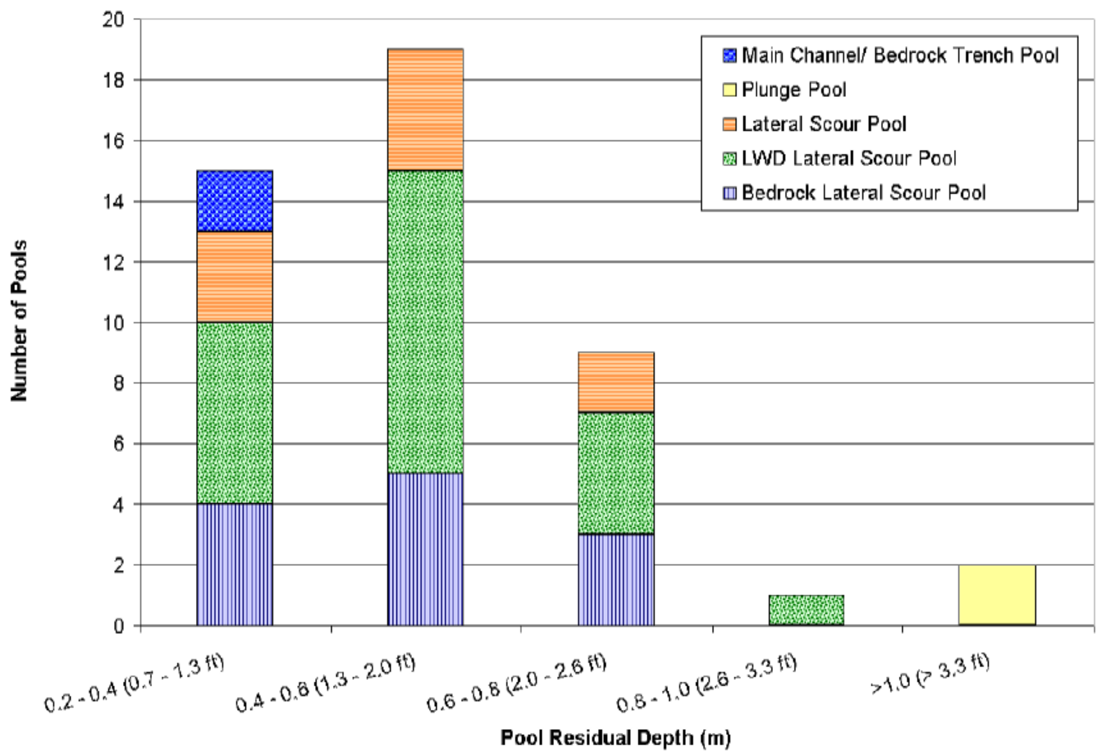

Figure 6-24. Number of pools per residual depth class and their associated cause for all sampled reaches.

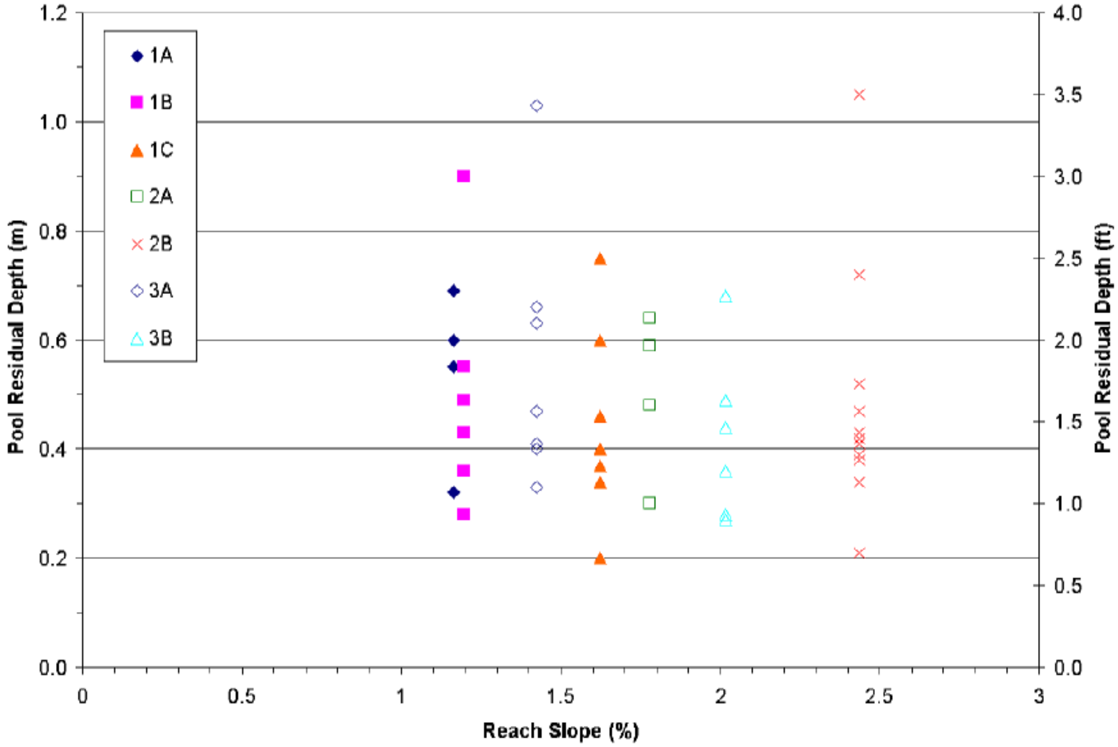

Figure 6-25. Residual pool depth versus reach average slope.

