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Stream Channel Assessment for Horse Creek Dam Removal Project

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Background

Horse Creek is a tributary to the Sisquoc River, a designated Wild and Scenic River in northern Santa Barbara County. Horse Creek lies entirely within the Los Padres National Forest, with most of the watershed lying within the San Rafael Wilderness. Horse Creek is the furthest downstream tributary to the Sisquoc River that is entirely within the National Forest.

This stream is believed to have historically served as spawning and rearing habitat for Southern Steelhead, an anadromous form of rainbow trout which is currently listed as Endangered under the Federal Endangered Species Act. However, on Horse Creek approximately 850 feet upstream of the Sisquoc River exists an abandoned concrete dam. The dam crest is nearly 9 feet above the downstream channel bed, and based on an earlier barrier assessment it is believed to block all upstream migrating fish (Stoecker, 2003). The dam is constructed of sacrete and rebar and contains a stilling well, likely installed for gaging stream flows. The dam is completely filled-in with sediment and no longer serves its intended purpose. The Community Environmental Council, the Los Padres National Forest, and the California Department of Fish and Game are working together to remove the abandoned dam and restore access for steelhead to the upstream habitat.

Michael Love & Associates was contracted to perform a site survey with the assistance of Stoecker Ecological to characterize the existing physical channel conditions, evaluate anticipated channel response associated with removal of the dam, and characterize the streams hydrology through estimation of peak flows and associated recurrence intervals.

Fieldwork

A field survey of Horse Creek and the dam site was conducted by Michael Love and Matt Stoecker on June 14-15, 2005. The survey was conducted using an autolevel, stadia rod, survey measuring tapes, and bearing compass. Survey elevations were based on an assumed common datum that was arbitrarily selected. The survey included a longitudinal profile of the channel thalwag that extended 2,200 feet upstream of the confluence with the Sisquoc River. In addition to the longitudinal profile, seven channel cross sections were surveyed: two below the dam, one along the dam crest, and four upstream of the dam. Using the bearing compass and tape, various features (including channel banks, toes of hill slopes, large trees, and vegetation changes) were mapped to create a scaled site map of the area. To roughly characterize the size of sediment stored behind the dam, a Wolman pebble count was conducted approximately 250 feet upstream of the dam.

