SECTION FOUR:

HYDROLOGY

4.1 GENERAL STATEMENT

The discharge section describes rainfall-runoff relationships that affect the amount of water routed through La Honda Creek. The discharges carried by the creek directly affect the stability of channel banks and slopes, and thus, Highway 84 and other adjacent structures, as well as affecting the habitat provided for aquatic organisms and salmonids. These discharges affect the mobility of sediment, the ability to modify channel geometry, and control the amount of scour, incision, and bank erosion in any given event.

4.2 PRECIPITATION

Existing information on rainfall was analyzed and new data were collected to understand 1) the flood characteristics of La Honda Creek, 2) the relationship between rainfall and the occurrence and triggering of landslides adjacent to Highway 84, and 3) the relationships between rainfall and the perennial flow that is important to salmonids.

Annual Rainfall for La Honda Creek

The La Honda station (044660), discontinued in 1977, was located midway up the watershed. Due to its location and high data quality, this station was chosen for a detailed analysis of the rainfall character of the watershed. For the period of record (1950-77), annual rainfall for a water year (October 1-September 30) varied from 330-1235 mm (13.0-46.8 in) and averaged 742 mm (29.2 in). Data from other watersheds in the Bay Area suggests that this period does not represent the expected long-term variability (about 42-200% of normal) (McKee et al., 2002). Annual rainfall correlates well within local areas. However, due to microclimates and rain shadows caused by relief and aspect relative to storm tracks, relationships between disparate locations are not always good.

Regional relationships were found between La Honda, San Gregorio (047807), Santa Cruz (047916), and Half Moon Bay (043714). Estimates of annual rainfall were generated using regression analysis (Dunne and Leopold, 1978) for a 70-year period 1933-2002 (in this section actual data is referenced by gauge name and gauge number, while data derived by regional regression is referenced by gauge name only). The water year rainfall for this period was estimated to range from 330-1469 mm (13.0-57.8 in or 44-183% of normal) and average 794 mm (31.3 in) (Figure 4-1). This data was plotted using a log Pearson Type III probability distribution (Figure 4-2). A line of best fit was drawn by eye and used to estimate the probability of exceedence and return interval for annual rainfall (Table 4-1). Based on the regression model, La Honda is estimated to have had 916 mm (36.1 in) of rain during WY 2003 with a return period of about 3.3 years on the annual series.

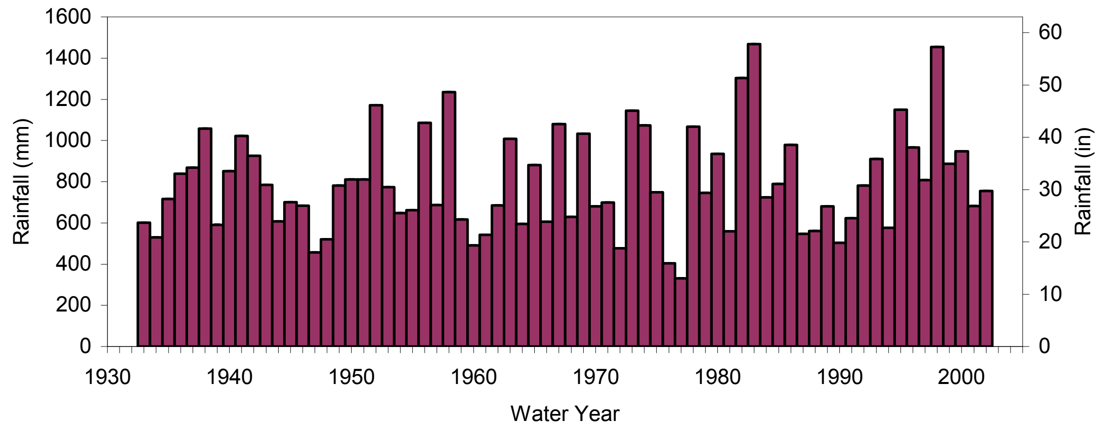

Figure 4-1. Estimated annual rainfall for La Honda Creek for the period WY 1933-2002. The average annual rainfall is 794 mm (31.3 in).

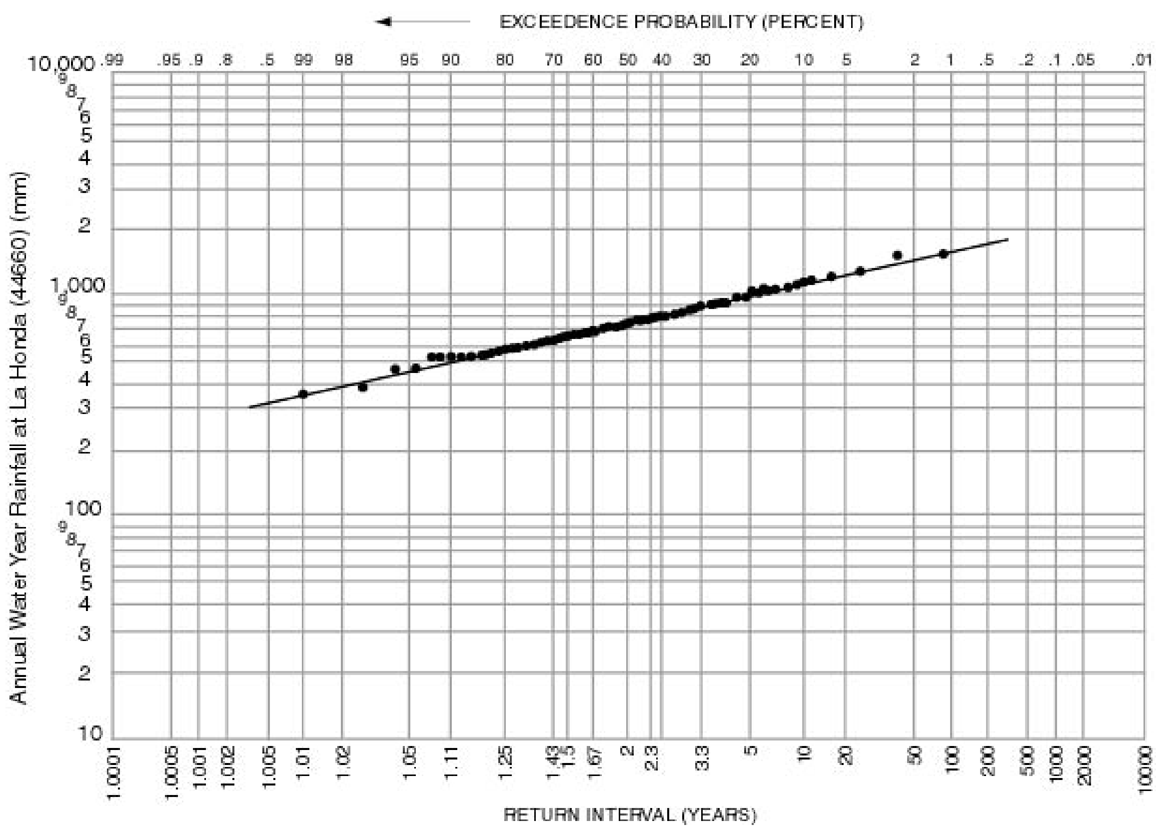

Figure 4-2. Recurrence of annual water year rainfall in La Honda Creek.

Table 4-1. Probability of exceedence of annual rainfall for the La Honda Creek watershed.