Large Woody Debris

Large woody debris (LWD) is important in maintaining the ecological health of a channel, but it can also negatively impact in-channel and streamside structures. LWD maintains channel health by providing shade and cover for aquatic species, adding habitat complexity, forming pools, providing leaf litter that feeds invertebrates, and increasing channel roughness during peak flow periods. Live, upright trees strengthen the banks and bars and help stabilize the channel's morphology and position. Unfortunately, LWD can also redirect energy at in-channel structures such as bridges and bank revetments, causing unwanted scour. LWD can also increase local stage during high flow due to increase roughness, further threatening the structure. In addition, LWD can destroy bridges by catching on the carriageway guardrails or webs, blocking water and causing sometimes fatal hydraulic loading. To prevent this, the public, city, and county authorities actively remove debris annually from selected high-risk locations. However, removing every potentially damaging piece of wood in La Honda Creek would be a massive undertaking because the annual rate of recruitment and the existing volume of LWD is relatively high (compared to rates in northern California redwood forests). In addition, given that 75% of the pools are associated with LWD, such removal efforts would drastically reduce the habitat quality.

Survey Methods

Characteristics of large woody debris (LWD) were measured continuously along the entire length (25 bankfull widths) of each sample reach (Appendix S) (Forest, Soil and Water, Inc., O'Connor Environmental, Inc., and East-West Forestry, 1998). Data collected on LWD and living trees that affected flow within the bankfull channel, included only pieces larger than 20 cm (8 in) in diameter and 1.8 m (6 ft) in length. Live, upright trees were included in the data if their trunk or root systems significantly affected the bankfull flow. Other data collected included: 1) the position of the piece relative to the bankfull channel; 2) the species; 3) the state of decay, here referred to as the decay class; 4) if the piece was associated with a pool; 5) the entry process for the piece; 6) whether the piece was a part of a debris jam; and 7) if it was a key structural piece in the debris jam. Based on these data, we assessed the role of LWD in channel morphology, including formation of pools, sediment storage sites, and the effects on flow hydraulics and roughness.

LWD Recruitment

LWD in La Honda Creek is recruited mainly bank erosion and landsliding, and to a lesser degree by mortality and windthrow. Although no large landslide events occurred during the winter of 2002/2003, much LWD was still recruited during this period, from the many other mechanisms. Recruitment appears to be high along La Honda Creek, based upon landowner's observations, and observations of many pieces in each decay class (from bark intact, limbs, twigs and needles present, to surface and center completely rotted) throughout the channel length (Appendix S). A landowner reported losing one tree from his property (property length is approximately 152 m or 500 ft length) every year to recruitment (D. Hinman, pers. comm.). In northern California, LWD recruitment rates average 2.5 $m^3km^{-1}yr^{-1}$ (5.3 $yd^3mi^{-1}yr^{-1}$) and 4.0 $m^3km^{-1}yr^{-1}$ (8.4 $yd^3mi^{-1}yr^{-1}$) for old-growth and second-growth forests, respectively (Benda et al., 2002). Other reported input rates include 0.132 $m^3km^{-2}yr^{-1}$ (0.279 $yd^3mi^{-1}yr^{-1}$) for old growth, and 0.056 $m^3km^{-2}yr^{-1}$ (0.118 $yd^3mi^{-1}yr^{-1}$) for second growth redwood forests in northern California (Wooster, 2000). The volume of a single riparian tree along the La Honda Creek corridor averages between 0.5 m^3 (0.66 yd^3) up to 10 m^3 (13 yd^3), with some of the larger redwood trees approaching 20 m^3 (26 yd^3) (Appendix S). Between mortality, bank erosion, windthrow, landslides, and the steep surrounding hillslopes, it is likely that each year at least one tree per kilometer is recruited into the channel of La Honda Creek.

Number and Species

The number of pieces of LWD in each reach is fairly consistent, typically between 10 and 30, reflecting the nearly continuous riparian vegetation corridor. Even if live, upright trees are removed from the dataset, every reach would still contain at least 10 LWD pieces. Reach 2B has the largest number of LWD pieces (99), and the largest LWD load (655 m^3/km). This reach contains an unusually large LWD jam at the base of a shallow landslide (jam located on Plate 1B). This jam is just upstream from Landslide Bend pressure point, described in detail in Section 7.6. Many of the pieces were recruited from this landslide, while others were being transported from upstream, and became lodged in the existing jam. Although this jam provides important habitat and temporarily buttresses the base of the landslide, it also impedes high flows and concentrates scour at the base of the landslide. Catastrophic failure of the jam during high flow could also cause significant damage downstream. The large, shallow landslide is not unique within Segment II; other similar LWD jams were observed outside of the sample reach. Although most of the pieces measured in the sample reach are located within this single jam, other styles of recruitment were observed, and equally contribute to habitat formation and complexity.

Many different species of LWD and live, upright trees were identified along La Honda Creek (Figure 6-26 and 6-27, Appendix S). Redwood and conifers are abundant in-channel LWD species because they are large, plentiful, and decay slowly. Other reaches contain large numbers of live, upright alders and other hardwoods whose roots extend into the bankfull channel, adding to the channel's roughness. Most hardwood logs in the channel have decayed beyond positive identification. Using the data collected, the load of LWD in each reach can be calculated. LWD loads range from 54 m^3/km (114 yd3/mi) in reach 1A to 655 m^3/km (1379 yd3/mi) in reach 2B (Figure 6-28). In second-growth forests on the California north coast, typical loads average 220 m^3/km (463 yd3/mi), whereas loads in old-growth forests average 1,200 m^3/km (2526 yd3/mi) (O'Connor Environmental, 2000).

LWD is abundant in La Honda Creek, and is recruited primarily from bank erosion and landsliding. Locations of LWD jams were noted in many reaches, with each jam providing beneficial functions, but also causing a hazard to downstream property and structures.