Existing Conditions

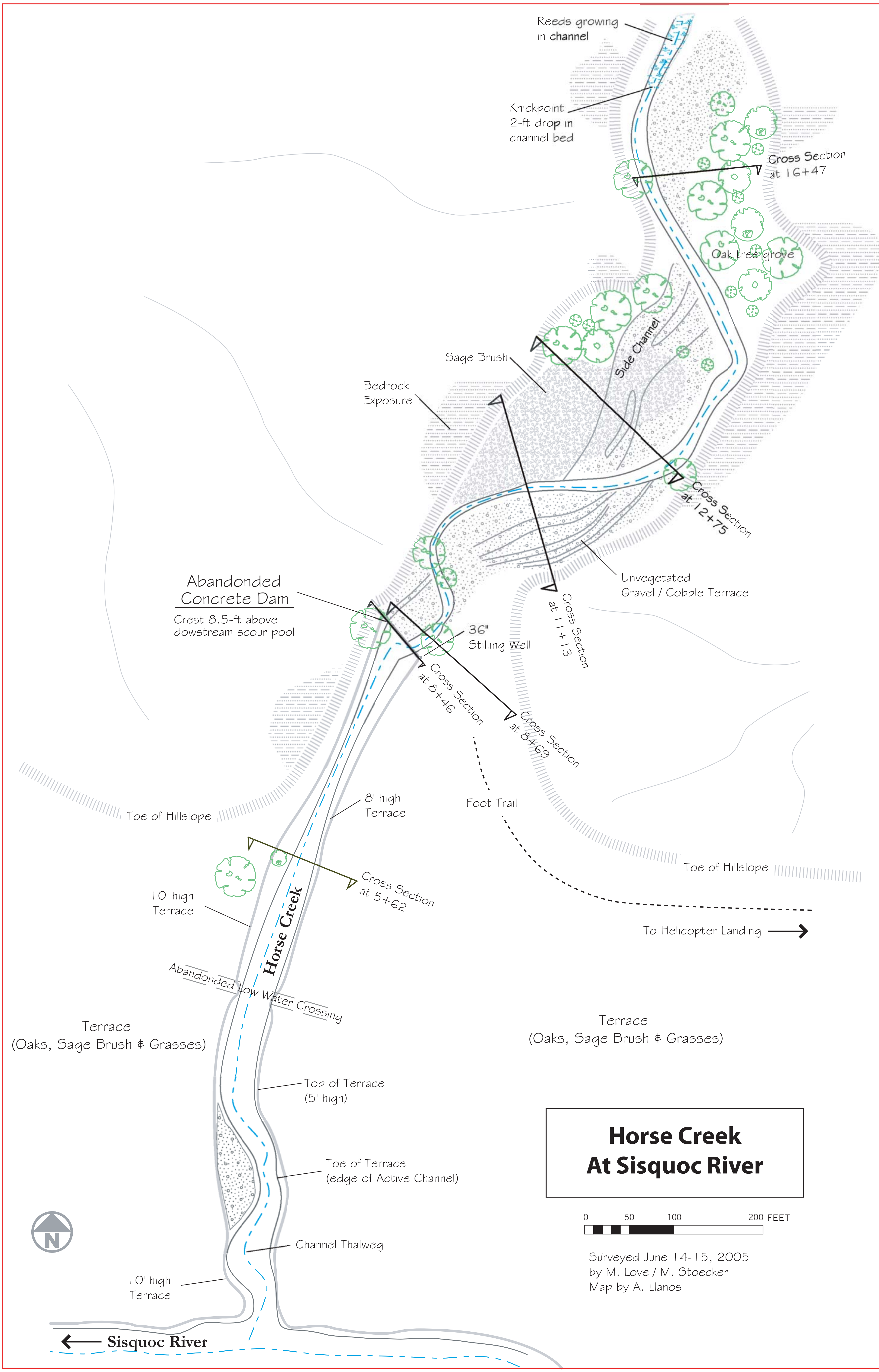
From Sisquoc River to the Abandoned Dam

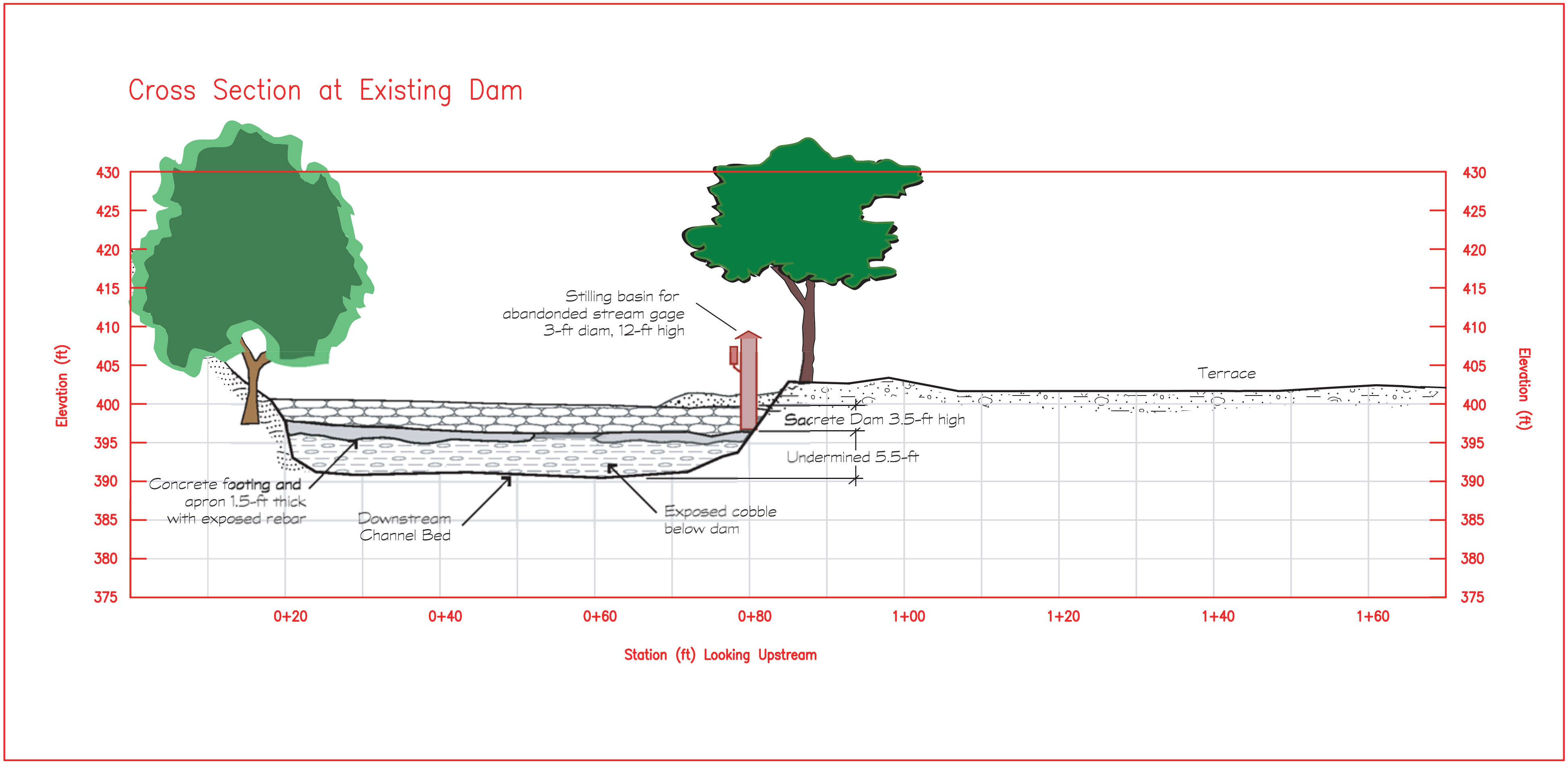
The dam lies 846 feet upstream of the Sisquoc River at a natural constriction of the stream channel by the adjacent hillslope. The channel below the dam is relatively straight and incised, cutting through an eight to ten foot high terrace formed by the river. The channel bed within this reach has an average bed slope of 2.2% and is predominately comprised of large gravel and cobble mixed with sand (Figure 1). The average width of the actively scoured channel is approximately 35 feet, and the width between the terrace tops varies between 30 and 60 feet (Figure 2 – Site Map). The banks are nearly vertical and show signs of regular sluffing. At the confluence with the river the channel bed drops steeply and shows signs of being backwatered by the river at high flows.

Figure 1 - Horse Creek approximately 400 feet downstream of the abandoned dam.

The Abandoned Dam

The abandoned dam is constructed of sacrete (bags of concrete stacked onto each other and cured in-place). The dam crest spans 62 feet, beginning on the hill slope above the right bank (looking downstream) and terminating at the terrace along the left bank (Figures 3 and 4). The dam crest slopes towards the left bank, concentrating low flows towards the left side. At the left edge of the dam there is a 12 feet tall stilling well constructed of 36” diameter corrugated metal pipe. Next to the stilling well, there is a hand written date stamp into the concrete of 11/3/69.


Reeds growing in channel
Knickpoint 2-ft drop in channel bed
Cross Section at 16+47
Oak tree grove
Side Channel
Sage Brush
Bedrock Exposure
Cross Section at 12+75
Unvegetated Gravel / Cobble Terrace
Cross Section at 11+13
Abandonded Concrete Dam
Crest 8.5-ft above dowstream scour pool
36" Stilling Well
Cross Section at 8+46
Cross Section at 8+69
Foot Trail
Toe of Hillslope
8' high Terrace
Toe of Hillslope
Cross Section at 5+62
10' high Terrace
Horse Creek
To Helicopter Landing
Abandonded Low Water Crossing
Terrace (Oaks, Sage Brush & Grasses)
Terrace (Oaks, Sage Brush & Grasses)
Top of Terrace (5' high)
Toe of Terrace (edge of Active Channel)
Channel Thalweg
10' high Terrace
Sisquoc River
N
Horse Creek At Sisquoc River
0 50 100 200 FEET
Surveyed June 14-15, 2005
by M. Love / M. Stoecker
Map by A. Llanos