Probability of exceedence (%)	Return interval (years)	Rainfall (mm)	Rainfall (in)
50	2	750	29.5
20	5	1020	40.2
10	10	1100	43.3
5	20	1200	47.2
2	50	1400	55.1
1	100	1500	59.1

To better understand the periodicity of annual rainfall, annual deviation from the mean was calculated (Figure 4-3). La Honda Creek typically undergoes successive years of lower than average rainfall; the longest period was the seven years of 1943-1949. Recently a severe drought occurred from 1987 to 1991. During drought periods, greater competition for the water resource in La Honda Creek might limit the success of salmonids, especially if perennial flow ceases or water quality is compromised. In contrast, successive years of greater than average rainfall have lasted only for a maximum of three years. These wetter periods are of particular concern to the transportation engineer because of the build up of antecedent soil moisture and associated decrease in soil strength and increased potential for landslide failures. Changes in salmonid habitat occur during wetter years, including changes in bar geometry, volume of sediment storage, and changes in thalweg elevation and gravel embeddedness.

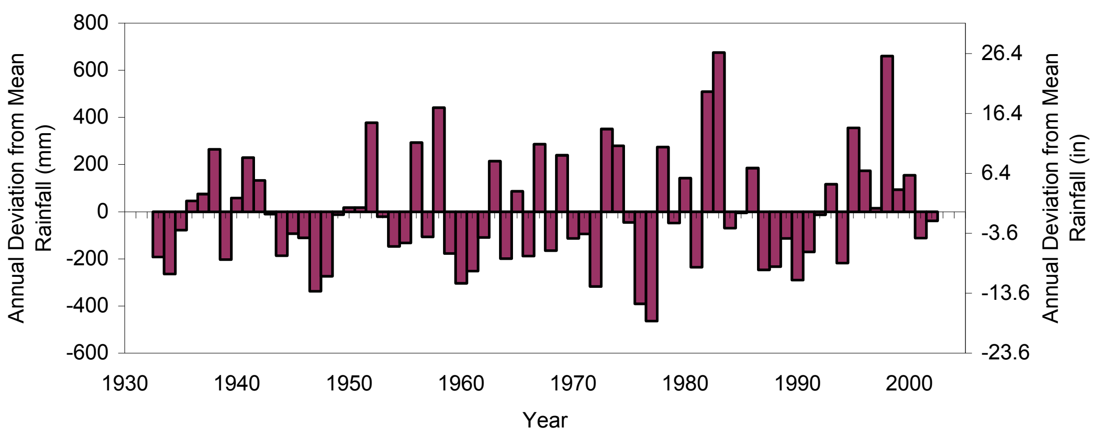

Figure 4-3. Annual deviation from the mean rainfall (794 mm) for La Honda Creek.

Seasonal Rainfall

Analyzing seasonal rainfall patterns clarifies rainfall-runoff relations and the seasonality of discharge. The Coast Ranges of central California have a Mediterranean-type climate, with cool, wet winters and warm, dry summers. On average, most (86%) precipitation occurs between November and April (Table 4-2), and is concentrated between December and February (Figure 4-4). During the 28 years of record for La

Honda (044660) (1950-77), 43 months had no rainfall (about three months every two years). The longest period with no rainfall was four months during the summer of 1960. Given the seasonality of rainfall, most groundwater recharge occurs during the winter, and so years with dry winters are likely to have highly diminished dry season flow. This will be explored further in the section on runoff.

Table 4-2. Seasonal distribution of rainfall for La Honda (044660) 1952-1977.

	Rainfall (mm)	Rainfall (in)	Portion of Annual (%)	Accumulative (%)
Nov	48	1.90	6.5	6.5
Dec	97	3.80	13.0	19.5
Jan	126	4.95	16.9	36.4
Feb	153	6.02	20.6	57.0
Mar	112	4.43	15.1	72.2
Apr	103	4.07	13.9	86.1
May	57	2.24	7.6	93.7
Jun	19	0.74	2.5	96.3
Jul	8	0.32	1.1	97.3
Aug	3	0.11	0.4	97.7
Sep	5	0.19	0.7	98.4
Oct	12	0.47	1.6	100
Annual average	742.4	29.2		

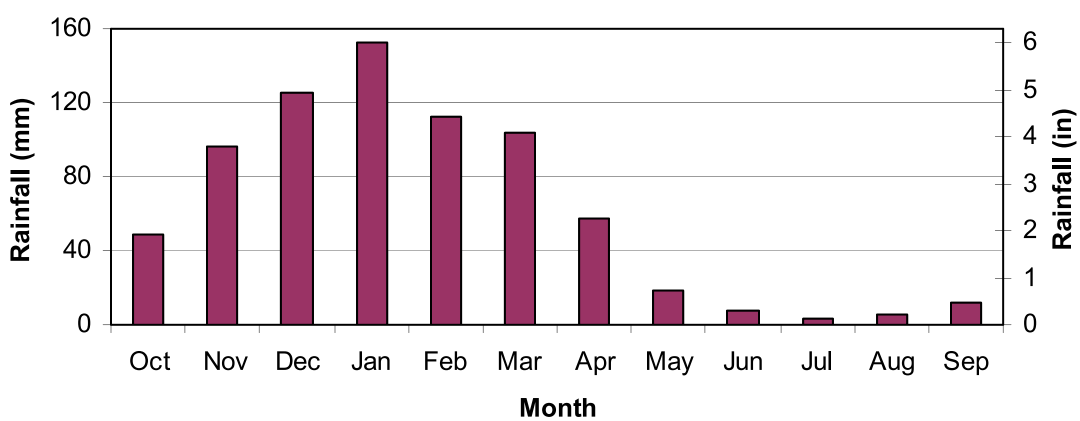

Figure 4-4. Average monthly rainfall totals for La Honda (044660) for the period 1952-1977.

Daily Rainfall

Understanding rainfall patterns at the time scale of days is particularly valuable because of the relationship between rainfall and runoff. During and immediately after a rain event, runoff is the fastest and most significant contributor of water to the creek. Large volumes of runoff cause higher stages in the creek, resulting in more stream power to modify the channel banks and bed. The amount of runoff depends on antecedent soil moisture and short-duration rainfall of high intensity. However, rainfall depth in the preceding 1-10 day period certainly accounts for some of the runoff signal especially later in the winter season during the largest floods on record, when the soil is saturated. Most rainfall statistics in the Bay Area are gathered using daily measurement. The time of measurement between locations depends on the observer's schedule; there is no agency standard. Daily rainfall records for La Honda Creek do not exist; however, daily rainfall is available for the San Gregorio gauge (047807) from January1, 1954 to present. Because a close correlation between San Gregorio and La Honda Creek has been established on an annual precipitation basis, an analysis of the San Gregorio daily rainfall was performed with the belief that the results would be reflective of that which would occur on La Honda Creek (Appendix Z). The results of this analysis found that there is no consistent relationship between rainfall at San Gregorio in the day or several days before a discharge peak. This is at least in part because the rain gauge at San Gregorio does not represent the upper watershed. As a result, this conclusion may or may not be true of La Honda Creek. However, it can generally be said that the La Honda Creek runoff magnitude is influenced by a combination of antecedent conditions, rainfall magnitude and intensity, and local variations in rainfall across the watershed.

Hourly Rainfall and Rainfall Intensity

Hourly rainfall data are collected by the California Department of Forestry in La Honda (LAH) to predict fire danger. Although data have been collected since March 1987, there are virtually no data from March 1987 to October 1989, and the record from October 1989 to present is patchy. Data for the winter of 2002 / 2003 were analyzed rigorously to determine the data quality. No consistent relationship was found between rainfall recorded in La Honda (LAH) and rainfall at San Gregorio (047807). Nor was there a relationship between rainfall in La Honda and discharge recorded at Delay's bridge, yet rainfall at San Gregorio did predict the occurrence of flood flow (not the magnitude). For purposes of hydrological modeling the La Honda (LAH) rainfall data overall is unreliable and therefore of little use for modeling, even on a storm-by-storm basis.