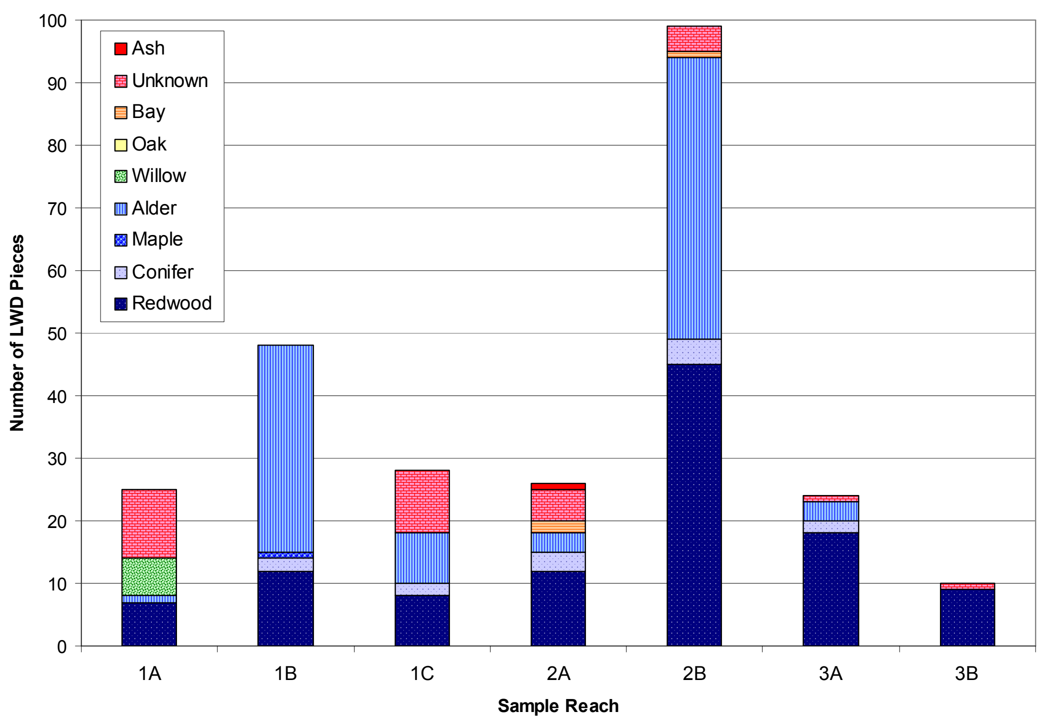

Figure 6-26. Number and species of large woody debris per sample reach.

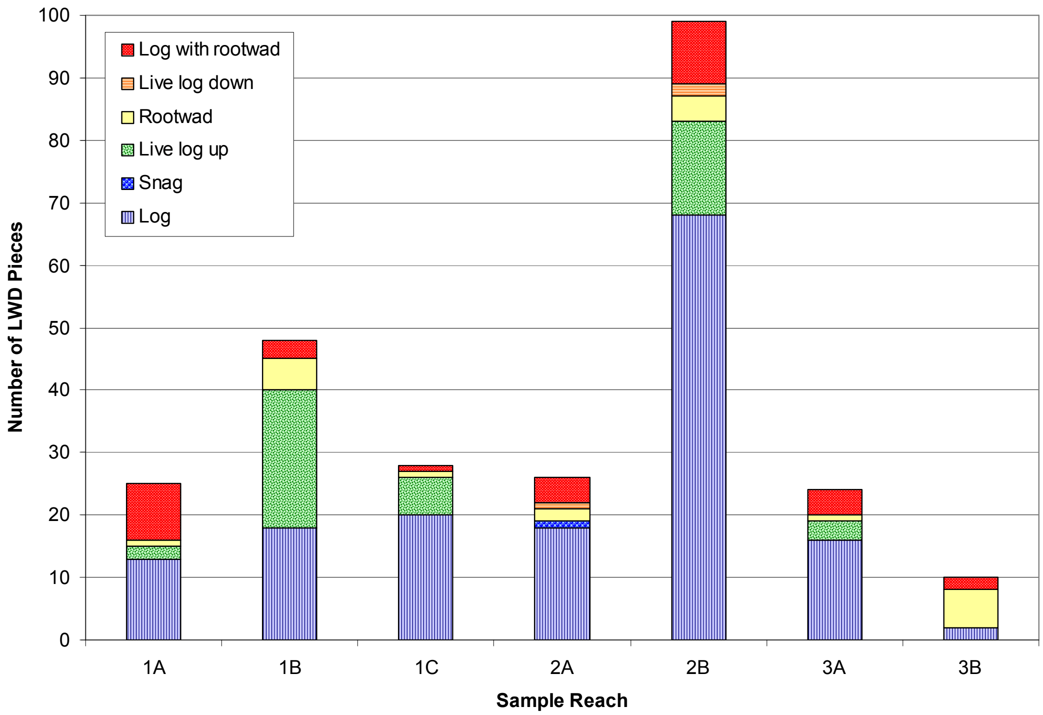

Figure 6-27. Number, position, and form of large woody debris (LWD) per reach.

