The influence of large woody debris on channel form, upper Scott Creek, Santa Cruz County

Garcia, Luis
Orduna, Rodrigo

2004-05-01

The Influence of Large Woody Debris on Channel Form

Upper Scott Creek, Santa Cruz County

Luis Garcia

and

Rodrigo Orduña

Landscape Architecture 222 – Hydrology for Planners

Spring 2004 – Matt Kondolf

Abstract

Lehi Park in Santa Cruz County is preparing to submit a long-term sustained yield timber harvesting plan (Non-industrial Timber Management Plan or NTMP) to the California Department of Forestry and Fire Protection for a portion of the Scott Creek Watershed. This portion of Scott Creek hosts a population of Rainbow Trout; the landowner wants to retain those trees that will contribute to pools with adequate structure to provide cover for trout.

We observed and described large woody debris and its orientation in the channel of Scott Creek and its effect on sediment storage and conveyance, as well as channel form; and we developed baseline data for water quality monitoring for the NTMP.

We surveyed a longitudinal profile (of the thalweg, water surface, and high water mark) and four cross sections, made fourteen sediment depth readings along the channel, and made several field sketches and took pictures to document the effects of large woody debris on channel form. This baseline data, in conjunction with regional hydrographs, allowed us to estimate the return interval of the measured high flow, which is approximately 1.5 years.

Our observations of large woody debris may contribute to future study and possible recommendations for bank-side tree protection. Lastly, this baseline data may become useful in subsequent surveys as a demonstration of change in stream profile over time.

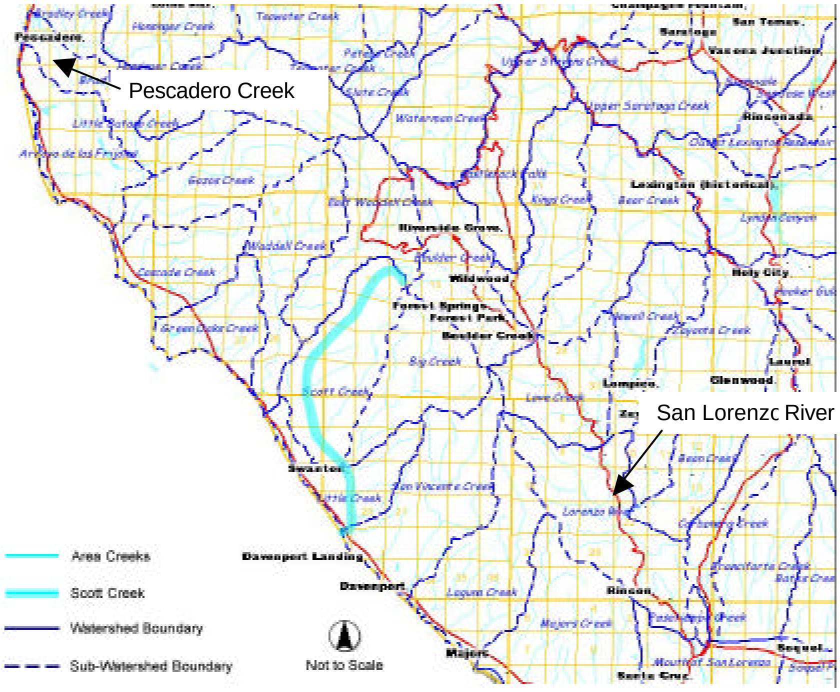


Image 1: Scott Creek Context Map

Study Purpose

1. How may management of bank-side trees improve trout habitat?
2. What is the condition of the channel?
3. Does the condition of the channel change over time?

Introduction

The Scott Creek Watershed (Cal Water version 2.2 id# 3304.110204) drains approximately 10,000 acres or 15.5 square miles in Santa Cruz County. It flows down the western face of the Santa Cruz Mountains approximately 15 miles to the Pacific Ocean. Scott Creek hosts runs of Steelhead (*Onchorychus mykiss*) and Coho Salmon (*Onchorychus kisutch*). The study reach is upstream from an impassible bedrock waterfall, and therefore is not accessible by anadromous salmonids. However, resident Rainbow trout (*O. mykiss*) do inhabit the creek. We studied a reach of Scott Creek in Lehi Park approximately 12 miles from the mouth at the Pacific Ocean, near Davenport, CA.

Large woody debris (LWD) is known to significantly contribute to stream-channel morphology. Where flow deflection results in the scouring of sediment, a resulting sediment bar will form. Deflection and deposition varies based on the orientation of the LWD obstruction. Orientation of LWD may be one of four functional positions for woody debris: horizontal, step, vertical, and pitched. (Montgomery et al., 2003) LWD affects the stream channel form by damming, scouring, eddy, undercut, and/or plunge, and sediment deposition. Horizontal and pitched LWD channels flow and focuses concentration to create scour and undercut, while depositing sediment in various bar formations. Vertical LWD contributes to pool, scour, and eddy, while creating slightly different bar formation. The observations of this study will answer the question of how channel morphology is influenced by the two main portions of a tree: the log and the root-wad, and how the pieces may be oriented. It is also important to keep in mind that channel form may also be influenced by vegetation type, bed particle size, and bed parent material.

Methods

Overall Channel Survey

We surveyed a 492-foot (150-meter) reach of Scott Creek in Santa Cruz County, beginning along the north edge of the Lehi Park property, at an approximate water surface elevation of 1,031 feet above sea level, and ending at an approximate water surface elevation of 1,012 feet above sea level.

Our benchmark was a spike marked with red tape on the side of a tree stump at the right top of bank, at an approximate elevation of 1,045 feet above sea level, about 10 feet from the channel. This benchmark was used as a land surveying monument and indicates the line between Sections 17 and 20. The elevation is approximated because the surveyor records could not be recovered by the time of submission. Estimation is based upon the contour lines of the Big Basin, CA USGS 7.5-minute Quadrangle (1997. Elevation reported in the analysis is relative to the estimation of this monument.

Image 2: Benchmark Nail at Tree

Long survey & Cross Sections

Our survey equipment consisted of a tripod, a level, and a rod to measure relative height differences from one survey point to another. We measured longitudinal and cross-sectional distances of the creek using tape measures that were located generally along the creek centerline for longitudinal measurements, and pulled taught along a horizontal line for cross-sectional measurements. We took longitudinal measurements for the entire 492-foot (150-meter) span of the creek surveyed. For the cross sections, we took measurements at every 164 feet (50 meters). Cross section measurements provided water depth readings at each cross section, but also yielded cross-sectional areas of the channel up to top of bank at each section. Cross sections were monumented using ¼-inch re-bar along the left side of the cross-section. Each cross section was taken perpendicular to the creek channel.

Flood Frequency Analysis

Surface water data was downloaded from the USGS Water Resources Website for Pescadero Creek and the San Lorenzo River. From this data, regional return intervals can be calculated for various water years. Since we have the high water mark for this year's flood at Scott Creek, we can estimate the return interval and probability of return for a calculated Q at the survey point of the reach. By establishing a history of estimated flood intensity, a flood frequency analysis may be established for Scott Creek.

We used Manning's Equation to calculate velocity of an open channel flow:

$$v = \frac{c\ (s^{0.5}\ R^{0.67})}{n}$$

where: v = velocity in feet per second
R = hydraulic radius in feet
s = energy slope (or river gradient)
n = roughness coefficient
c = coefficient of 1.49 to convert formula into English units

$$R = \frac{A}{WP}$$

$$s = \frac{dh}{dl}$$

Once we have velocity, we use the discharge equation to find the amount of water flow past a certain point in the channel:

$$Q = v\,A$$

where: Q = discharge in cubic feet per second
v = velocity in feet per second
A = cross-sectional area in square feet

To obtain the hydraulic radius, we divide channel cross-sectional area in square feet, by the wetted perimeter (WP), which is the perimeter along the channel bottom, in feet: Energy slope (or river gradient) is obtained by dividing the difference in heights (dh) in feet at different measurement stations along the longitudinal section of the river, by the longitudinal length between those measurement stations (dl) in feet: The roughness coefficient represents the resistance to flow within a channel; and it depends on stepping along the length of the channel, the composition of the creek bed, vegetation within the channel (such as LWD), channel meandering, and how much sediment and water is transported. To find the roughness coefficient (*n*), we looked at Chow (1959), Table 5-5 "Values for the Computation of the Roughness Coefficient".