In the absence of a suitable hourly data set of high quality, we estimated rainfall depth, duration, and frequency using regional relationships (Rantz, 1971a) and the estimated mean annual rainfall for La Honda (794 mm or 31.3 in) (Table 4-3). During large storms such as in 1982 and 1998 rainfall intensities of > 2.5 cm/hr (>1 in/hr) and >15 cm/day (>6 in/day) probably occurred. Yet the rainfall record in La Honda (LAH) showed a maximum rainfall intensity of 0.9 cm/hr (0.36 in/hr) and 6.5 cm (2.55 in) during the 1998 event for the 24-hour period, another indication of the low quality of the record.

Table 4-3. Estimated depth-duration-frequency of rainfall at La Honda based on a long-term average rainfall of 794 mm (31.3 in).

	Frequency											
	2-year		5-year		10-year		25-year		50-year		100-year	
Duration	**(mm)**	**(in)**	**(mm)**	**(in)**	**(mm)**	**(in)**	**(mm)**	**(in)**	**(mm)**	**(in)**	**(mm)**	**(in)**
1 hour	14	0.57	18	0.73	22	0.86	26	1.01	28	1.09	30	1.17
2 hours	22	0.87	28	1.09	31	1.21	35	1.37	37	1.47	40	1.58
3 hours	28	1.12	35	1.37	40	1.57	44	1.73	47	1.86	51	1.99
6 hours	45	1.78	58	2.28	65	2.57	73	2.86	78	3.08	83	3.28
12 hours	65	2.57	82	3.22	92	3.61	102	4.02	111	4.38	119	4.68
1 day	84	3.32	111	4.36	129	5.08	151	5.96	168	6.63	183	7.20
2 days	110	4.32	153	6.03	182	7.18	218	8.58	242	9.52	269	10.61
5 days	147	5.77	206	8.11	238	9.36	285	11.23	317	12.48	349	13.73
10 days	194	7.64	262	10.30	301	11.86	349	13.73	380	14.98	412	16.22

4.3 DISCHARGE

Channel discharge determines the amount of energy or power the creek has to do work. Although most of a creek's power is spent on internal friction of the water particles moving past one another, some power remains to carry sediment or modify the creek's channel geometry. Determining the sediment size that is potentially mobile, and understanding the stability of specific bank locations requires knowing the runoff characteristics under a range of climatic conditions. Describing runoff character is best achieved through developing stage-discharge relationships and analyzing the frequencies or return periods of discharges at magnitudes pertinent to a given application. The following sections describe discharges ranging from annual return events (mostly of interest because of the influence on anadromous fish habitat) to 100-year return events that profoundly influence bank and slope stability and the integrity of Highway 84. With the exception of measurements made during the present study, there is no information available of discharge of water through the La Honda Creek study reach. Water discharge character is described in Appendix AA for the larger San Gregorio watershed to provide context and calibration for the sub-watershed of La Honda Creek.

La Honda Creek Estimated Runoff Magnitude-frequency Relationships

Four named tributaries, Woodhams, Langley, Woodruff and Weeks Creeks, contribute water to La Honda Creek (Table 4-4). The volume of water contributed by each tributary is proportional to the rainfall received and the area. The behavior of water within each tributary greatly affects the nature of flows in La Honda Creek.

Table 4-4. Contributing area of each tributary or portion of the La Honda Creek watershed.

Tributary Name	Area (km^2)	Area (mi^2)
La Honda Creek upstream of Weeks Creek confluence	10.68	4.12
Weeks Creek	2.65	1.02
La Honda Creek upstream and inclusive of Weeks Creek	13.33	5.15
Woodruff Creek	7.85	3.03
La Honda Creek upstream and inclusive of Woodruff Creek	21.94	8.47
Langley Creek	1.12	0.43
La Honda Creek upstream and inclusive of Langley Creek	23.59	9.11
La Honda Creek upstream of Delay's Bridge	25.11	9.70
Woodhams Creek	2.21	0.85
La Honda Creek upstream and inclusive of Woodhams Creek	27.37	10.57
La Honda Creek upstream of Applejack's	28.23	10.90
Entire La Honda Creek Watershed	29.74	11.48

Measures or estimates of discharge and flow recurrence intervals are necessary to understand how these discharges might affect engineered structures along the La Honda Creek Highway 84 corridor. Although data for La Honda Creek are lacking, the runoff character can be estimated from regional relationships (Table 4-5) of annual rainfall and the area draining to the point of interest (Rantz, 1971b).

Using the regression equations in Table 4-5, the discharge estimated at given recurrence intervals for San Gregorio and Pescadero compares closely to the actual data (Appendix AA). Therefore, the regional relationships developed by Rantz appear to be useful for estimating discharge in La Honda Creek. At Delay's bridge (Post mile SM9[34] on Highway 84), the discharge for a flood with a 50 and 100-year return period is estimated to be 85 and 113 m^3/s (3,000 and 4,000 cfs) (Figure 4-5).

Table 4-5. Regional magnitude-frequency relationships for watersheds in the Bay Area (after Rantz, 1971b).

Return Interval	Multiple Regression Equation	Coefficient of Multiple Correlation
2	$Q_2 = 0.069\ A^{0.913}\ P^{1.965}$	0.964
5	$Q_5 = 2.00\ A^{0.925}\ P^{1.206}$	0.976
10	$Q_{10} = 7.38\ A^{0.922}\ P^{0.928}$	0.977
25	$Q_{25} = 16.5\ A^{0.912}\ P^{0.797}$	0.950
50	$Q_{50} = 69.6\ A^{0.847}\ P^{0.511}$	0.902

Note: Q = discharge (cfs);
A = Drainage Area (mi^2);
P = Mean Annual Basin-wide Precipitation (in).

Measuring Discharge, La Honda Creek

Water velocity was measured in La Honda Creek during WY 2003 to develop a stage-discharge relationship. The study area was reconnoitered during October 2002 to locate a suitable site for measurement. The criteria for selection included worker safety, stable cross-sectional geometry, proximity to Highway 84, and access to a structure that does not constrict flow appreciably and from which measurements can be made when the stream cannot be waded. A small, private bridge owned by Mr. Ari Delay near Post mile SM9[34] on Highway 84 was selected as the best location. Figures 4-6 through 4-9 show Delay's bridge and the nature of La Honda Creek in the vicinity of the bridge.

A nine-foot, ceramic-coated staff gauge (graduated to hundredths of feet) was secured to the downstream side of the right bank concrete footing of Delay's bridge (Figure 4-10). The bottom of the gauge was placed at the sediment interface, although the thalweg of the channel is at a lower elevation than the bottom of the staff gauge. The concrete bridge footings generally align with the flow direction, provide a stable channel cross-section at discharges up to 2.2 m (9 ft) (Figure 4-11), and allow easy measurement of stage.