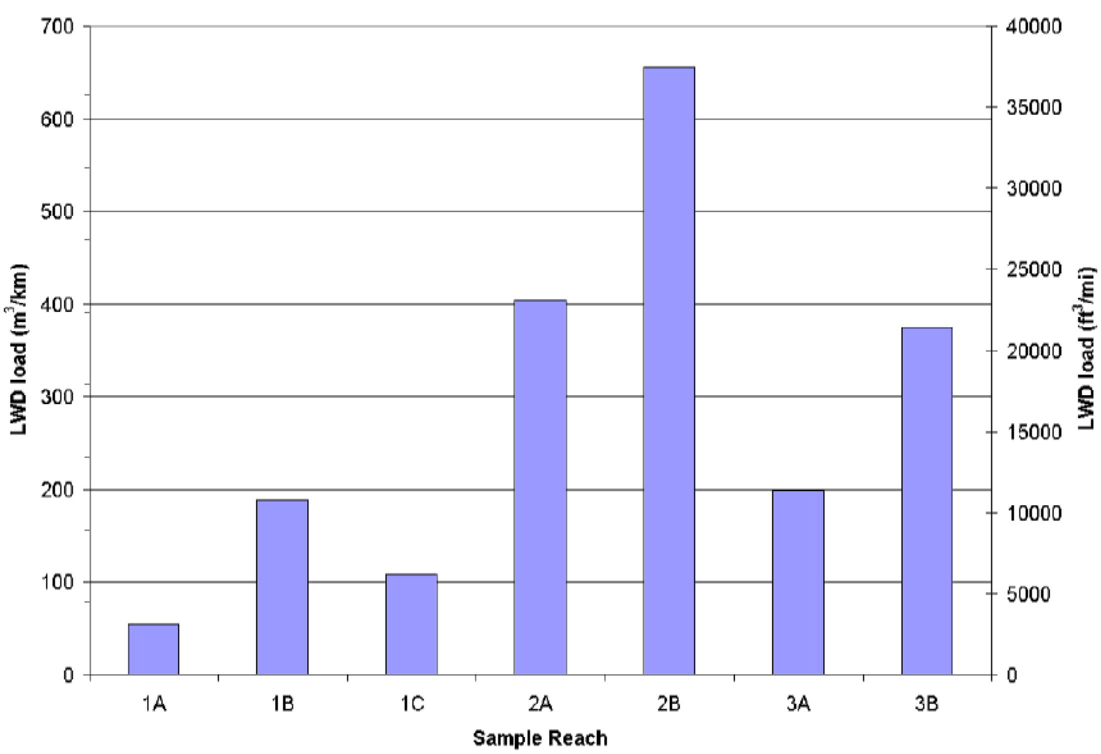

Figure 6-28. LWD load (m^3/km) for each sample reach.

The La Honda Creek Channel

The features and conditions that control La Honda Creek, its channel pattern, morphology, sediment transport capacity, and primary mechanism of pool formation, are important for understanding the functioning of the channel. La Honda Creek does not have a typical self-forming alluvial channel whose bed and banks are composed of material eroded and deposited by the creek, and is able to meander virtually unimpeded in its alluvium-filled valley. Alluvial channels are able to adjust their hydraulic geometry based upon the amount of water and sediment supplied to the channel, and upon the lithology and tectonics of the watershed (Leopold and Maddock, 1953). In these systems, the channel-forming discharge, the discharge that corresponds to bankfull stage, does the most work on the channel, controlling channel gradient, pattern and geometry (Wolman and Miller, 1960). On the other hand, La Honda Creek does not have a purely bedrock channel either. Bedrock channels, sometimes known as resistant-boundary channels, have bed and banks primarily composed of bedrock, or cohesive resistant material, with a veneer of alluvium. Compared with alluvial channels, these channels typically have less roughness and sinuosity, and thus, greater water velocities and more efficient sediment transport.

The study area, or the lowest 5 km (3.1 mi) reach of La Honda Creek, appears to be partly alluvial but mostly a bedrock channel type. Bedrock outcrops and other objects resistant to scour most strongly affects the location of pools. Channel morphology more closely reflects the locations of bedrock outcrop and landslides than sediment transport hydraulics. Most of the sediment in alluvial reaches is supplied by landslides, which is then redistributed and transported downstream. Sediment transport appears to be quite efficient: an approximately 1:3 year recurrence interval discharge event produced many noticeable changes in sediment deposit location and morphology. The bed of La Honda Creek is moderately embedded, due more to the in-situ breakdown of mudstone clasts than to hydraulic deposition of fine sediment. Reaches having greater sediment embeddedness have lower roughness, making them function more like a resistant boundary channel.

6.5 SALMONID SPAWNING HABITAT

The *Draft Strategic Plan for Restoration of Endangered Coho Salmon South of San Francisco Bay* (1998) identified San Gregorio Creek and its tributaries as one of nine creeks in which recovery of coho salmon (*Oncorhynchus kisutch*) is a priority. This draft strategic plan identified the following as primary factors that are likely limiting the success of steelhead and coho salmon in the larger San Gregorio watershed:

1) Stream flows necessary to maintain critical salmonid life stages
2) Excessive streambed sedimentation, particularly fine sediment
3) Inadequate refugia from natural and man-made events
4) Impediments to upstream and downstream migration
5) Insufficient recruitment and maintenance of large woody debris (LWD)
6) Poor water quality
7) Incidental water take associated with unscreened or improperly screened diversion

8) Threats to existing riparian vegetation

Many individual factors contribute to appropriate habitat for salmonid spawning success. The quality of each and the functioning of the system as a whole must be considered during habitat assessment. Elements that could potentially affect available spawning habitat in La Honda Creek include: stream flows for in- and out-migration; gravel size distribution, proportion of fine sediment, gravel embeddedness, and hydraulic locations for spawning; adequate pools for spawners to rest or hide, and other refugia from high water velocities; migration barriers, both physical and related to flow; continuity of the riparian corridor; and water temperature and quality.

Spawning Habitat in La Honda Creek

Although the La Honda Creek study was not designed to address every limiting factor on the *Draft Strategic Plan* list, the habitat assessment herein clarifies the role of potentially limiting factors, including sedimentation, LWD and riparian vegetation. Based upon the data collected, it appears that La Honda Creek provides adequate spawning habitat for salmonids with the main limitation being substrate embeddedness.