Cross Section at Existing Dam
Elevation (ft)
430
425
420
415
410
405
400
395
390
385
380
375
Stilling basin for
abandonded stream gage
3-ft diam, 12-ft high
Terrace
Sacrete Dam 3.5-ft high
Undermined 5.5-ft
Concrete footing and
apron 1.5-ft thick
with exposed rebar
Downstream
Channel Bed
Exposed cobble
below dam
0+20
0+40
0+60
0+80
1+00
1+20
1+40
1+60
Station (ft) Looking Upstream

The face of the dam is approximately 3.5 feet in height. Below the sacrete is a poured concrete footing and apron for the dam that is approximately 1.5 feet thick. However, the downstream channel bed has incised, leaving the footing perched about 4 feet above the outlet pool. There is substantial scour and undermining of the footing. Approximately ¼” rebar was observed protruding vertically through the footing, suggesting that the entire dam is reinforced with rebar. This likely explains why the dam has not collapsed from the extensive undermining.

Figure 4 - Horse Creek dam, 846 feet upstream of the confluence with the Sisquoc River.

Upstream of Abandoned Dam

The upstream side of the dam has completely filled with sediment. The channel meanders within the deposited sediment. Paralleling the stream are two steep hill slopes with numerous nearly vertical bedrock exposures. Between the hills and adjacent to the stream channel exist two large depositional bars that are scoured regularly by high flows, preventing vegetation from becoming established (Figure 5). There are also several sizable side channels cutting through the bars.

In various locations mature oaks and sycamores appear to be partially buried by the deposited sediment. Further upstream there are several groves of mature oak trees that predate the dam and appear to be unaffected by the channel aggradation caused by the dam. Along the right side of the channel (west side) there is a large terrace comprised of sage brushes. This terrace appears to have been formed prior to the construction of the dam and show no signs of being recently inundated or scoured by flows.

Approximately 930 feet upstream of the dam there is a knick point (hard point) in the channel bed formed by a mat of roots from cattails (or similar aquatic flora). At the knick point the channel bed drops nearly two feet. Upstream of the knick point the channel becomes overgrown by stands of cattails. Cattails growing within the active channel continue for approximately 500 feet upstream. Within this reach aggradation resulting from the dam appears to be limited to within the channel. Immediately upstream of the cattails the channel becomes slightly steeper with little to no signs of aggradation caused by the dam.

Figure 5 – Depositional bar about 270 feet upstream of dam.

Anticipated Channel Profile following Dam Removal

The 2,200 feet longitudinal profile was used to estimate the extent that the channel bed would regrade upstream of the dam once removed (Figure 6). The analysis incorporated techniques outlined by Castro (2003). The first step involved using linear regression of the surveyed thalwag points to estimate the average slope of the channel below the dam (not including the steep drop at the confluence with Sisquoc River) and upstream of the dam. The downstream and upstream slopes were estimated to be 2.2% and 1.8%, respectively. Projecting both of these slopes beyond the end of the survey, we found that they intersect 2,321 feet upstream of the dam. This provides a reasonable estimate of the extent the channel will regrade following dam removal.

The estimated distance is based on several important assumptions. It assumes no hard bedrock features will be exposed as the upstream channel cuts through the deposited streambed material. If hard bedrock is exposed, it will likely limit any further upstream regarding of the channel bed. This is not anticipated based on the width between the valley walls and that the channel bed did not expose bedrock below the dam.

Another important assumption is that the plan-form of the channel will remain unchanged following dam removal. Currently the channel has several meanders immediately upstream of the dam. Removal of the dam and increasing the slope of the stream may cause it to straighten some of the existing meanders. This will shorten the overall stream length and could cause the regrading to proceed further upstream than anticipated. However, it is unlikely that changes in the stream's plan-form will be substantial.