Image 3: Sediment Depth Measurements

Sediment Depth Survey

To record sediment depth, we used a ½ inch diameter reinforcement bar (rebar) that was 6 feet long, which we pounded through loose sediments in the creek bed with a sledgehammer until we hit a more resistant material, and measured the thickness of the sediment from the rebar. We measured sediment depth at every cross-section from the edge water spaced approximately one-foot)\ apart and at the clumps of LWD where sediment deposition appeared greatest and at various points to define the extent of the sediment deposit.

Descriptive Survey

Along the survey reach we took pictures and made notes on changes in channel form, such as steps, pools, runs, and riffles, and locations of LWD. We made field sketches and took pictures of the channel areas containing LWD, to show the extent of modification to the channel form due to the debris.

Image 4: LWD Stations 1 and 2

Analysis

Longitudinal Survey & Cross Sections

The longitudinal survey reveals the gradient of high-water marks, water surface, and the thalweg. We noticed that the prevalence of pools occur after stepping of the creek. As will be shown later in this paper, this condition is due to the existence of obstacles within the channel, which cause scouring at the obstacle, followed by pooling. The data is charted in Figure 1 below:

Figure 1 shows the locations of the cross sections that we measured for this stretch of Scott Creek. Included in the cross sections are the high water marks for all four cross sections, and the wetted perimeters and cross sectional areas for cross sections one and four, from which we calculated peak flow for water year 2004. From this chart the slope of the high water marks was determined to be 3.83%.

Figure 1

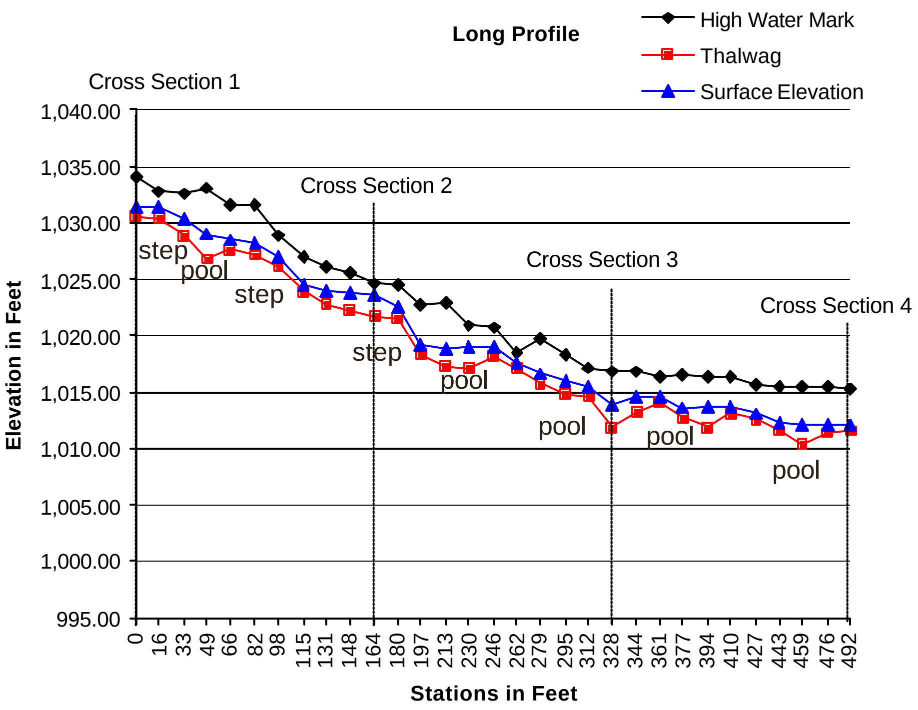
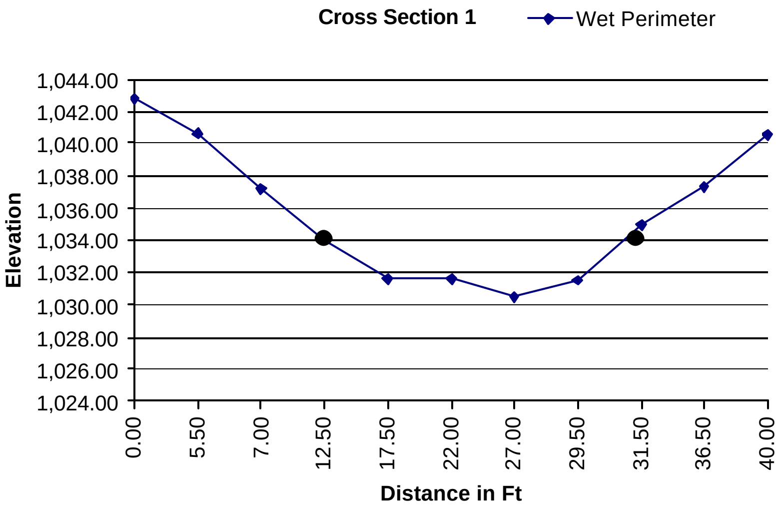


Figure 1 shows that high water marks did not have a constant slope. This is because of wider and narrower channel width as it traveled downhill, which means, since flow volumes remain constant throughout the length of the creek, that a variation high water mark height would be likely to compensate for the variation in channel width. Water surface slope also varied, depending on areas of pooling or stepping water as it runs along the creek. Thalweg slopes also changed depending on creek channel composition.

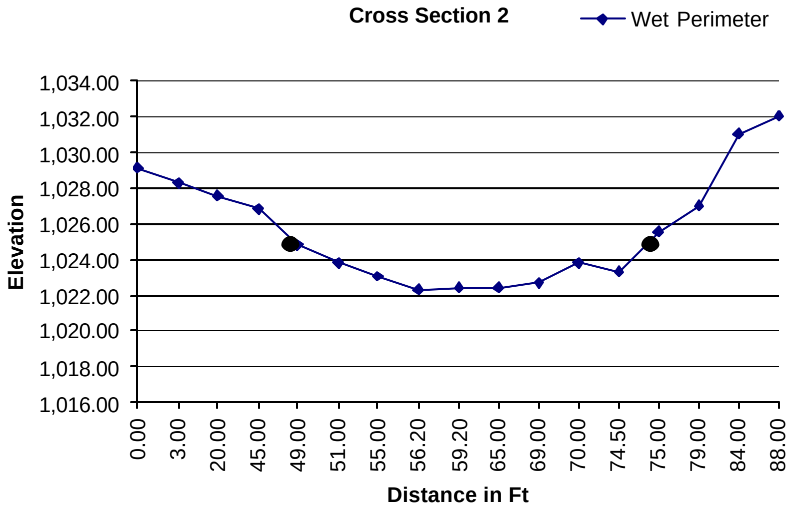
The cross-sections in Figures 2 through 5 depict a slice of the channel from bank to bank. Please note that scale varies from figure to figure. The high water marks, wetted perimeter, and cross-sectional area are noted on the first and last figures. This data was later used in the Manning's equation for the Flood Frequency Analysis. It is interesting to compare the cross sections with the long profile and the sketches.