Stream Flow

Successful in-migration of spawning adults depends upon precipitation events creating sufficient discharges concurrent with the timing of each species' spawning run. Most discharge in La Honda Creek occurs during the winter and spring months (approximately November through April), primarily driven by precipitation events. Although the hydrograph of today's events may be more peaked due to changes in land management over the past 200 years, the character of winter season flow is probably not greatly different from natural conditions. A few, small reservoirs exist in some tributaries for water supply as well as for storage of water for agriculture and horticulture, but these probably have little influence on the flood hydrograph. Depending on the timing and intensity of precipitation events, winter and spring water levels appear to be appropriate for the in-migration of spawning adults during moderate and wet years. However, in a dry year, or when the precipitation occurs only early in the season, both adult and juvenile out-migration may be limited by low water levels. For example, a completely dry bed was observed at Riprap Bend pressure point (see Plate 1B) during August, 2002. During these years, diversions may make migration more difficult, while increased future diversions will only worsen the situation.

Sedimentation

Excess fine sedimentation can negatively affect salmonid spawning by increasing gravel embeddedness, reducing pool volumes, or reducing water through-flow in the redds. In La Honda Creek, fine sediment appears to be limiting the success of salmonids.

Based upon geology, slope, and landslide hazard maps, landslides and hillslope erosion transport most of the sediment into La Honda Creek. The volume of these sediment sources far outweigh that of either bank erosion, land use or input from Highway 84. Despite the volumes of sediment supplied from these sources, it does not appear that excessive sedimentation is occurring in the channel.

Bank erosion was minor (114 – 165 m^3 or 149 – 165 yd^3) in reaches without landslides, however where landslides are present and directly impinge on the stream, bank erosion rates increased. For example, in reach 2B a single, large landslide has contributed approximately 2,900 m^3 (3,795 yd^3) of sediment to the channel (located near the Call box on Plate 1B). The landslide here appears to have been a catastrophic event, however, elsewhere many other landslide blocks have not yet fully entered the channel. In those locations, the channel is slowly eroding the toes of the slides, continuously releasing sediment. La Honda Creek, during relatively modest flows, and especially during high flows, is capable of transporting large amounts of sediment, and large grain sizes, as evidenced by turbidity measurements, bed and bar D_{50} and D_{84} grain sizes, and the number of pools without significant pool deposits.

<u>Substrate Grainsize and Distribution</u>

Subsurface streambed sediment size distributions were analyzed to ascertain the quality of substrate for spawning and rearing. Following the approach described by Kondolf (2000), three sediment-size criteria were evaluated in relation to critical biological aspects of spawning:

1) the 50^{th} percentile (D_{50}) and 84^{th} percentile (D_{84}) of the bed material determines the ability of spawning fish to move these "framework" clasts during construction of the redd,
2) the percentage of bed material finer than 1 mm determines whether fine sediment will affect incubation of eggs in redds, and
3) the percentage of bed material finer than 6.35 mm (0.25 in) affects emergence of fry from the redd.

Kondolf (2000) suggested that the subsurface D_{50} and D_{84} (the framework material) of potential spawning gravel be compared to documented spawning gravel size distributions. Kondolf and Wolman (1993) compiled such data for salmonids, including steelhead trout. The range of D_{50}s from these data for steelhead is about 18 to 34 mm (0.71 – 1.34 in), with D_{84}s about 100 mm (3.94 in), and ranges of D_{50}s for coho salmon between 14 mm and 29 mm (0.55 – 1.14 in). Data for La Honda creek indicate framework bed sediment ranges between 14 and 90 mm (0.55 – 3.54 in) for the D_{50}, ranging between 34 and 155 mm (1.34 – 6.10 in) for the D_{84} (Table 6-8). These grain sizes are consistent with other documented grain size distributions, suggesting that appropriate framework gravels are provided in La Honda Creek.

In addition, Kondolf (2000) suggests based on a review of prior studies that spawning gravels with less than 12 to 14% sediment finer than 1 mm (0.04 in) (fines) is correlated with 50% survival to emergence on average. The 50% emergence is an arbitrary cutoff, yet is widely accepted by biologists as a benchmark for comparison. Kondolf also suggests that a downward adjustment should be applied to bed samples to account for removal of fine sediment during redd construction. An empirical relationship estimates the final percentage of fines as 0.67 times the initial percentage. Hence, samples with up to 21% fines would be predicted to have levels of about 14% after spawning. However, fines deposited in the redd during the egg incubation period (e.g. intrusion of fines due to high turbidity outside the redd, see Section 4.5) could fill the gravel interstices and ultimately bring fine sediment levels back up to pre-redd construction levels. Amounts of sediment finer that 1 mm (0.04 in) in bulk sediment samples ranged from 1.5 to 16.2%.

The levels of subsurface sediment finer than 1 mm (0.04 in) in La Honda Creek is within the range that does not excessively impact steelhead egg incubation.

With respect to fine gravel impeding steelhead fry emergence, Kondolf (2000) suggests that previous studies are somewhat variable. However, for steelhead in particular and salmonids in general, the 50% emergence criterion indicates that sediment finer than 6.35 mm (0.25 in) should not be greater than about 30%. Again, measured streambed percentages should take into account the fact that some fines will be removed during the process of redd construction. An empirical relationship estimates the final percentage of sediment finer than 6.35 mm (0.25 in) as 0.58 times the initial percentage. Hence, samples with up to 52% sediment finer than 6.35 mm (0.25 in) would be predicted to have levels of about 30% after spawning. This empirical relationship has a relatively wide scatter, however, and the specific correction should be used with caution. In La Honda Creek, samples ranged between 3 and 30% sediment finer than 6.35 mm (0.25 in), suggesting that with a moderate removal of fines during redd construction, these gravels would not have an adverse effect on emergence. Overall, spawning conditions in terms of subsurface sediment size distributions in La Honda Creek appear to be suitable for steelhead, based upon sediment sizes reported in the literature and observed to be utilized elsewhere.