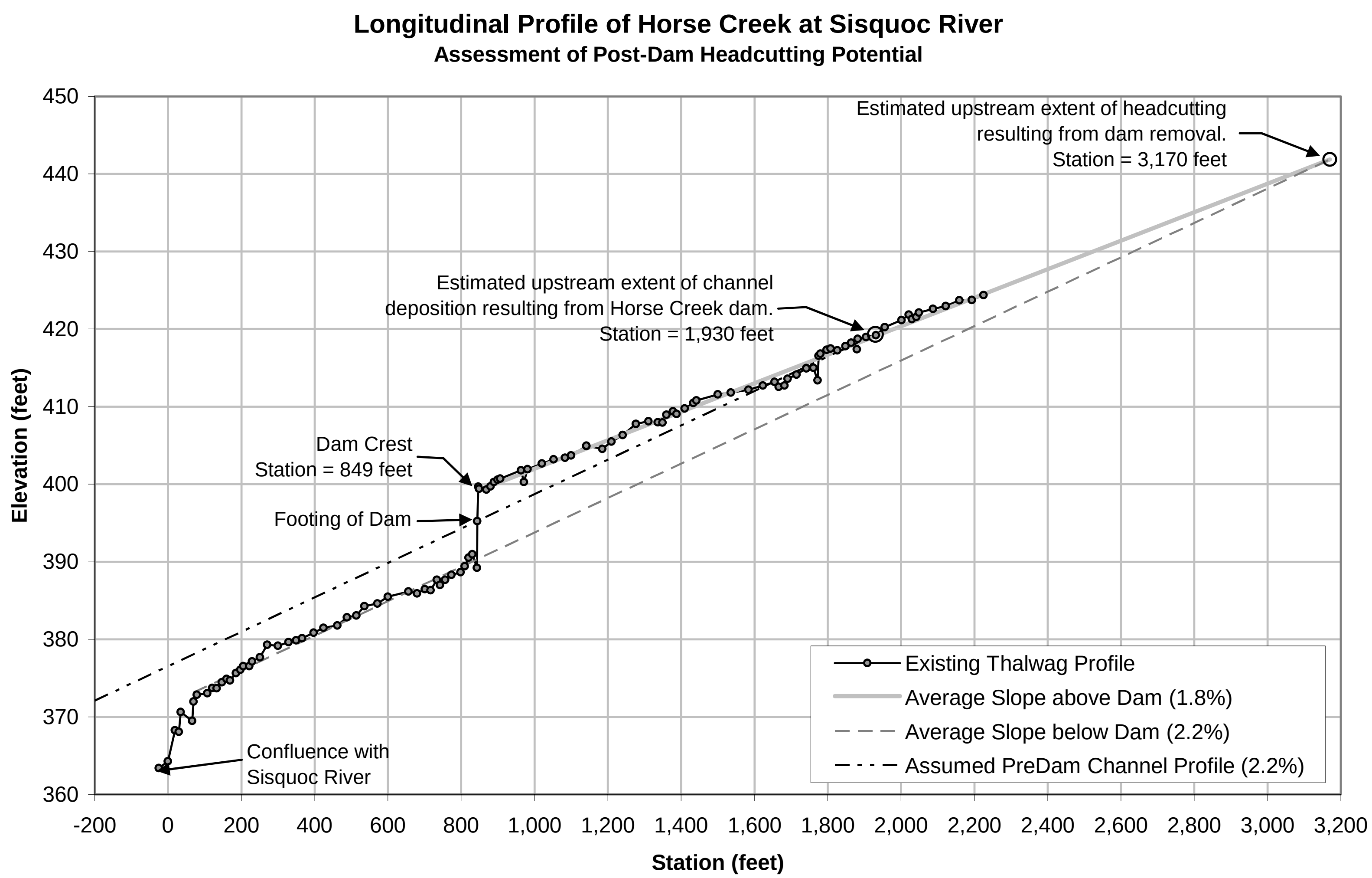


Figure 6 - Longitudinal profile of Horse Creek, showing the estimated extent of headcutting resulting from removal of the existing dam. Also shown is the suspected pre-dam channel grade based on existing slope of the downstream channel and the elevation of the dam's footing.

Downstream Channel Incision and Channel Regrade

When constructed the dam was no more than 4 feet in height above the downstream channel bed. However, since then the channel below the dam appears to have incised nearly 5 feet, as evidenced by the elevation of the dam's undermined footing and apron. Several possible explanations were considered for the channel incision.

1. Localized scour below the dam
2. Sediment starvation of the downstream channel
3. Change in "base level" through:
    a. Lateral migration of the Sisquoc towards the north, shortening the Horse Creek Channel, or
    b. Degradation (lowering) of the Sisquoc River bed at the confluence.