Figure 2



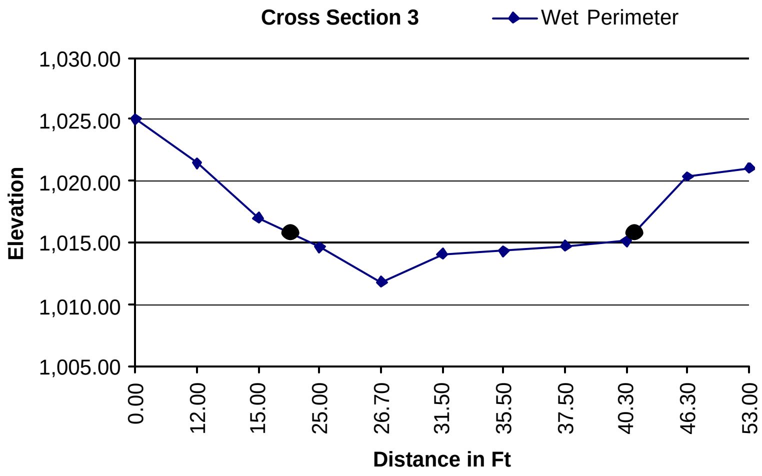
high water mark = = ●,034.93 ft
wetted perimeter = 21.50 ft
cross sectional area = 42.50 sq. ft.

Figure 3



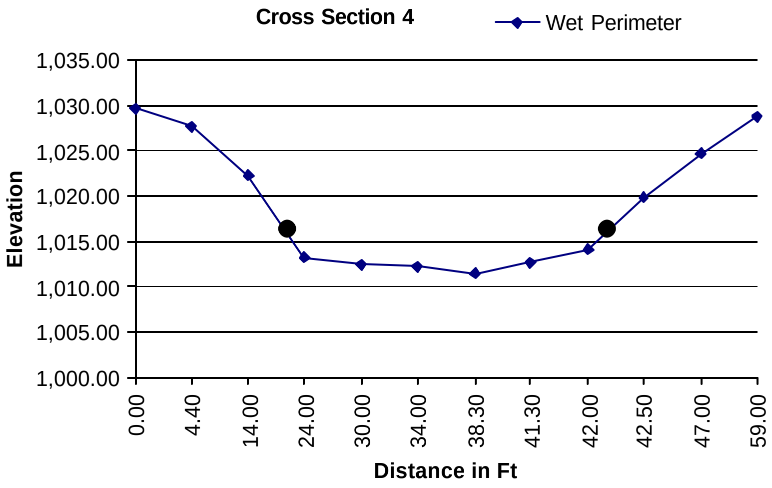
high water mark = = ●,024.60 ft

Figure 4



high water mark = = ●1,016.88 ft

Figure 5



high water mark = = ●1,015.26 ft
wetted perimeter = 25.42 ft
cross sectional area = 55.50 sq. ft.

Flood Frequency Analysis

Figures 2 through 5 show the cross sections taken at the 0, 164, 328, and 492-foot markers of the longitudinal profile for Scott Creek (cross sections 1, 2, 3, and 4, respectively). Estimated peak flow (Q), at the high water mark of Sections 1 and 4, is 202.30 and 281.94 cubic feet per second, respectively, with an average slope for the surveyed stretch of 3.83%.

The regional hydrographs include 2004 peak flows in the return interval calculations. For Pescadero Creek (period of record from 1952 to 2004) the 2004 peak of 1080cfs on 1/1/04 had a return interval of 1.5 with a probability of return of 66.67%. For the San Lorenzo River (period of record from 1938 to 200) the 2004 peak of 3140cfs on 12/19/03 has a return interval of 1.47. (An interesting note was that the second highest peak for the San Lorenzo River occurred on 1/1/04 at 2900cfs.) Thus, Scott Creek probably experienced a 1.5-year flood in 2004. (Table 3)

As can bee seen from Figures 2-5, the cross sections with the most "ideal" flow conditions (those cross-sections with the least flow resistance and most trapezoidal-like features) are cross sections 1 and 4. Because the creek bed has fewer jagged edges at cross sections 1 and 4 than at cross sections 2 and 3, water flow at the former cross sections is more uniform and consistent than at the latter cross sections. Therefore, we calculated peak flows at cross sections 1 and 4 for this stretch of Scott Creek. To determine cfs for Q, we used the Manning's "*n*" equation to perform a back-calculation. To estimate the roughness coefficient "*n*", we looked at Chow (1959), Table 5-5 "Values for the Computation of the Roughness Coefficient". The following is how we determined the values for "*n*" calculation:

1. material involved – materials varied from large boulders to fine sands; mostly, there were largely melon-sized granite rocks, so we assigned the value of 0.027;
2. degree of irregularity – the channel shape and gradient varies, given this, we assigned the value of 0.01;
3. variation of channel cross section would alternate rather frequently; therefore, we assigned the value of 0.01;

4. relative effect of obstructions in the stream were appreciable; therefore, we assigned the value of 0.025;
5. we also noted medium to high incidents of vegetation within a channel merit a roughness coefficient value of between 0.010 and 0.050; we assigned the value of 0.025;
6. the degree of meander was fairly minor.

These values were somewhat challenging to determine given that in certain stretches the channel is relatively smooth, and at times the channel is relatively rough. Therefore, knowing that, as Chow himself points out "there is no exact method of selecting the *n* value" (Chow, pg. 101), we made the best guess based upon the entire reach between the two cross sections.

Sediment Depth Survey

Figures 6 through 9 show the sediment depths at cross sections 1, 2, 3, and 4, respectively. Figures 6-9 show that there were usually greater sediment deposits at the edges of the creek channel. Sediment depths of zero mean that we hit a rock at the channel surface, so that the rebar could not be pounded into the ground. The existence of deeper sediment along the channel edge is most likely due to the constant contact and friction between moving water and channel banks and debris, to the depositing of sediment along the outer edges of meanders, and to the reduced speed of water along the edges of a channel relative to the speed of the water along the center of the channel, which causes deposit of sediment along the edges and carrying of sediment along the center. Data tables for all sediment depth measurements are shown in the Appendix of this report.

Figure 6

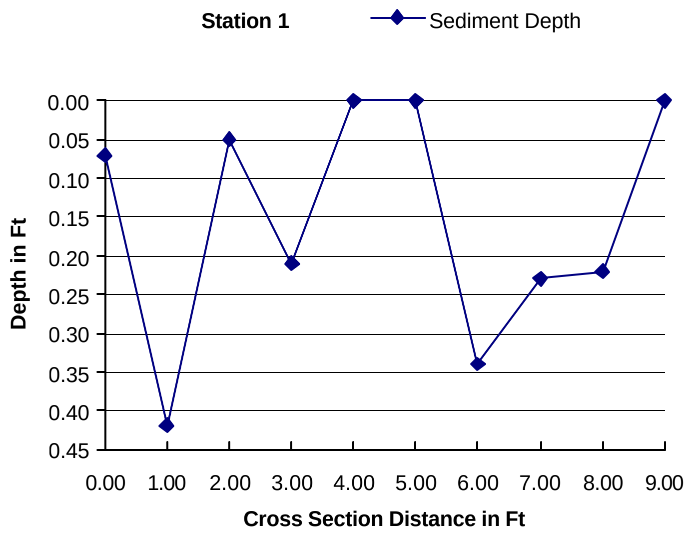
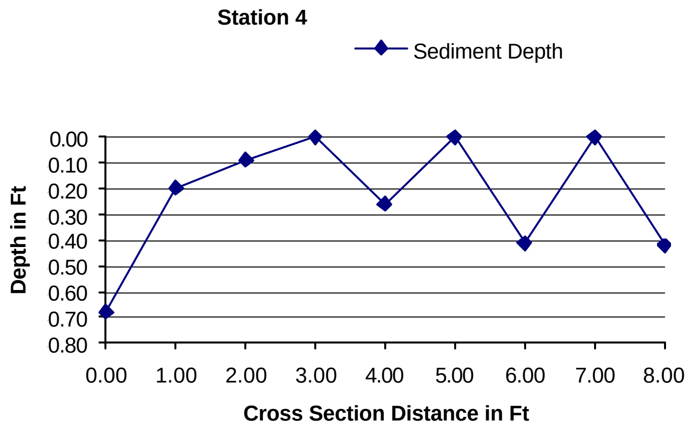


Figure 7



It is curious to note for Figures 6 through 9 that stream width remained fairly constant 8 to 9 feet in width.