<u>Substrate Embeddedness</u>

Embeddedness is the degree to which a clast is surrounded by finer sediments. A highly embedded channel bed can be detrimental to spawning salmonids because it limits their ability to construct a redd, and detrimental to eggs and alevins because it limits the amount of oxygenated water that flows through the gravels. Embeddedness also reduces the bed roughness, causing faster water velocities, especially during flood.

Although not explicitly measured, gravel embeddedness was observed in many phases of data collection in La Honda Creek. For example, embeddedness was noted during a reconnaissance of the study area, and again during surface and subsurface sediment grain-size analyses. Larger clasts of gravel and cobble were commonly surrounded by sand and silt, making them very difficult to remove from the bed. These clasts had to be pried from the bed with a rock hammer. During sieving of the subsurface bulk sediment samples, sediment finer than 8 mm (0.32 in) often formed a cement-like slurry that stuck to the sieve pan, and had to be scraped out with a trowel. Although the grain size and distribution are appropriate for successful steelhead spawning, adult female steelhead may not be able to move the gravel and construct a redd due to the substrate embeddedness.

Landslides that impinge directly on the creek provide a fresh source of gravel that is loose enough initially for successful spawning. However, with time, the sediment becomes embedded, making redd construction more difficult. Although embeddedness is commonly caused by the deposition of fine sediment from the water column, the results of the turbidity measurements (see Section 4.5) and transport capability (see Section 6.3) indicated that detrital deposition of fine sediment is not a major cause of embeddedness in La Honda Creek. The embeddedness in La Honda Creek appears to be mainly due to in-situ breakdown of the mudstone clasts providing fine sediment that surrounds the larger clasts. This process is essentially self-driven; the fine sediment is primarily supplied from within the bed or deposit, rather than being supplied by fines deposited on top of the bed. As discussed in Sections 3.3, 6.3 and Figure 6-15, this process occurs when the clasts containing the clay mineral montmorillonite are exposed to continual wetting and drying. Despite occasional modification (during moderate to high flows) of the bed and sediment deposits, embeddedness will likely remain high due to this process. We expect salmonids to experience greater spawning success in years that fresh landslide-derived sediment is supplied to the channel compared to years where more embedded sediment is the only spawning option available.

Pools and Refugia

During migration and spawning, adults require refugia from high water velocities, and pools to rest and hide from predators. Also, migrating adult salmonids tend to avoid waters with high levels of turbidity (see Section 4.5). An appropriate number of pools and refugia appear to exist in La Honda Creek for adult spawners. In the seven sample reaches, 46 total pools were measured (Figure 6-21), with an average pool spacing less than one pool every five bankfull widths (Table 6-11), and pool residual depths ranging between 0.2 and 1.05 m (0.66 – 3.44 ft) (Figure 6-24). In addition, nearly 75% of all pools were either formed by or associated with a LWD piece (Figure 6-23). Although quantifying velocity shelters was not in the scope of this project, many shelters were observed, including LWD jams, large boulders, deep pools, irregular banks, and channel margins. Besides providing rest and cover, pools also provide a potential spawning location at their tail-out. Pool tail-outs are often chosen as spawning sites because the water is forced through the gravel as it exits the pool, ensuring oxygenation of the eggs and alevins, and removal of their metabolic wastes. The number of spawning locations available in La Honda Creek appears to be sufficient for salmonid success.

Migration Barriers

In the 5 km (3.1 mi) study reach length, no complete physical migration barriers were observed. The entire length of channel is likely accessible to steelhead during periods of flow higher than summer baseflow.

In the study reach, three double-box bridge culverts, one corrugated metal pipe culvert and two spanning bridges cross the channel. The culverts do not represent migration barriers because the channel maintains a natural gravel and cobble substrate through all four. The culverts are readily passable because they are gently sloped, at grade, and are not long enough to fully block out all sunlight, necessary to help migrating fish stay oriented (<46 m (150 ft) for new and replacement culverts, CDFG, 2002).

One concrete sill crosses the channel bed at Sackrete Bend pressure point (see Plate 1B), and forms a plunge pool. However, the pool is deep enough and the sill is low enough to allow fish passage.

An area of localized bed aggradation located at Riprap Bend pressure point approximately 50 m (164 ft) downstream of Delay's bridge (see Plate 1B) is a partial migration barrier during low flow. The bed has aggraded in the eddy of fallen of riprap, preventing natural channel sediment transport and modification. The riprap was intended to protect the road prism, however, the pieces have fallen into the centerline of the channel, where they now trap sediment. Channel flow disperses, and dives down into the aggraded gravels, leaving only a shallow thalweg during low flow. Although careful consideration is necessary in planning for the incision that would occur if these riprap pieces were removed, the new channel morphology that develops would likely improve salmonid migration through the reach.

Although outside of the study area, a reach in San Gregorio Creek, immediately downstream of the La Honda Creek confluence, may be affecting migration. Here, a substantial gravel bar, likely formed by the hydraulics of the confluence, significantly reduces the local surface water level in the creek, especially during low flow conditions. This bar may represent a partial migration barrier limiting access to La Honda Creek.