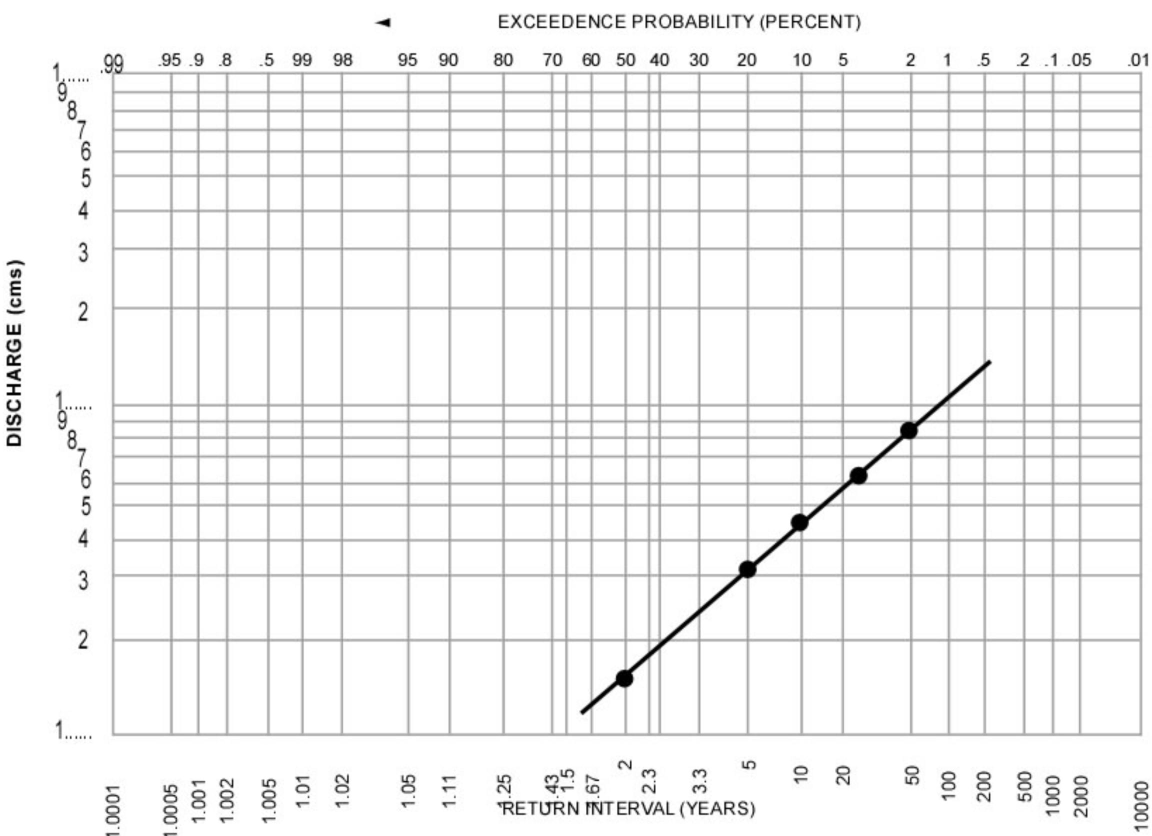

Figure 4-5. Estimated magnitude and frequency of discharge (m^3/s) at Delay's bridge (Post mile SM9[34] on Highway 84) based on regional regressions relationships (Rantz (1971b).

Figure 4-6. Downstream face of Delay's bridge looking upstream.

Figure 4-7. La Honda Creek channel upstream of Delay's bridge.

Figure 4-8. La Honda Creek channel downstream of Delay's bridge.

Figure 4-9. Right overbank of La Honda Creek channel upstream of Delay's ridge.

Figure 4-10. Photo of staff gauge at Delay’s bridge. Stage is approximately 0.6m (1.5 ft), exposing 2.3 m (7.5 ft) of the gauge. Flow is from right to left.

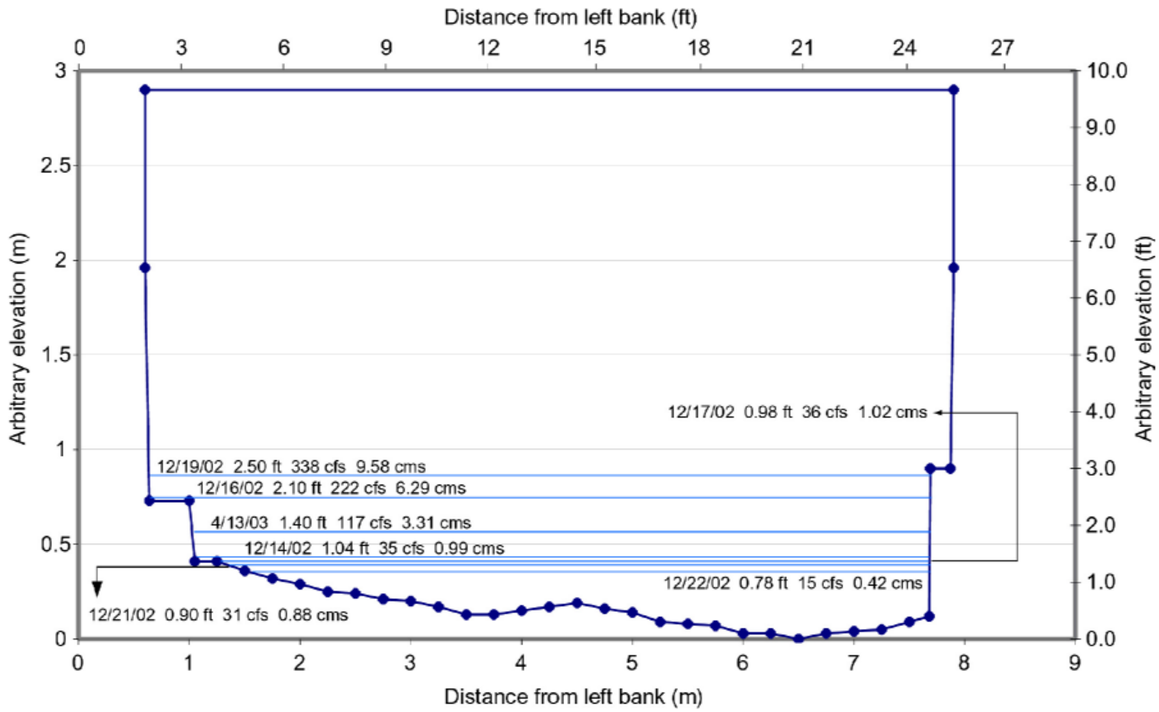

Figure 4-11. Cross-section geometry measured at Delay's bridge. Cross-section is oriented looking downstream. Staff gauge is placed on the right bank bridge footing. Lines show the stage and calculated discharge for each observation.

The channel cross-section was surveyed using a Sokkia C3A self-leveling optical level and stadia rod. Data were measured in English units (feet) conforming to USGS standards. The cross-section (measured perpendicular to the staff gauge) provides a precise measure of channel area, and allows changes in the bed elevation (scour or deposition) to be measured (Figure 4-11). The cross-section was divided into 0.3 m (1-ft) wide "cells" to cover the entire width of the cross-section between bridge footings. The cells begin at zero at the left bank, and increase toward the right bank. A water depth and velocity were measured at the center of each "cell".

For wadeable stages, typically 0.5 m (1.5 ft) or lower, channel discharge was measured using a Marsh-McBirney flow meter and top-setting rod. Velocity was measured three times at 10-second intervals, and the average was recorded as the velocity for that cell. At stages >0.5 m (> 1.5 ft), velocity and depth data were measured from the bridge. A USGS bridge-board, Canfield sounding reel (calibrated in tenths of feet), and 13.6 kg (30 lb) sounding weight (Figure 4-12) were used to lower the Marsh-McBirney flow meter into the water column (Figure 4-13). Data were collected in the same cells using the same methods.

Figure 4-12. Left: Marsh-McBirney flow meter. Right: USGS bridge board, Canfield sounding reel, and 13.6 kg (30 lb) sounding weight used to measure water velocity.

Figure 4-13. The equipment in action, Delay's bridge.

A number of storms occurred during WY 2003. The first occurred on November 7, 2002 when 52.6 mm (2.07 inches) of rain fell over a two-day period (measured at San Gregorio (047807)). During this storm La Honda Creek sustained a 152 – 203 mm (6-8 in) rise in stage. No discharge measurements were made on this occasion. Velocity measurements were made at a variety of stages during subsequent storms (Table 4-6). The discharge versus stage relationship is plotted on a linear scale, forming a well-defined rating curve for this location (Figure 4-14). For stages between 0.21 and 0.76 m (0.7 and 2.5 ft), discharge appears to have a linear relationship. The highest observed stage at Delay's bridge (0.88 m or 2.9 ft) during the 2002/2003 wet season occurred early in the morning on December 16, 2002. During the storm of February 1998, water overtopped Delay's bridge reaching a stage exceeding 3.4 m (11 ft) (Ari Delay, pers. communication, November 2002). It is unclear if the stage-discharge relationship remains linear at higher stages or has another function.