Figure 8

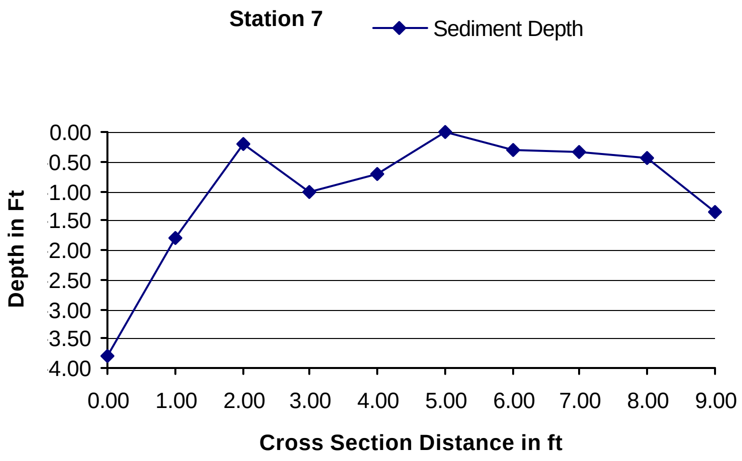
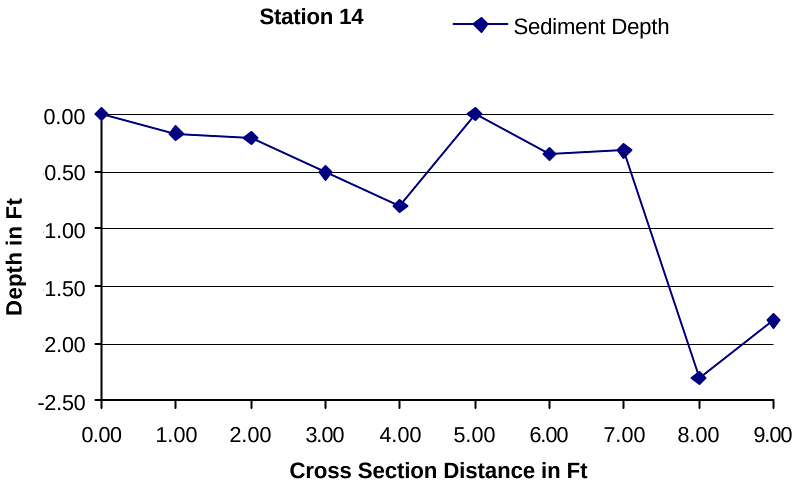


Figure 9



Sediment depths at the LWD locations were greater overall than sediment depths at non-LWD locations (see Appendix for data tables). The deepest sediment was found at sediment depth station 10 (Image 5), which is located at 400 feet (122 meters) into our stretch of Scott Creek, behind a big-leaf maple tree that, because its roots began to grow roughly five feet above current ground level, showed signs of substantial scouring since the tree grew on that spot.

We measured the sediment at four feet downstream of this big-leaf maple tree at 4.23 feet deep. The location of this LWD well within the creek channel created back eddy deposits and point bars downstream of the debris. These deposits and sand bars are deep with sediment because of the slow water currents created directly downstream of obstructions in the stream flow. All suggestions are mere postulation of channel morphology it is difficult to destinguish vertical scour from lateral bank erosion because vegetation failed.

Image 5: Big-leaf Maple Tree Shows Signs of Creek Bed Scouring

Descriptive Survey

Various changes in channel composition were noted, which seemed to correlate to the location and orientation of obstructions within the channel, such as LWD. In general, creek composition follows a predictable sequencing of steps followed by pools, then followed by runs. A verbal description of the procession of channel composition is listed in Table 1 below:

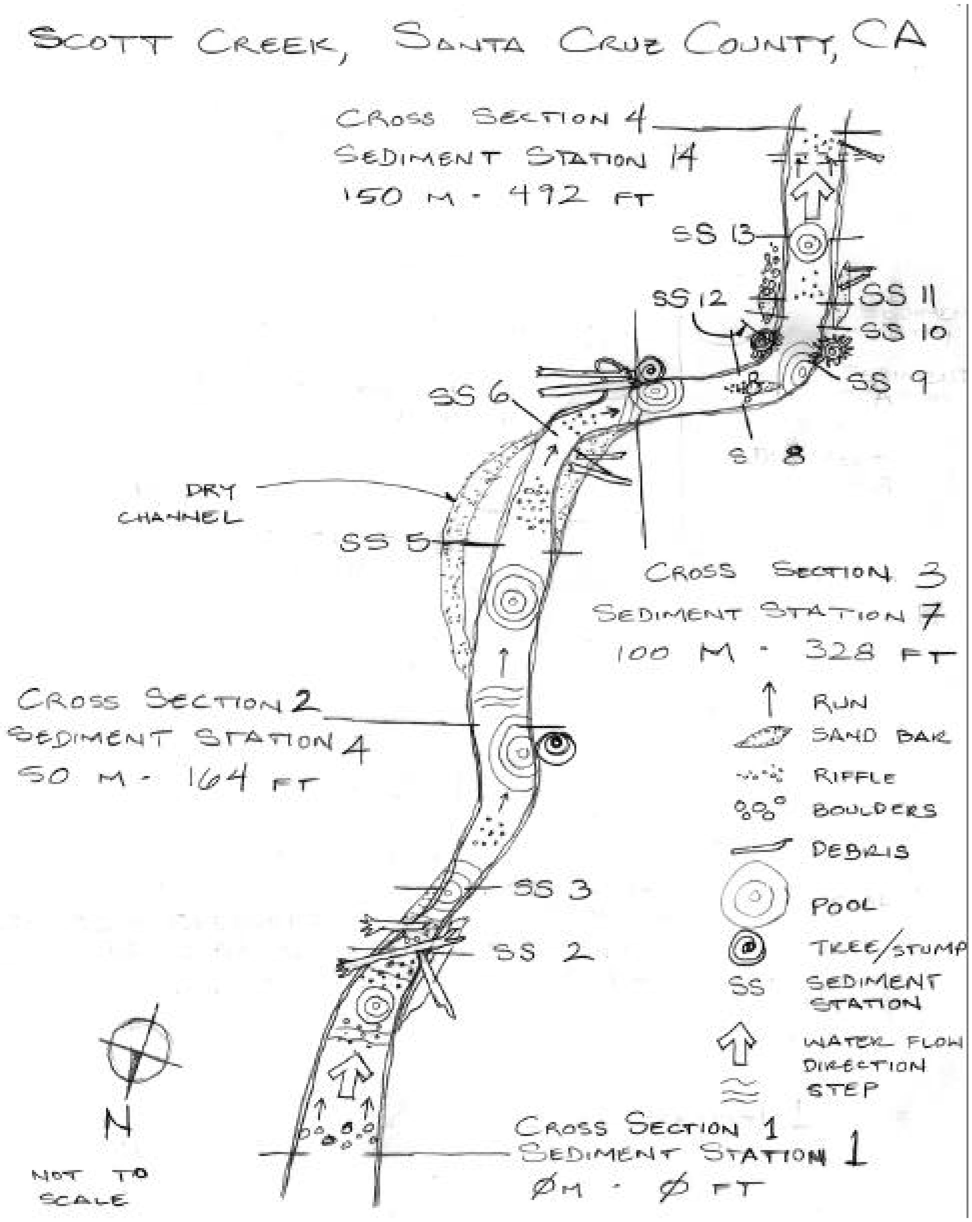
Table 1 – Description of Channel Composition

from (in ft)	to (in ft)	description of creek composition
0.00	17.72	run with boulders
17.72	31.17	step and riffle
31.17	57.41	pool
57.41	75.46	riffle
75.46	108.27	step and LWD station 1
95.14		LWD station 2
108.27	129.27	riffle
129.27	144.36	run and pool
144.36	160.76	riffle
160.76	181.76	run
181.76	190.29	step
190.29	213.25	run
213.25	248.69	pool
248.69	269.03	Riffle and LWD station 3
269.03	318.24	Riffle and LWD station 4
318.24	328.08	Riffle
328.08	354.33	run
354.33	375.66	riffle
375.66	410.10	pool
374.02		sharp bend in the creek to the left
374.02		large boulder at the bend in the stream
390.42		large tree stump at the bend
400.26		big-leaf maple tree (evidence of scouring)
410.10	439.63	riffle
439.63	472.44	pool
472.44	492.13	run and riffle

Image 6: Creek at Bend to the Left

The verbal descriptions in Table 1 are shown graphically in Sketch 0* below:
(*Note: in this and the following sketches, water flow is generally toward the top of the page.)