The longitudinal profile indicates that the entire downstream channel has a relatively constant slope and the incision is not localized. Although the channel may be slightly sediment starved due to the interruption of sediment transport by the dam, it is likely not significant enough to account for the degree of channel incision observed. The area upstream of the dam appears to have filled-in many years ago and no longer interrupts sediment transport. The release of sediment from removal of the dam will temporarily cause portions of the downstream channel to aggrade. However, it is uncertain if the aggradation will persist once the upstream channel re-stabilizes.

Change in base level is the most likely explanation for the observed incision of the downstream channel. The Sisquoc River is a sediment rich fluvial system and these types of rivers often experience rapid change in their plan-form over the course of a single large flood event. The USGS 1:24,000 topographic map of the area shows the river being multi-channeled. The main channel of the river could have either changed locations or, as a result of bank erosion, migrated towards Horse Creek. Also, the bed of the Sisquoc River may have locally lowered for numerous reasons. With any of these situations Horse Creek would respond with channel incision that would migrate upstream until being stopped by dam.

We attempted to estimate the location of the channel bed prior to the dam's construction by assuming it had the same overall slope as currently exists in the reach below the dam but was positioned 5 feet higher, matching the elevation of the dam's footing and apron. From the longitudinal profile we can see that the predicted depth and length of sediment deposited above the dam after construction is relatively small in comparison to the depth and length the channel will likely regrade after the dam is removed.

Estimated Volume of Sediment Release

The potential volume of sediment to be mobilized following dam removal was estimated using the anticipated post dam profile (Figure 6) combined with the surveyed cross sections. The channel shape below the dam is relatively uniform. The downstream cross section 5+62 (285 feet below the dam) was used as a reference section. We assumed the post dam channel shape within the regraded reach, once restabilized, would resemble the existing channel shape below the dam. The new channel is assumed to have a trapezoidal shape with a bottom width of 20 feet and 2:1 (horizontal: vertical) side slopes (Figure 7).

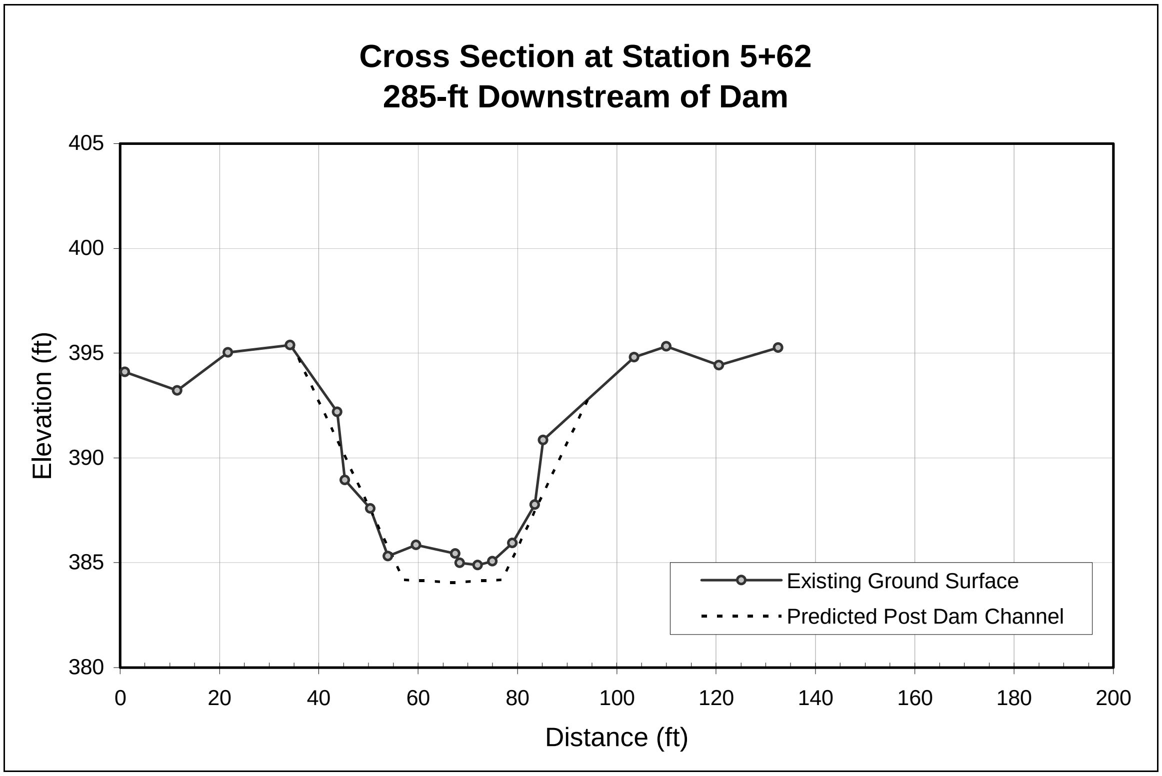


Figure 7 – The channel shape below the dam was used to predict the stabilized shape of the upstream channel after removal of the dam.