Table 4-6. Storms during the wet season of WY 2003.

Date	Rainfall at San Gregorio (047807) in the Preceding 48-Hours [mm (in)]	Velocity Measurements on Each Day (n)	Maximum Stage [m (ft)]
12/14/2002	121 (4.75)	3	0.32 (1.04)
12/16/2002	60 (2.38)	2	0.64 (2.10)
12/17/2002	59 (2.33)	1	0.30 (0.98)
12/19/2002	32 (1.26)	1	0.76 (2.50)
12/21/2002	17 (0.68)	1	0.27 (0.90)
12/22/2002	8.6 (0.34)	1	0.24 (0.78)
04/13/2003	2.5 (0.10)	3	0.43 (1.40)
		12	

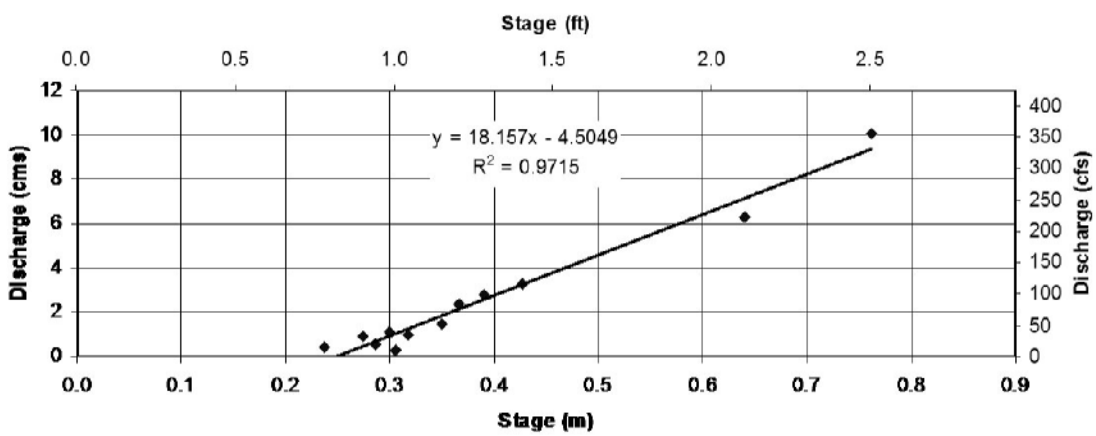

Figure 4-14. Rating curve showing discharge (cms) versus stage (m) at Delay's bridge.

In the absence of velocity measurements at stages greater than 0.76 m (2.5 ft), the stage-discharge relationship was extrapolated using the Manning Equation (Equation 1). Manning's Number (n), a measure of channel roughness, was estimated to be 0.05 based on field indicators. The cross sectional area (A) for a given stage was calculated from the cross-section measured in the field. Water surface slope was approximated by measuring the local bed slope (0.019). Given that Delay's bridge somewhat constricts the channel cross-section, the water surface slope will be less than local channel slope but it is unknown by how much. Discharge estimates were calculated for a given stage using water surface slopes ranging from 0.015 to 0.019 (Table 4-7).

Manning's Equation

$$Q_h = 1.49 \frac{1}{n} A_h R_h^{2/3} S^{1/2} \quad (1)$$

Q_h = Discharge (cfs) at a given stage (h)
n = Manning's number
A_h = Cross-section area at a given stage (h)
R_h = Hydraulic Radius at a give stage (h) = Area divided by wetted perimeter
S = Water Slope

Table 4-7. Stage-discharge rating table for Delay's bridge based upon data collected during WY 2003 and estimates of discharge using Manning's Equation.

Stage (ft)	**Measured Discharge [m3/s (cfs)]**	**Estimated Discharge [m3/s (cfs)]**		
		Slope (S) = 0.015	**(Best estimate) Slope (S) = 0.017**	**Slope (S) = 0.019**
1.0	1.99 (35)			
1.5	3.85 (136)			
2.0	6.68 (236)			
2.5	9.57 (338)			
3.0		13.4 (474)	14.3 (505)	15.1 (534)
5.0		29.6 (1046)	31.5 (1113)	33.3 (1177)
7.0		49.5 (1748)	52.7 (1861)	55.7 (1967)
9.0		72.2 (2550)	76.8 (2714)	81.2 (2870)

Estimates of discharge using Manning's equation were made for stages of 2.74 m (9 ft) or less because above 2.74 m (9 ft) the bridge is inundated. At 2.74 m (9 ft) of stage, a small amount of flow would run across the roadway outside the bridge abutment. This was not taken into account for the calculations using Manning's Equation and therefore, the discharge at high flow is slightly underestimated. La Honda Creek is capable of at least another 0.9 m (3 ft) of stage at Delay's bridge (Ari Delay pers. comm., November 2002). The choice of Manning's number (n) based on field indicators was tested by back-calculating the discharge measurements from WY 2003. At stages greater than 0.5 m (1.5 ft) the calculated "n" stabilizes at 0.048-0.057 suggesting that the choice of 0.05 is appropriate.

Published relationships between drainage area and discharge for the Bay Area based upon a 0.8 m (30 in) annual rainfall (Leopold, 1994) were used to estimate a discharge on a 1.5-year recurrence interval (bankfull discharge). Using this method, an estimate of ~12.7 m^3/s (~450 cfs) was calculated for the Creek at Delay's bridge. This corresponds to a stage of (0.76 – 0.91 m (2.5-3.0 ft) and compares closely with field indicators of bankfull (see Section 6). Using regional relationships (Rantz, 1971b) (Figure 4-5) an estimate of 1.5-year recurrence interval discharge is ~10.8 m^3/s (~380 cfs). A comparison of estimated discharge versus stage (Table 4-7) with discharge versus frequency (Figure 4-5) suggests that a stage of 2.74 m (9 ft) at Delay's bridge would have a recurrence interval of 40-45 years. The 1998 flood, which overtopped the bridge bed, has an estimated recurrence interval of 50 years (Figure 4-9). The accuracy of estimated discharge versus stage at Delay's bridge appears to be supported by the other, independent methods.

These preliminary measures and estimates of discharge provide data that are valuable indicators of the hydraulic environment that bank stabilization structures, bridges, and other structures along the Highway 84 corridor may be subject. As illustrated by the data and landowner observations, La Honda Creek is capable of routing discharges with stages in excess of the height of many existing structures along the creek. These discharges are capable of causing major changes in channel cross-sectional morphology, undermining stream-side structures, and potentially causing large areas of bank instability.

Although beyond the scope of this investigation, a detailed WMS hydrologic analysis should be performed prior to attempting any kind of design. The results of this analysis should then be used in conjunction with supplemental cross section data to develop a HEC RAS model of La Honda Creek. The model would be used to perform a detailed hydraulic study of La Honda Creek under various storm frequencies, particularly the 50- and 100-year storms, which cause pressure flow conditions at Delay's bridge.

4.4 WATER TEMPERATURE

Water temperatures vary greatly with season, air temperature, amount of sunlight reaching the water surface, runoff, and depth and flow velocity. A continuous measure of water temperatures in the channel allows a better understanding of the quality of aquatic habitat provided. The health and survival of many aquatic species, especially cold-water fish, depends upon the water temperature. For example, many physiological and behavioral processes are affected by temperature, including: metabolism; food requirements; growth rates; development of embryos and alevins; timing of life-history events; competitor and predator-prey interactions; and disease-host and parasite-host relationships (Spence et al., 1996). Ideal temperatures for rearing juvenile steelhead should be below 20°C (68° F). Temperatures above 24 - 27° C (75 - 81° F) severely stress steelhead, and are often fatal. Temperature requirements vary between species, and for different life stages within a single species (Table 4-8).

Table 4-8. Temperature ranges for steelhead trout and coho salmon. After Flosi, et al., 1998 and Reisner and Bjornn, 1979.