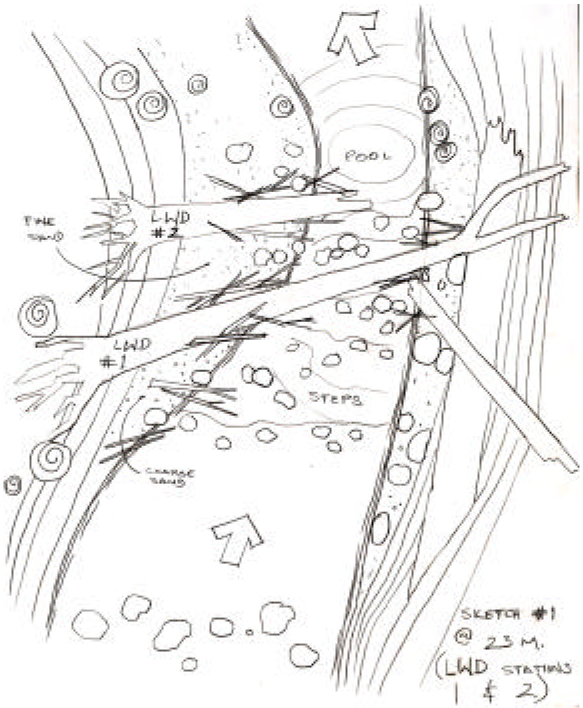
Sketch 0 – Scott Creek Site Plan



The sketch does draw a reasonable likeness to the survey area. It demonstrates channel characteristics in relation to influences such as LWD. Note the locations of the cross sections in relation to the orientation of the creek.

We also sketched the composition of certain points of the creek channel, as follows:

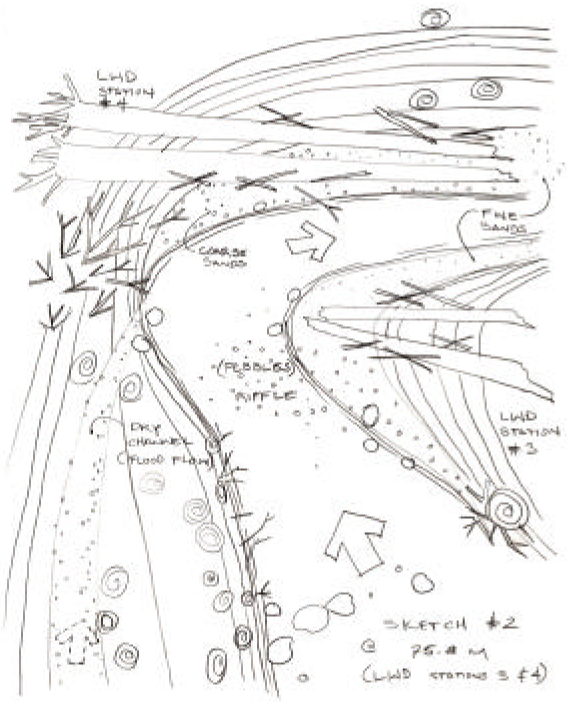
Sketch 1 – LWD at Stations 1 and 2



In Sketch 1, it is difficult to determine which fell first, however, either LWD #1 or #2 contributed to the morphology depicted in sketch 1 being oriented horizontally and perpendicular to channel flow. It is also difficult to tell if either created a dam by spanning the width of the channel. Regardless, it is apparent that the root wads on the left edge deflected flows to the right. As the flow was concentrated, it gained energy and proceeded to pipe and scour under the log, creating a series of steps to the pool.

Image 7: Photo of area of Sketch 1

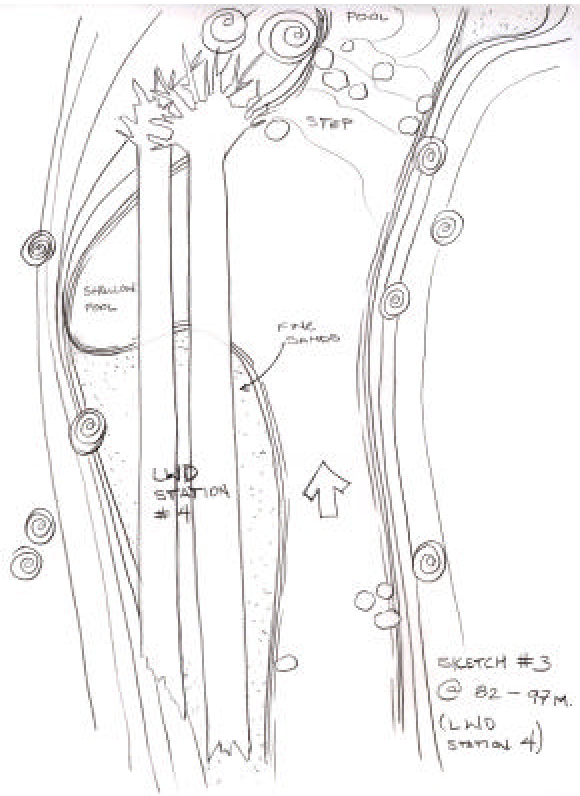
Sketch 2 – LWD at Stations 3 and 4



In Sketch 2, we would like to draw your attention to LWD station #3. The LWD structure is perpendicular to the flow and extends across half of the observed channel width. The LWD creates a bar with coarse sediments in front of the point of the LWD. Flow is diverted to the left. Perhaps, at higher flows, water pipes and scours under the logs. Burying the top of the log into the bed and extending out of the channel at an acute angle, may classify this station as pitched.

Image 8: Photo of area of Sketch 2

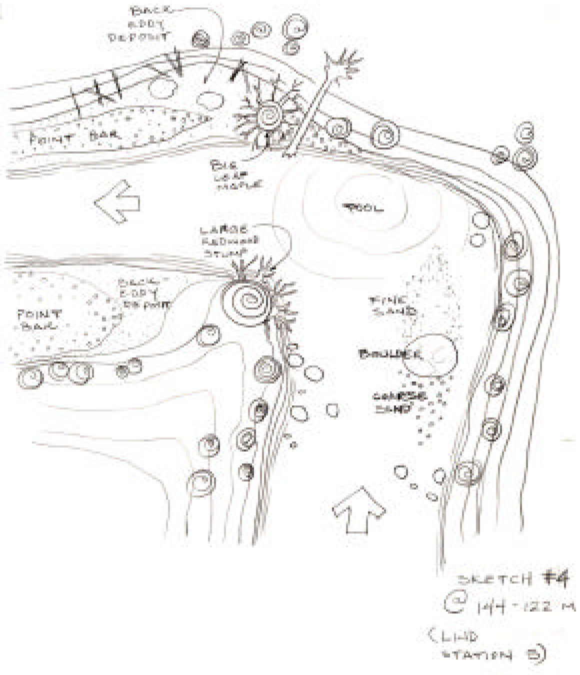
Sketch 3 – LWD at Station #4



Sketch 3 depicts LWD that is horizontal and parallel to the stream channel, and vertical LWD. Scour was observed under the deflecting flank of the parallel LWD and a straight, confined channel. The side opposite the flow was filling in with sediments. The upturned root-wad created a vertical LWD structure. Water is deflected from the root-wad both down stream and back against the bank to scour the observed shallow pool.