This trapezoidal channel shape was overlaid upon each of the five cross sections located at and above the dam (Appendix A). The bottom of the post dam channel was placed at the elevation given by the anticipated post dam profile shown in Figure 6. Next, the differences in areas between the existing cross sections and the post dam channel sections were calculated. The areas were then multiplied by the distance between cross sections to estimate volumes.

Using this approach, the predicted total sediment volume to be mobilized following dam removal is **15,400 cubic yards.**

Comparison of Sediment Volumes

We examined sediment transport rates associated with rivers within the region to give perspective to the estimated volume of sediment to be released after removal of the dam. Average rates of sediment transport can be estimated based on sedimentation rates within nearby reservoirs. Three nearby reservoirs on rivers similar to the Sisquoc River were considered: Twitchell Reservoir on Cuyama River, Cachuma Reservoir on Santa Ynez River, and Matilija Dam on Matilija Creek. Average annual sedimentation rates were obtained from the *California Beach Restoration Study* (2002). The rates were then divided by the reservoir's contributing drainage area to produce an estimate of average annual volume of sediment transported per unit drainage.

Table 1 – Estimates of average annual sediment transport rates per unit drainage area for three South Coast rivers, based on reservoir sedimentation rates reported in the *California Beach Restoration Study* (2002).

River System	Impoundment	Contributing Drainage Area	Annual Sediment Transport Rate
Cuyama River	Twitchell Dam	1,132 mi^2	1,528 yd^3/mi^2
San Ynez River	Bradbury Dam	417 mi^2	1,391 yd^3/mi^2
Matilija Creek	Matilija Dam	188 mi^2	1,063 yd^3/mi^2

The Sisquoc River at the confluence with Horse Creek has a drainage area of approximately 240 mi^2. Using the sediment transport rates in Table 1 gives an average annual volume of sediment transported in the Sisquoc River at Horse Creek between 255,000 yd^3 and 367,000 yd^3. The removal of the Horse Creek Dam is estimated to release an additional 15,400 yd^3. We suspect that the vast majority of channel regrading and resulting mobilization of sediment will occur within the course of a single year. This volume of sediment released downstream into the Sisquoc River represents a 4 to 6% increase in annual sediment input for one year. If the regrading occurs over several years or during a wetter than average year when the Sisquoc moves more than average amount of sediment, the percentages will be much lower.

Characterization of Sediment to be Released

The type of material released following the dam removal may be as important as the volume released. Releasing large amounts of fine grain bed material can have a negative effect on downstream aquatic habitat. However, releasing courser materials may have little to no negative impacts, and may even be beneficial to stream reaches that have been sediment starved. Horse Creek, like the Sisquoc River, is mostly comprised of cobbles, gravels and sands. Large gravel and small cobble is dominate both below the dam as well as on the recently scoured depositional areas above the dam. To characterize the surface material deposited above the dam, a Wolman pebble count was performed following procedures outlined in *Stream Channel Reference Sites: An Illustrated Guide to Field Techniques* (Harrelson et al., 1994). The pebble count was performed from 200 to 300 feet upstream of the dam. It was limited to the depositional terrace along the east side of the channel, in the vicinity of cross section 11+13.

Using a 100 count sample size, a cumulative frequency plot was constructed (Figure 8). The d35 (35 percentile), d50, and d84 were estimated to be 10 mm (medium gravel), 23 mm (coarse gravel), and 82 mm (small cobble) respectively. This represents relatively course substrate suitable as spawning gravel for adult steelhead and resident rainbow trout.