This study	Species	Adult Migration	Spawning	Incubation	Juvenile Rearing
4 – 20° C (40 – 68° F)	**Steelhead**	-	3.9 – 9.4ºC (39 – 49ºF)	-	7.2 – 14.4ºC (45 – 58ºF)
	Coho salmon	7.2 – 15.6ºC (45 – 60ºF)	4.4 – 9.4ºC (40 – 49ºF)	4.4 – 13.3ºC (40 – 56ºF)	11.7 – 14.4ºC (53 – 58ºF)

Continuous water temperatures were measured in La Honda Creek at Delay's bridge. The location is in the thalweg of the upper third of a pool that has perennial flow, has ample shading, is not affected by direct groundwater inflows, and generally represents average conditions. A continuous temperature sensor (Hobo Optic StowAway Temp sensor, Onset Computer Corporation) (Figure 4-15) was placed in a steel tube with holes drilled for continual water through-flow, and anchored to the abandoned bridge footing immediately upstream of Delay's bridge (Post mile SM9[34]). The sensor remains in the water column during all flow levels, while being protected from LWD and bedload moving in the channel. The sensor hung freely and did not contact the bed surface, the steel tube, or the bridge footing. The sensor collected data hourly, from December 17th, 2002 – October 25th, 2003.

Figure 4-15. Photograph of the Hobo Optic StowAway Temperature sensor.

Temperatures measured during this time period ranged from 4 – 20° C (40 - 68° F) (Figure 4-16). Generally, temperatures are consistent, with small fluctuations due to changing air temperature or flow. Seven-day average air temperatures show the variability that occurred through the winter months, and the warming trend through May, June, July and early August and then a cooling trend from mid September through October (Figure 4-17). The seven-day average water temperature generally follows the air temperature trend, but with a lesser magnitude of change. The maximum seven-day water temperature (16.6° C or 61.9°F) occurred in the last week of July. Daily and seven-day average water temperature recorded during 2002/2003 are similar to or less than temperatures recorded in DFG surveys (August 3, 1964: 16-19º C or 61-66°F; September 27, 1973 12-15º C or 54-59°F; July 19, 1985: 16º C or 61°F; September 5-14,: 10-16º C or 50-61°F). A good correlation between air and water temperature exists, allowing future predictions of seven-day average water temperatures at Delay's bridge in the absence of water temperature data (Figure 4-18).

Water temperature data is most relevant to aquatic ecologists and fisheries biologists for the assessment of habitat suitability for aquatic species, including all life stages of salmonids. However, water temperature data can also reveal trends important to the transportation engineer. Increases in annual temperature patterns could relate to decreases in riparian vegetation, increases in sediment deposition in pools, or decreases in flow, especially in the summertime. Less vegetation or increased sediment deposition can affect bank stability, and in turn, the stability of the adjacent highway.

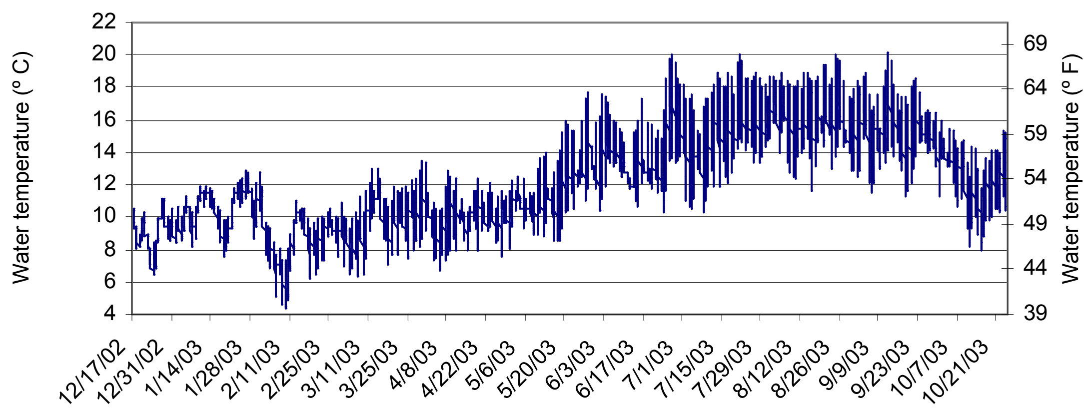

Figure 4-16. La Honda Creek water temperatures at Delay's bridge. Data is collected hourly from December 17, 2002 to October 24, 2003.

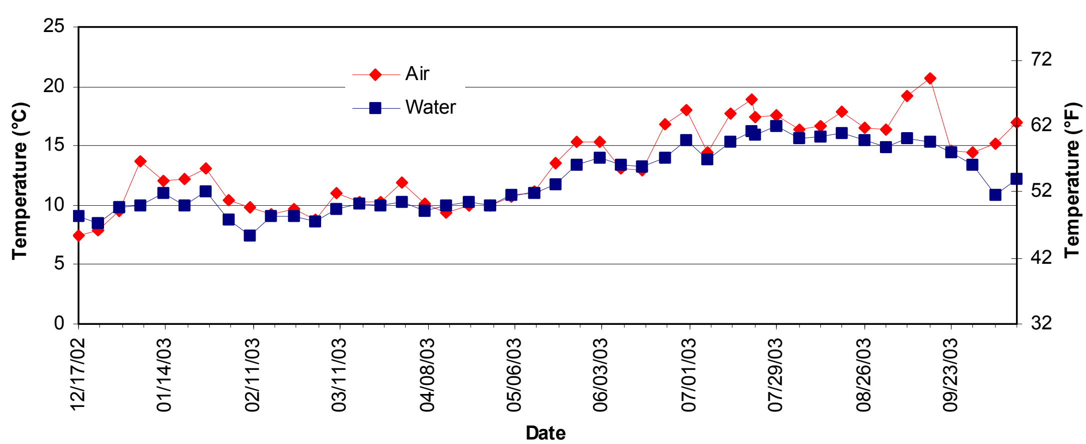

Figure 4-17. Seven-day average air temperature (measured at LAH) and water temperature measured at Delay's bridge for the period December 17, 2002 through October 24, 2003.

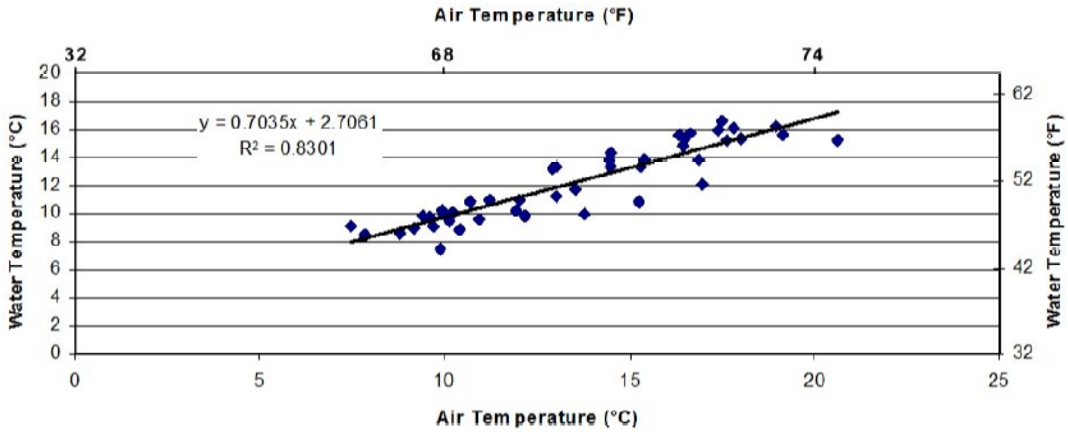

Figure 4-18. The relationship between air and water temperature on La Honda Creek.