Image 9: Photo of area of Sketch 3

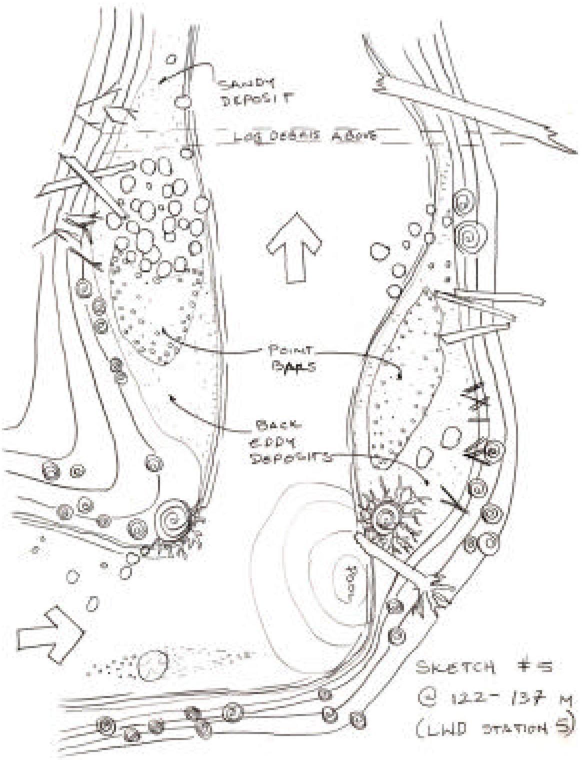
Sketch 4 – Debris at sharp left turn



The boulder in Sketch 4 was examined for comparison purposes. The deposition of course deposits in front of the obstruction and fine sediments below, appear very similar to sediment stratification by LWD station #3. As also seen at LWD station #3, the stream becomes divided.

Image 10: Photo of area of Sketch 4

Sketch 5 – Back eddy deposits and point bars



Sketch 5 depicts a unique opportunity to view vertical LWD structures that mirror each other. As the flow is forced around the structure, velocity in crease, causing scour and a back eddy. The eddy deposits were significantly deeper than other areas absent LWD structures. What was interesting to note was the stratification of sediments within the deposition bar.

Image 11: Photo of area of Sketch 5

Discussion

Longitudinal survey & Cross Sections

The longitudinal survey establishes baseline data of channel condition. The survey spike in the old growth redwood stump was selected as the benchmark because it will likely remain as a landmark for many years. It will certainly exist for long enough to detect any changes to the watercourse morphology, such as down-cutting or aggradation, through several timber harvesting cycles. Down cutting or aggradations of stream channel is directly affected by channel roughness.

We observed pools along the creek bed that are located after a stepping of the creek profile. Image 12, looking upstream, shows a pool formation after the stepping of the creek. Another interesting note about the image above is that the pool is forming at the base of a bank-side tree.

Image 12: View of Creek Upstream Shows Pool and Steps

The descriptive survey could be super imposed upon the long profile for description of channel form and proximity to LWD. After duplication of the survey, results would demonstrate the amount of change occurring within the watercourse.

Flood Frequency Analysis

Establishment of flood frequency analysis by way of comparison with regional hydrographs is an effective, though imperfect method. North to south, we evaluated Pescadero Creek, Scott Creek, and San Lorenzo River. All are coastal, and flow to the west. Scott Creek is roughly equidistant between the two gages, and they are 10-12 miles from the study reach. We anticipate minor differences in the regional rainfall intensity and consequently on return interval however difference of probability of return is less significant.

Our findings of Q created some new questions that are not address by our assessment. At Cross Section 1 of our study reach, the Q = 202 cfs and at Cross Section 4 of our study reach, the Q = 281cfs. Our concern is, where does the additional 80 cfs come from? Since Q in is supposed to equal Q out, we have to assume several sources of error. There exists the following possibilities; survey error, error in selection of high water mark, input of tributaries and ground water flow.

Sediment Depth Survey

The sediment depth survey demonstrates the depth of unconsolidated bed material at different portions of the reach. During receding flows, fine sediments will settle into the scour and eddies, however the sediments will be flushed out during the next heavy flow. Three of the cross sections were taken in portions of the reach that were absent of LWD. The third cross section had LWD present.

Comparing the sediment depth and the cross section water levels in this case is not possible because sediment depth and water level readings were not taken at the same cross sectional distances at the field. Therefore, the sediment depths are shown as different charts than the cross sectional charts.

Sediment depth measurements were taken at one or two points at LWD locations, labeled as stations 2, 3, 5, 6, 8, 9, 10, 11, 12, and 13. This was done to take a quick reading of deposits around the debris. The measurement points were therefore taken at obtuse angles to a cross section, and could not lend themselves readily to a cross section profile. We thus made no attempt to extrapolate these readings into cross section charts.

In regards to Figure 8 there was a twin tanoak that fell directly upstream and deposited its root-wad in the stream channel, and there was an old growth conifer stump, both at left edge water. The depth measurements at the left edge water were very deep. There may be several reasons why this occurred. First is that the sediment probe managed to find a root cavity from the decomposing conifer stump. Another possible explanation for this is that there has been significant scouring at the base of the stump and it has filled in with sediment fines because there was not sufficient flow to scour it out.

Descriptive Survey

The channel composition descriptions in Table 2 and Sketches 1 through 5 show much different sediment and obstruction conditions along the stretch of creek that we surveyed. The LWD mentioned previously in this paper effects creek formation as shown in each of the five sketches. Whether by narrowing channel width through obstruction (thereby increasing velocity water at that point), by causing a shallower water depth through sediment deposition around the debris, or by causing a pool directly downstream of the debris, LWD appears to influence the creek form consistently with LWD orientation throughout the length of the surveyed reach.

There was a significant factor that influences channel form that was noted in the field, though, not noted in this report. And, that factor is the formation of pools immediately beneath live trees on the stream bank. The interwoven root mass within the stream creates a great obstruction to flow and causes scour and undercutting. The submerged interwoven root mass is significant for trout habitat suitability because it provides cover from predators during low flows and refuge from great velocity during high flows. This was not taken into account because there is a distinction between debris and live trees.

Conclusion

From our evaluations, we may conclude how orientation of the piece of LWD affects channel morphology by modes of input. Logs may fall horizontal, pitched or as a step. Root wads and standing trees create vertical obstructions. Managers may control for desired channel morphology by retaining trees that lean in a particular direction in relation to the channel. Stream data collected may be valuable to gauge the effectiveness of control.

In the interest of managing watercourse, on Lehi Park, to perpetuate the present LWD and corresponding channel form conditions we recommend:

- Do no impact bank-side trees such that root-ball is hindered from growing.
- Retain all trees within 50’ of watercourse that lean towards the creek to create pitched LWD structures.
- Incorporated best-management practices for logging roads, trails, and landings to minimize sediment input.