Riparian Vegetation

The continuity of riparian vegetation is important in spawning success because it shades the creek, maintaining the cool water temperature, provides protective cover, is a source for the recruitment of LWD, and stabilizes the banks. Although portions of the riparian vegetation along the La Honda corridor are threatened by landslides, and by impinging land uses, such as suburban development and Highway 84, overall, it is fairly continuous and of good quality.

Landslides in La Honda Creek often occur along an entire hillslope, bringing all the riparian trees and landslide debris into the channel. While this process removes segments of the riparian vegetation, typically the adjacent canopy is left intact. Housing and road development has only moderately reduced the canopy in the watershed, typically removing the canopy for 10 to 20 m (33 to 66 ft) along the channel. Because redwood and hardwood trees are abundant along the channel, the water temperature, amount of cover, LWD loads, and overall levels of bank stability appear to be suitable for salmonids.

Water Temperature

Water temperatures measured in La Honda Creek from December 2002 to October 2003 ranged from 4 – 20.2° C (39 - 68° F) (see Section 4.4). Salmonid egg development is highly dependant upon water temperature. Steelhead trout prefer temperatures of 3.9 – 9.4° C (39 - 49° F) for spawning, while coho prefer temperatures of 7.2 – 15.6° C (45 - 60° F) for adult migration and 4.4 – 9.4° C (40 - 49° F) for spawning (Flosi et al., 1998, Reiser and Bjornn, 1979). This data suggests that water temperature does not significantly limit salmonid spawning success in La Honda Creek.

6.6 SALMONID REARING HABITAT

Successful spawning is only the beginning of the salmonid life cycle; egg survival, alevin emergence and summer rearing all affect successful reproduction. Steelhead eggs hatch in about 31 days at 10° C (50° F) while coho eggs hatch in about 50-60 days depending on temperature (Flosi et al., 1998). Salmonids hatch as alevins and spend the first two to four weeks in the channel bed gravel before emerging into the stream. The young coho typically spend one year, and young steelhead spend between one and two years in the stream. During this time, the salmonids feed primarily on aquatic insects and other benthic macroinvertebrates in riffles, and grow until they reach lengths adequate to out-migrate to the ocean. Summer rearing requires appropriate habitat elements such as appropriate water temperatures, adequate numbers and depths of pools, appropriate cover elements, maintained flow over riffles and water levels.

Optimal temperatures during juvenile rearing range from 7.2 – 14.4° C (45 - 58° F) for steelhead and 11.7 – 14.4° C (53 - 58° F) for coho (Flosi et al., 1998, Reiser and Bjornn, 1979). Water temperatures measured in a perennial shaded pool in La Honda Creek vary between 4 – 20.16° C (39 - 68° F) for the period December 2002 to October 2003. Through the summer months, especially the critical months of August through October, the water temperature was 20° C (64° F) or higher for only a total of three hours in two separate days.

Rearing habitat in La Honda Creek

Salmonid rearing depends on the success of adult spawners and the survival of eggs until hatched. Juvenile salmonids require a series of habitat elements, many of which are similar to requirements for spawning. Based upon the data collected, it appears that La Honda Creek provides adequate rearing habitat for salmonids with the main limitation being food resources that are affected by low summertime flows and embeddedness, and potentially overall water quality.

Benthic Macroinvertebrates

Besides providing cool, oxygenated water, perennial discharge, especially over riffles also provides a source of food for rearing salmonids. Juvenile salmonids are dependant upon the aquatic insects and benthic macroinvertebrates (BMI) carried in from the riffles to the pools. These BMIs are the primary source of food; if water levels remain high enough to support and transport BMI populations, the juveniles will have an ample food source and will grow rapidly. In streams with low summer flows, food is limited, causing salmonids to grow very little during the summer, and typically require a longer period of time before being able to migrate to the ocean (Koehler, 2003). The success of rearing salmonids in La Honda Creek is partially dependant upon maintaining summer flow levels. Currently adequate summer flow is maintained, but changes in the amount of water directly withdrawn from the creek, or groundwater usage could potentially affect these levels.

BMIs are also affected by embeddedness; in channels with greater embeddedness, BMIs are less successful in colonizing and inhabiting the interstitial spaces of the sediment. Both numbers and diversity of BMI populations should be negatively affected by greater embeddedness. Although La Honda Creek is fairly embedded, the BMI population is only slightly affected. Data collected in the winter of 2002 and spring of 2003 suggest that the population is fair (see Section 5). A gradient in the physical habitat does exist in the study reach, with the upstream portion being less embedded than the downstream portion. Possibly this gradient allows enough BMI success to support the population, and provide a large enough food source for rearing salmonids. Or potentially the ability of the channel to transport sediment in a modest flow event is enough to overcome the continual in-situ breakdown of mudstone clasts, which is contributing to the levels of embeddedness. Even occasional modification of the bed might be enough to allow the BMI population to recover from difficult conditions. Alternatively, the BMI community in La Honda Creek could have evolved with this high level of embeddedness, and now has a greater ability to survive, despite the conditions.

Pools

Data collected on the number and spacing of pools suggest that an adequate number of pools exist in La Honda Creek. Measured pool residual depths show that a wide range of pool depths are present in La Honda Creek. While some shallow (approximately 0.2 m or 0.66 ft) and some deep (greater than 1.0 m or 3.3 ft) pools exist, the majority of pool residual depths are between 0.3 and 0.7 m (0.012 and 0.028 ft). Pools of these depths tend to persist all summer long, provide enough habitat volume, maintain cool temperatures, and help provide cover from predators. In addition to water depths, other escape or cover elements are provided by large boulders, undercut banks and LWD pieces. Shade provided by LWD and live upright trees keeps water temperatures cool, however, too much shade can reduce photosynthesis in-channel and affect juvenile's ability to locate food. In general, a 75 to 90% canopy cover is desirable for streams along the central coast of California (Koehler, 2003), which is generally consistent with the cover observed in La Honda Creek.