4.5 TURBIDITY

To test whether runoff from Highway 84 increases water turbidity in La Honda Creek, a pilot turbidity study was designed. We initially hypothesized that due to fine sediment contributed from the highway, reaches of La Honda Creek that are downstream of where the highway is immediately adjacent to the channel would have increased turbidity levels. This hypothesis was tested by collecting water samples at three locations in the study area during two separate high-flow events.

Suspended sediment impacts salmonids in variety of ways including physiological effects such as gill trauma, gill flaring in response to short-term sediment pulses, increased coughing frequency and mucus buildup, changed blood physiology, and impaired reproduction and growth; behavioral effects such as avoidance, foraging and predation, prey abundance and diversity, homing and migration; and habitat effects including increased embeddedness, and reduced habitat abundance and complexity (See review Bash et al., 2001).

Turbidity meters measure light attenuation in water due to suspended sediments. Instruments vary widely in their design and method of measuring backscatter, so measurements between instruments are usually not comparable. In addition, the relationship between turbidity and suspended sediment is partially dependant upon particle size and composition. For these reasons, unique relationships between turbidity and suspended sediment are normally made for each study location.

In spite of these and other issues, the San Francisco Bay Water Quality Control Basin Plan (RWQCB, 1997) set guidelines for turbidity. Where freshwater fish are present, turbidity may not exceed the established normal by more than 10% in areas where natural turbidity is >50 NTU (Nephelometric turbidity unit, measuring the clarity of a water sample, based upon the amount of suspended material in the sample). Since background levels are seldom defined, these standards are somewhat ambiguous and hard to enforce. Using salmon as an indicator species, the State of Idaho has set a background turbidity of

50 NTU based on data that suggests that displacement occurs at >50 NTU. In addition, a 10-day standard of 25 NTU is set based upon data suggesting that prolonged exposure affects feeding and growth. The standards for Alaska are set at <25 NTU above natural, for Oregon are set at <10% above natural, and for Washington (<5 NTU above natural when natural is <50 NTU and <10% increase in turbidity at >50 NTU) (Bash et al., 2001).

Water was sampled during two separate, high-flow events in La Honda Creek to understand turbidity patterns during flood events (see also Section 7.5). Samples were collected in three locations: at the confluence with San Gregorio Creek, at Delay's bridge, and immediately upstream of the confluence with the Weeks Creek tributary. Water was sampled from the center of the channel, approximately in the middle of the water column using a grab sampling method without a DH-48 (i.e. without depth or cross-section integration). The results might be 10-20% higher than the true depth and cross-section integrated turbidity value, because water velocity, suspended sediment concentrations, and therefore turbidity, tend to be greatest mid-channel.

Samples were taken on December 19, 2002 and April 13,2003 corresponding with peak stages of 0.75 m (2.45 ft) and 0.45 m (1.48 ft) respectively measured at Delay's bridge. In addition, a single winter low-flow sample was taken on December22,2002 at a stage of 0.24 m (0.77 ft), three days after a high-flow event. Samples were analyzed using a Hach 2100P Portable Turbidimeter. Changes in turbidity associated with different parts of the hydrograph illustrate the variability in suspended sediment carried by La Honda Creek during periods of high flow (Table 4-9).

Table 4-9. Measured turbidity (NTU) of water samples collected during high flow events. Stage is measured at Delay's bridge. ND = no data

Date/Time	Stage [m (ft)]	Relative position on hydrograph	Confluence with San Gregorio Creek	Delay's bridge	Upstream of Weeks Creek Tributary
12/19/2002 12:30 PM	0.27 (0.87)	Rising limb	1328	940	79
12/19/2002 4:00 PM	0.75 (2.45)	Peak	1878	1838	2731
12/19/2002 7:45 PM	0.44 (1.45)	Falling limb	1329	1045	ND
12/22/2002 2:20 PM	0.24 (0.77)	Low flow	ND	29	ND
4/13/2003 9:00 AM	0.44 (1.45)	Peak	1376	1072	307
4/13/2003 1:30 PM	0.37 (1.20)	Falling limb	552	485	162

We established three sample sites: 1) upstream of Weeks Creek to capture the "background" turbidity, without fine sediment input from the highway (see Figure 7-7), 2) at Delay's bridge which includes turbidity due to sediment from the highway, and 3) at the confluence with San Gregorio which captures turbidity caused by the highway, as well as by development and channel modifications in the town of La Honda. Samples were collected on different parts of the hydrograph to capture the variability during a high-flow event.

These "spot" measurements for two, discrete high flow events and a single, low-flow period do not characterize the turbidity of La Honda Creek throughout the entire wet season or between years. However, these measurements illustrate the magnitude and variability of turbidity in La Honda Creek in the context of land uses, underlying geology, and position in the watershed. Given that the flood events measured had recurrence intervals of <3 years, turbidity in this basin might reach >10,000 NTU during larger floods. Concentrations of this magnitude are commonplace in some Bay Area and Coast-side creeks of similar size and varying geology (Table 4-10).

Measurements during the high-flow of December 19, 2002 show increased turbidity on the rising limb of the hydrograph, which reached a maximum and then decreased on the falling limb. The sample on December 22, 2002 represents water quality during low-flow conditions, and contrasts with the high turbidity values measured during higher flows. The turbidity measured for the April 13, 2003 high-flow event is lower than that of the December 19, 2003 event. This could be due to the lower stage of the April event, or because most of the fine sediment was flushed out earlier in the wet season. There appears to be a weak relationship between stage at Delay's bridge and turbidity in the three locations (Figure 4-19). The slopes of the lines suggest that for similar stages, turbidity increases downstream from Weeks Creek to the confluence with San Gregorio Creek. There are at least three possible reasons for this downstream increase in turbidity: 1) sediment is deposited in the channel, 2) sediment concentrations are diluted by flow from tributaries, or 3) sediment concentrations are diluted by road runoff. Regardless of the reason, there is no evidence in these data (although minimal) that runoff from Highway 84 appreciably increases the turbidity of La Honda Creek.

Table 4-10. A summary of suspended sediment concentration measured in local tributaries or near San Francisco Bay by the USGS and calculated flow-weighted mean concentration (FWMC) (McKee et al., 2002). * represents locations with ongoing data collection.

Location	Station Number	Years with part or full record	Watershed area [km^2 (mi^2)]	Number of non-zero data points	Maximum concentration ($mg\ l^{-1}$)	FWMC ($mg\ l^{-1}$)
*CULL C AB CULL C RES NR CASTRO VALLEY	11180960	1978-89 1991-92 1994-00	15 (5.8)	2,778	22,400	4,472
*SAN LORENZO C AB DON CASTRO RES NR CASTRO V	11180825	1980-89 1991-92 1993-94 1997-00	47 (18.1)	2,593	15,300	2,610
COLMA C A SOUTH SAN FRANCISCO	11162720	1965-76	28 (10.8)	2,507	19,400	2,442
PINE C A BOLINAS	11460170	1967-70	20 (7.7)	1,145	5,370	837
WILDCAT C AT VALE ROAD AT RICHMOND	11181390	1977-80	20 (7.7)	1,093	13,400	2,329
CORTE MADERA C A ROSS	11460000	1977-80	47 (18.1)	1,065	1,240	374
PERMANENTE C NR MONTE VISTA	11166575	1985-87	10 (3.9)	810	5,800	560
WEST FORK PERMANENTE CR NR MONTE VISTA	11166578	1985-86	7.7 (3.0)	347	1,850	491
PESCADERO C NR PESCADERO	11162500	1980	119 (45.9)	305	2,980	683
*CROW CREEK NEAR HAYWARD	11180900	1999-00	27 (10.4)	214	11,200	3,369
SAN LORENZO C AT SAN LORENZO	11181040	1991-92	116 (44.8)	213	1,230	424
CULL C BL CULL C DAM NR CASTRO VALLEY	11180965	1978-79	16 (6.2)	192	256	124
SPRUCE BRANCH AT SOUTH SAN FRANCISCO	11162722	1966-67	1.8? (0.7)	84	6,350	2,490
AGUA FRIA C AT WARM SPRINGS ROAD AT FREMONT	11172300	2000	4.6 (1.8)	2	124	-
TOROGES C AT WARM SPRINGS ROAD AT FREMONT	11172360	2000	3.2 (1.2)	3	8,130	5,139?
ZONE 6 LINE B AT WARM SPRINGS BOULEVARD AT FREMONT	11172365	2000	2.15 (0.8)	7	73,500	55,548?
SAN ANTONIO C NR SUNOL 1 KM BL LAKE SAN ANTONIO	11174000	2000	96 (37.1)	6	11	-