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Appendix

Table 3 Flood Frequency Analysis for San Lorenzo River and Pescadero Creek

San Lorenzo River				Pescadero Creek			
Date	Peak	RI	P	Date	Peak	RI	P
12/23/1955	30400	69.00	1.45	2/3/1998	10600	54.00	1.85
1/5/1982	29700	34.50	2.90	12/23/1955	9420	27.00	3.70
2/27/1940	24000	23.00	4.35	1/4/1982	9400	18.00	5.56
2/17/1986	19800	17.25	5.80	4/2/1958	7630	13.50	7.41
2/3/1998	19400	13.80	7.25	1/26/1983	7550	10.80	9.26
4/2/1958	17200	11.50	8.70	1/31/1963	6700	9.00	11.11
2/9/1941	15500	9.86	10.14	1/9/1995	6210	7.71	12.96
1/12/1952	14900	8.63	11.59	1/16/1973	5380	6.75	14.81
3/10/1995	14200	7.67	13.04	2/17/1986	5270	6.00	16.67
1/21/1943	13900	6.90	14.49	1/13/1993	5060	5.40	18.52
1/31/1938	13800	6.27	15.94	2/13/2000	4660	4.91	20.37
1/24/1942	13400	5.75	17.39	1/21/1967	4100	4.50	22.22
1/24/1983	13400	5.31	18.84	2/12/1992	4100	4.15	24.07
2/2/1945	13200	4.93	20.29	1/14/1978	4060	3.86	25.93
1/31/1963	13000	4.60	21.74	12/7/1952	4030	3.60	27.78
1/16/1973	11800	4.31	23.19	3/14/1952	3870	3.38	29.63
2/15/1969	11500	4.06	24.64	1/2/1997	3870	3.18	31.48
12/10/1996	11400	3.83	26.09	1/5/1965	3310	3.00	33.33
1/14/1978	11300	3.63	27.54	2/4/1996	3180	2.84	35.19
11/18/1950	10600	3.45	28.99	2/19/1980	2940	2.70	37.04
2/19/1980	10500	3.29	30.43	1/19/1969	2900	2.57	38.89
1/21/1967	10400	3.14	31.88	12/2/2001	2770	2.45	40.74
2/12/1992	10400	3.00	33.33	1/30/1968	2740	2.35	42.59
2/14/1937	9910	2.88	34.78	2/9/1999	2700	2.25	44.44
12/7/1952	9250	2.76	36.23	4/1/1974	2370	2.16	46.30
1/30/1968	8720	2.65	37.68	1/16/1970	2300	2.08	48.15
1/5/1965	8450	2.56	39.13	12/25/1983	2150	2.00	50.00
1/16/1970	8190	2.46	40.58	2/14/1979	1900	1.93	51.85
12/2/2001	7880	2.38	42.03	3/22/1975	1740	1.86	53.70
2/13/2000	7550	2.30	43.48	2/15/1962	1720	1.80	55.56
2/16/1959	6690	2.23	44.93	2/8/1985	1680	1.74	57.41
1/13/1993	6430	2.16	46.38	2/16/1959	1380	1.69	59.26
12/25/1983	6290	2.09	47.83		1380	1.64	61.11
2/6/1950	6190	2.03	49.28	3/4/1991	1180	1.59	62.96
2/14/1962	6090	1.97	50.72	1/20/1964	1170	1.54	64.81
2/19/1996	5790	1.92	52.17	2004	1080	1.50	66.67
2/13/1979	5080	1.86	53.62	2/19/1994	991	1.46	68.52
3/21/1975	5040	1.82	55.07	1/17/1954	953	1.42	70.37
3/28/1974	4220	1.77	56.52	5/18/1957	908	1.38	72.22
3/24/1991	4100	1.73	57.97	12/2/1954	840	1.35	74.07
3/10/1949	3880	1.68	59.42	2/8/1960	816	1.32	75.93
2003	3320	1.64	60.87	11/29/1970	770	1.29	77.78

12/2/1954	3300	1.60	62.32
2/8/1985	3290	1.57	63.77
2/13/1987	3220	1.53	65.22
2/9/1999	3200	1.50	66.67
2004	3140	1.47	68.12
2/1/1960	2990	1.44	69.57
12/27/1945	2810	1.41	71.01
1/17/1954	2710	1.38	72.46
1/21/1964	2660	1.35	73.91
2/24/1957	2560	1.33	75.36
11/29/1970	2530	1.30	76.81
3/21/1981	2410	1.28	78.26
2/19/1994	2290	1.25	79.71
3/4/2001	1900	1.23	81.16
3/4/1944	1890	1.21	82.61
1/17/1988	1460	1.19	84.06
11/22/1946	1450	1.17	85.51
4/29/1948	1390	1.15	86.96
2/16/1990	1170	1.13	88.41
3/11/1989	1150	1.11	89.86
12/29/1965	1080	1.10	91.30
12/27/1971	1060	1.08	92.75
3/9/1939	678	1.06	94.20
11/26/1960	639	1.05	95.65
2/29/1976	458	1.03	97.10
3/15/1977	263	1.01	98.55

3/11/1989	751	1.26	79.63
3/4/2001	710	1.23	81.48
2/13/1987	702	1.20	83.33
3/21/1981	631	1.17	85.19
12/28/1965	626	1.15	87.04
2/16/1990	508	1.13	88.89
1/17/1988	475	1.10	90.74
12/27/1971	205	1.08	92.59
3/15/1961	150	1.06	94.44
2/29/1976	86	1.04	96.30
3/16/1977	67	1.02	98.15

Table 4 – Longitudinal Data

Meters	Feet	Station	Instrument Station	High Wtr Mark	Absolute Elev HWM	Thalweg	Absol Elev Thlwg	Instr Height	Water Depth	Surface Elev
0	0.00	1	1	9.79	-10.90	13.38	-14.49	-1.11	0.94	-13.55
5	16.40	2		11.14	-12.25	13.54	-14.65		1.10	-13.55
10	32.81	3		11.41	-12.52	15.13	-16.24		1.58	-14.66
15	49.21	4		10.87	-11.98	17.05	-18.16		2.21	-15.95
20	65.62	5		12.35	-13.46	16.20	-17.31		0.76	-16.55
25	82.02	6		12.39	-13.50	16.69	-17.80		1.00	-16.80
30	98.43	7	2	4.65	-16.11	7.42	-18.88	-11.46	0.90	-17.98
35	114.83	8		6.50	-17.96	9.61	-21.07		0.51	-20.56
40	131.23	9		7.36	-18.82	10.77	-22.23		1.10	-21.13
45	147.64	10		7.86	-19.32	11.31	-22.77		1.60	-21.17
50	164.04	11		8.94	-20.40	11.76	-23.22		1.87	-21.35
55	180.45	12		9.13	-20.59	11.91	-23.37		0.92	-22.45
60	196.85	13	3	8.33	-22.23	12.78	-26.68	-13.90	0.84	-25.84
65	213.25	14		8.20	-22.10	13.69	-27.59		1.49	-26.10
70	229.66	15		10.26	-24.16	13.94	-27.84		1.91	-25.93
75	246.06	16		10.39	-24.29	12.96	-26.86		0.89	-25.97
80	262.47	17		12.62	-26.52	13.89	-27.79		0.50	-27.29
85	278.87	18	4	7.73	-25.24	11.66	-29.17	-17.51	0.90	-28.27
90	295.28	19		9.17	-26.68	12.70	-30.21		1.20	-29.01
95	311.68	20		10.30	-27.81	12.80	-30.31		0.70	-29.61
100	328.08	21		10.61	-28.12	15.61	-33.12		2.10	-31.02
105	344.49	22		10.62	-28.13	14.24	-31.75		1.40	-30.35
110	360.89	23		11.10	-28.61	13.42	-30.93		0.48	-30.45
115	377.30	24		11.07	-28.58	14.66	-32.17		0.85	-31.32
120	393.70	25	5	2.63	-28.63	7.02	-33.02	-26.00	1.88	-31.14
125	410.10	26		2.74	-28.74	5.96	-31.96		0.82	-31.14
130	426.51	27		3.31	-29.31	6.35	-32.35		0.48	-31.87
135	442.91	28		3.56	-29.56	7.43	-33.43		0.74	-32.69
140	459.32	29		3.57	-29.57	8.54	-34.54		1.64	-32.90
145	475.72	30		3.58	-29.58	7.63	-33.63		0.78	-32.85
150	492.13	31		3.74	-29.74	7.43	-33.43		0.44	-32.99

Table 5 – Cross Section Data

Cross Section 1 (Instrument Station 1 - 0 Meters)

Description	Distance in Ft	Height	Elevation
Left T O B	0.00	1.09	-2.20
	5.50	3.28	-4.39
	7.00	6.68	-7.79
High Wtr Mark	12.50	9.79	-10.90
L Edge Water	17.50	12.29	-13.40
	22.00	12.31	-13.42
Thalweg	27.00	13.42	-14.53
R Edge Water	29.50	12.37	-13.48
	31.50	8.96	-10.07
	36.50	6.55	-7.66
Right T O B	40.00	3.31	-4.42