Large Woody Debris

Based upon our observations and measurements of LWD pieces, including live downed trees and riparian live upright trees that affect flow within the bankfull channel, the amount of LWD present in La Honda Creek appears to be suitable for both the in-channel and riparian functions. One of the most important cover elements for salmonids is the cover provided by LWD in pools that are either formed by or associated with LWD pieces. And because a large number of the in-channel pieces are either redwoods or conifers, these pieces are likely to have a long residence time, continuing to provide cover for many seasons. Also, the nearly continuous riparian canopy provides an ample source for the recruitment of future LWD pieces. The large number of landslides along the creek also contributes to the continual input of LWD pieces to the channel. However, discussions with many different landowners have confirmed that LWD removal occurs to prevent flooding, and to protect bridges and other structures. Limiting LWD removal to only the pieces necessary to protect houses, structures or roads will ensure that cover, complexity and scour elements important for rearing habitat will continue to be provided to the channel.

Water Temperature and Quality

When compared to published temperature ranges for successful salmonid rearing, data collected in La Honda Creek suggest that shaded pool locations that maintain appropriate water temperatures throughout the summer exist. Temperatures are slightly above the upper limits of published ranges, but are likely still acceptable due to thermal stratification of the water column. The localized influence of cooler groundwater inputs to the stream, and the degree to which pools thermally stratify is unknown. While some individual pools may be isolated from flow, or subject to direct sunlight (typically associated with landslide-derived openings in the canopy), the majority of the creek is well shaded, with flow maintained throughout the summer and fall. These conditions suggest that water temperatures in La Honda Creek are not a limiting factor for rearing steelhead or coho salmon.

Although measuring water quality was beyond the scope of this project, local degraded water conditions that probably negatively impact salmonid viability were noted during late spring, 2003. Because the creek is near the highway, large bags of household and commercial trash had been thrown over the road into the creek. Liquids were also dumped: the bed of one pool and riffle was completely coated with a dark, hydrocarbon substance, probably an oil-based paint. Septic smells and soap/detergent bubbles were evident in a few locations directly downstream of creek side residences. Although steep hillslopes and channel banks prevent cattle from reaching the channel directly, runoff from grazed hillslopes flows into the creek. Several, localized areas of dense algal growth were probably due to nutrient loading by this or other processes.

6.7 CONCLUSIONS

La Honda Creek is not a typical self-forming alluvial channel, nor is it a purely resistant boundary (bedrock) channel. Instead, La Honda Creek appears to be a combination of the two end-member channel types, in which locations where landslides provide large amounts of sediment function more like an alluvial channel, but with the majority of the reach functioning most like a resistant boundary channel. Within the study reach, channel slopes vary from 1.16 to 2.44%, with channel cross sections reflecting the localized bedrock and sediment supply conditions. A total of 7,750 m^3 (10,143 yd^3)of active sediment is currently in storage in the seven sample reaches, with most stored in bars. Most of the stored sediment has been deposited recently (in the past 10 years), reflecting the relative mobility and efficient sediment transport capabilities of the creek. Pool deposits are not significant throughout the entire study reach length. The deposits are significant in a few pools, but are only temporary, before the pool is scoured and the deposit is transported further downstream. Surface grain size distributions reveal median grain sizes that range between 10 and 26 mm (0.39 – 1.02 in) in the sample reaches, with distributions reflecting the underlying geologic lithology. The bed of La Honda Creek is moderately embedded, due primarily to the in-situ breakdown of mudstone clasts during wetting and drying associated with variable discharges.

A total of 46 pools are measured in the seven sample reaches, with average pool spacing less than one pool every five bankfull widths, and typically, less than every three bankfull widths. Three quarters of these pools are either directly formed by, or are associated with large woody debris (LWD). Riparian canopy is nearly continuous throughout the reach, providing many benefits for aquatic habitat, as well as providing a source for recruitment of LWD pieces to the channel. Each study reach contains between 10 and 30 LWD pieces, with one reach containing nearly 100 pieces in a single LWD jam. Average LWD loadings vary between 54 and 655 m^3/km in La Honda Creek.

The spawning and rearing habitat provided by La Honda Creek appears to be adequate to support populations of both steelhead and coho salmon. Habitat elements essential to spawning include: flows for in- and out-migration, suitably-sized spawning gravel distributions, low levels of fine sediment, low gravel embeddedness, refugia from high water velocities, pools for spawners to rest or hide, lack of migration barriers, LWD pieces for cover, cool water temperatures, hydraulic locations for spawning. Of these elements, gravel embeddedness is probably the factor most responsible for limiting salmonid success. Specific habitat elements are required for salmonid rearing success, however many overlap with the spawning requirements. These elements include: maintained flow over riffles, perennial water levels, adequate numbers and depths of pools, appropriate water temperatures, and appropriate cover elements. Again, embeddedness and low seasonal flows may be reducing the success of benthic macroinvertebrates (BMIs), the food source for rearing salmonids. Besides the fair population of BMIs, all other geomorphic data suggests that La Honda Creek is currently providing adequate rearing habitat.

Despite the quality and quantity of habitat in La Honda Creek, the success of these fish may be more limited by the conditions in San Gregorio Creek. Any spawning or rearing that occurs in La Honda would require the adults to survive a journey of approximately 19 km (11.8 mi) from the ocean, up San Gregorio Creek, to the mouth of La Honda Creek. A number of potential limiting factors could exist in San Gregorio, including migration barriers, inadequate water quality or temperatures, lack of cover elements, or high rates of predation. We recommend that these issues be studied before resources are spent on improving and maintaining habitat in La Honda Creek.