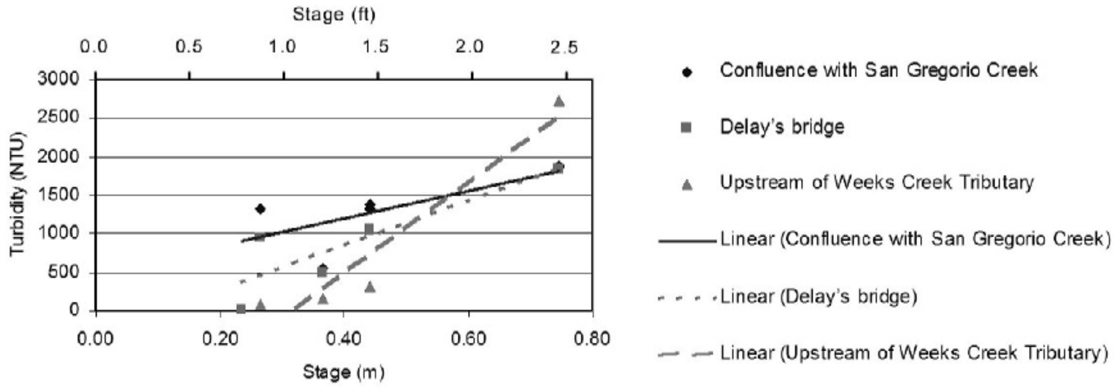

Figure 4-19. The relationship between stage at Delay's bridge and turbidity at each of three sampling locations.

Suspended sediment has been suspected as being a potential limiting factor to salmonid success in La Honda Creek, however turbidity data gathered during WY 2003 should be considered a pilot study, used to explore this hypothesis in the context of existing literature. For example, if fine sediment concentration in the stream is high, fines may intrude into previously constructed redds during moderate to high flows. Because the redd is a depression in the streambed, a venturi force can draw fine sediment-laden water down into the gravel. High turbidity after juvenile steelhead trout and coho salmon emerge can impact their feeding ability (Newcombe and MacDonald, 1991). Turbidities as low as 25 (NTU) can reduce salmonid growth (Sigler et al., 1984). Even if turbidity remains below lethal levels for salmonids in disturbed watersheds, there might be long-term effects if their outmigration size makes them more vulnerable to predation while in the ocean.

In the 80's and early 90's a number of studies were conducted to test the influence of turbidity on behavioral avoidance in salmonids. For example, Sigler et al., 1984, noted that no fish were found in tank areas with turbidities >167 NTU where as tanks at 57-77 NTU supported fish at near carrying capacity. Other laboratory studies showed that newly emerged fry appear to be susceptible to turbidity even in the 25-50 NTU range causing migration to other clearer laboratory simulated streams (Sigler et al., 1984). Juvenile salmonids tend to avoid streams that are chronically turbid or impacted by human activities (Lloyd et al., 1987). Bisson and Bilby (1982) subjected juvenile coho to elevated suspended sediment concentrations and found little avoidance with small increases in turbidity when background was low but noted significant avoidance at 70 NTU. Berg and Northcote (1985) reported that short-term exposures (2.5-4.5 days) to turbid water up to 60 NTUs disrupts feeding and territorial behavior of juvenile coho. Larger juvenile and adult salmonids and trout appear to be little affected by ephemerally high concentrations of suspended sediment that occur during most storms (and periods of snow melt) (Cordone and Kelly, 1961; Sorenson et al., 1977).

Migrating salmonids have been observed to avoid waters with high silt loads, or to cease migration when such loads are unavoidable (Bjornn, 1978; McCabe et al., 1981; Bell, 1986; Bjornn and Reiser, 1991). In one case, salmonids avoided areas where suspended sediment concentrations exceeded 4,000 mg/L due to landslide sediment in the stream (Bell, 1986). Bjornn (1978) noted that the arrival time to spawning grounds of chinook can vary a month or so depending on suspended sediment concentrations. Upstream migration on the Columbia River was slowed when secchi disk readings were less than 0.6 m (2 ft).

This short review illustrates some potential impacts that turbidity might have on salmonids in La Honda Creek. The small amount of information gathered during the present study suggests that more detailed study on water column and interstitial suspended sediment is warranted. Information on the magnitude and temporal distribution of potentially chronic and acute suspended sediment concentrations relative to life habits of salmonids could be gained by emplacing a turbidity probe and data logger for continuous monitoring at 15 minute intervals. Data would also include collecting suspended sediment concentration data suitable for calibrating the probe to give estimates of suspended sediment concentration also on a 15 minute basis. Several probes could be used strategically to determine sources of suspended sediment and potentially determine depositional characteristics of the creek in areas between the probes.

The data collected in this pilot study, although minimal, does suggest that road runoff from Highway 84 is not significantly contributing to increased turbidity in La Honda Creek. The values also suggest that turbidity could potentially reach levels > 10,000 NTU in larger flood events. Given the effects of turbidity upon salmonids as documented in the literature, the turbidity in La Honda Creek, especially during flood flows, may have detrimental effects on salmonid populations in the creek.

4.6 CONCLUSIONS

Analysis of existing precipitation records for the La Honda watershed provides average annual rainfall, return periods, and probabilities of exceedence for annual precipitation totals. At La Honda, annual rainfall varied from 356-1205 mm (14.0-47.4 in) and averaged 744 mm (29.3 in) for the period of record (1950-77). In addition, seasonal, daily, and hourly precipitation trends and intensities are derived from the existing records. Rainfall on the scale of days controls the amount of runoff. Slope stability depends on antecedent rainfall, and the intensity and duration of hourly rainfall.

Measures and estimates of channel discharge at Delay's bridge are given. Discharge and flow recurrence intervals are necessary to understand how flow will affect engineered structures along the La Honda Creek Highway 84 corridor. Measured discharge ranges from 1.0 m^3/s (35 cfs) at 0.31 m (1 ft) of stage to 9.57 m^3/s (338 cfs) at 0.76 m (2.5 ft) of stage. Estimated discharge corresponding to 2.74 m (9 ft) of stage is 76.4 m^3/s (2,700 cfs). These discharges are capable of causing major changes in channel cross-sectional morphology, undermining stream-side structures, and causing large areas of bank instability.

A continuous measure of water temperatures in the channel allows an understanding of the quality of aquatic habitat provided. Water temperatures were collected continuously from December 2002 to October 2003, and ranged from 4 – 20° C (40 - 68° F) during this period. A good correlation between air and water temperature exists, allowing future predictions of seven-day average water temperatures at Delay's bridge in the absence of water temperature data.

A pilot study was designed to test whether runoff from Highway 84 increases water turbidity in La Honda Creek. Three locations were sampled to assess whether increases in turbidity are related to fine sediment contribution from the highway. A weak relationship exists between stage at Delay's bridge and turbidity in the three locations; for similar stages, turbidity decreases downstream from Weeks Creek to the confluence with San Gregorio Creek. Based upon the limited data, these data provide no evidence that runoff from Highway 84 appreciably increases the turbidity of La Honda Creek.