Cross Section 2 (Instrument Station 2 - 50 Meters)

Description	Distance in Ft	Height	Elevation
Left T O B	0.00	4.41	-15.87
	3.00	5.25	-16.71
	20.00	5.95	-17.41
	45.00	6.70	-18.16
High Wtr Mark	49.00	8.69	-20.15
	51.00	9.75	-21.21
L Edge Water	55.00	10.49	-21.95
	56.20	11.18	-22.64
	59.20	11.10	-22.56
Thalweg	65.00	11.10	-22.56
R Edge Water	69.00	10.86	-22.32
	70.00	9.70	-21.16
	74.50	10.18	-21.64
Right T O B	75.00	8.00	-19.46
	79.00	6.50	-17.96
	84.00	2.50	-13.96
	88.00	1.50	-12.96

Cross Section 3 (Instrument Station 4 - 100 Meters)

Description	Distance in Ft	Height	Elevation
	0.00	2.44	-19.95
Left T O B	12.00	5.99	-23.50
	15.00	10.50	-28.01
L Edge Water	25.00	12.85	-30.36
Thalweg	26.70	15.61	-33.12
	31.50	13.37	-30.88
	35.50	13.15	-30.66
R Edge Water	37.50	12.76	-30.27
	40.30	12.27	-29.78
Right T O B	46.30	7.18	-24.69
	53.00	6.51	-24.02

Cross Section 4 (Instrument Station 7 - 150 Meters)

Description	Distance in Ft	Height	Elevation
	0.00	1.59	-15.41
Left T O B	4.40	3.52	-17.34
	14.00	9.04	-22.86
	24.00	17.95	-31.77
L Edge Water	30.00	18.84	-32.66
	34.00	18.95	-32.77
Thalweg	38.30	19.61	-33.43
R Edge Water	41.30	18.61	-32.43
	42.00	17.10	-30.92
	42.50	11.39	-25.21
Right T O B	47.00	6.61	-20.43
Road Edge	59.00	2.43	-16.25

Table 6 – Sediment Depth Measurements

Station 1 @ 0 Meters - X Sec 1

Description	X Sec Distance	Depth		
L Edge Water	0.00	0.07	-0.07	Notes:
	1.00	0.42	-0.42	Depth of 0.00 = Rock
	2.00	0.05	-0.05	Unit of Distance = 1 Wader Boot
	3.00	0.21	-0.21	
	4.00	0.00	0.00	
	5.00	0.00	0.00	
	6.00	0.34	-0.34	
	7.00	0.23	-0.23	
	8.00	0.22	-0.22	
R Edge Water	9.00	0.00	0.00	

Station 2 @ 23 Meters - Log Jam #1

Description	X Sec Distance	Depth	
Measurements taken in front of Log Jam 1	0.50	0.54	-0.54
	1.50	0.42	-0.42

Station 3 @ 29 Meters - Log Jam #2

Description	X Sec Distance	Depth	
	1.00	1.55	-1.55
Measurement taken in front of Log Jam 2			

Station 4 @ 50 Meters - X Sec 2

Description	X Sec Distance	Depth		
L Edge Water	0.00	0.68	-0.68	Notes:
	1.00	0.20	-0.20	Depth of 0.00 = Rock
	2.00	0.09	-0.09	Unit of Distance = 1 Wader Boot
	3.00	0.00	0.00	
	4.00	0.26	-0.26	
	5.00	0.00	0.00	
	6.00	0.41	-0.41	
	7.00	0.00	0.00	
R Edge Water	8.00	0.42	-0.42	

Station 5 @ 75.8 Meters - Log Jam 3

Description	X Sec Distance	Depth	
	3.00	1.29	-1.29
1st Measurement taken in front of Log Jam 3			
	5.00	0.76	-0.76
2nd Measurement taken downstream			

Station 6 @ 90 Meters - Behind Log Jam 4

Description	X Sec Distance	Depth	
Measurement taken 2.5' left of Log Jam 4	2.50	1.42	-1.42

Station 7 @ 100 Meters - X Sec 3

Description	X Sec Distance	Depth		
L Edge Water	0.00	3.80	-3.80	Notes:
	1.00	1.80	-1.80	Depth of 0.00 = Rock
	2.00	0.22	-0.22	Unit of Distance = 1 Wader Boot
	3.00	1.00	-1.00	
	4.00	0.72	-0.72	
	5.00	0.00	0.00	
	6.00	0.29	-0.29	
	7.00	0.33	-0.33	
	8.00	0.44	-0.44	
R Edge Water	9.00	1.34	-1.34	

Station 8 @ 114 Meters - At Large Boulder

Description	X Sec Distance	Depth	
	1.00	0.66	-0.66
Measurements taken downstream from boulder	2.00	0.58	-0.58

Station 9 @ 119 Meters - At Large Redwood Stump

Notes:
These are back eddy deposits.

Description	X Sec Distance	Depth	
	1.00	0.66	-0.66
Measurements taken downstream from stump	2.00	0.58	-0.58

Station 10 @ 122 Meters - Behind Bigleaf Maple Tree

Notes:
Bigleaf Maple Tree grows on a logjam.

Description	X Sec Distance	Depth	
	1.00	2.75	-2.75
Measurements taken downstream from log jam	4.00	4.23	-4.23

Station 11 @ 125 Meters - Point Bar Behind Station 10

Description	Long Distance	Depth	
	125.00	1.30	-1.30
Measurements taken downstream from log jam	128.90	1.45	-1.45

Station 12 @ 121.5 Meters - Point Bar Behind Station 9

Description	Long Distance	Depth	
	121.50	2.08	-2.08
Measurements taken downstream from stump	124.30	1.44	-1.44

Station 13 @ 137 Meters - Sandy Deposit Behind Rock Pile

Description	Long Distance	Depth	
	137.00	2.96	-2.96
Measurement taken downstream from rock pile			

Station 14 @ 150 Meters - X Sec 4

Description	X Sec Distance	Depth		
L Edge Water	0.00	0.00	0.00	Notes:
	1.00	0.17	-0.17	Depth of 0.00 = Rock
	2.00	0.21	-0.21	Unit of Distance = 1 Wader Boot
	3.00	0.51	-0.51	
	4.00	0.80	-0.80	
	5.00	0.00	0.00	
	6.00	0.35	-0.35	
	7.00	0.32	-0.32	
	8.00	2.30	-2.30	
R Edge Water	9.00	1.80	-1.80	

Table 7 – Manning's Formula for Calculating Q_{peak}

$$v = \frac{c(s^{0.5}\ R^{0.67})}{n}$$

where: v = velocity in feet per second
R = hydraulic radius***** in feet
s = energy slope****** (or river gradient)
n = roughness coefficient*******
c = coefficient of 1.49 to convert formula into English units

To obtain the hydraulic radius, we divide channel cross-sectional area in square feet, by the wetted perimeter (WP), which is the perimeter along the channel bottom, in feet:

R = A / WP

Energy slope (or river gradient) is obtained by dividing the difference in heights (dh) in feet at different measurement stations along the longitudinal section of the river, by the longitudinal length between those measurement stations (dl) in feet:

slope = dh/dl

Once we have velocity, we use the discharge equation to find the amount of water flow past a certain point in the channel:

Q = v A

where: Q = discharge in cubic feet per second
v = velocity in feet per second
A = cross-sectional area in square feet

CS 1		c=	1.49	CS 4		c=	1.49
		A=	42.5			A=	55.5
$v = \frac{c(s^{0.5}\ R^{0.67})}{n}$		WP=	21.5	$v = \frac{c(s^{0.5}\ R^{0.67})}{n}$		WP=	25.42
		Slope =	0.0383			Slope =	0.0383
		n=	0.097			n=	0.097
v=	4.7457	R=	1.97674	v=	5.07251	R=	2.18332

Q = (4.76 ft / sec) (42.50 sq ft)

Q = (5.08 ft / sec) (55.50 sq ft)