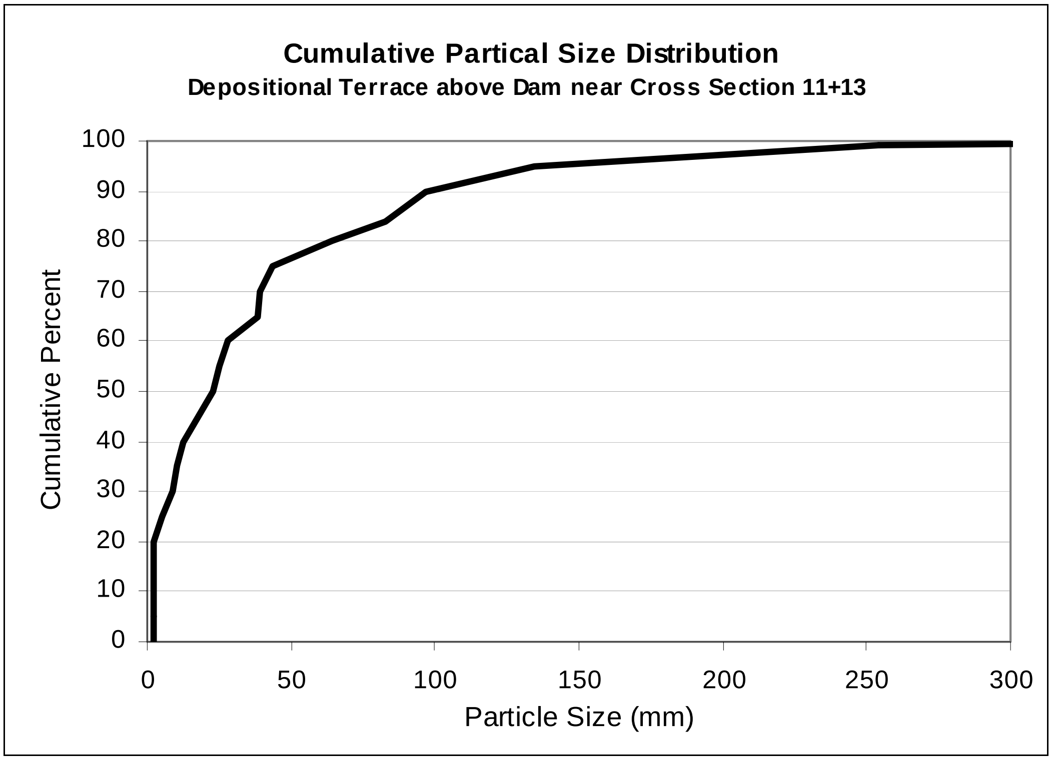


Figure 8 – Particle size distribution measured between 200 to 300 feet upstream of Horse Creek Dam.

Estimates of Peak Flows for Horse Creek

Peak flows within Horse Creek were estimated as part of this assessment. The Horse Creek watershed is relatively large (21.8 mi^2) and ranges in elevation from approximately 1,000 feet at its confluence to over 5,000 feet. Mean annual precipitation within the watershed is estimated to range between 20 and 24 inches per year (Daly and Taylor, 1998).

Two methods were used to estimate peak flows and their associated recurrence intervals:

1. Regional peak flow estimation equations developed by the USGS (Waananen and Crippen, 1977) and

2. Probability analysis of long term flow records from near by stream gages using procedures outlined in Bulletin 17B (USGS, 1982).

For the South Coast region, in which Horse Creek lies within, the peak flow estimation equations require estimates of drainage area and mean annual precipitation. The equations predict the 2, 5, 10, 25, 50, and 100 year peak flows. The equations have a standard error ranging between 32 and 47 percent. Results are presented in Table 2.

For the probabilistic analysis of historic stream flow records, four near-by local streams were identified that had no impoundments or diversions affecting peak flows, drainage areas between 29 and 40 mi^2 and record lengths exceeding 20 years (Table 3). The data was fitted to a Log Pearson Type III probability distribution. Then, to extrapolate the results to Horse Creek, the estimated peak flows were divided by the drainage area of the gaged stream and multiplied by the drainage area of Horse Creek.

The two methods gave drastically different flow estimates, especially for the less frequently occurring events. Since the regional peak flow estimation equations were developed for a large region that has varying hydrologic characteristics, the estimates based on the local stream flow records is likely more realistic.

Table 2 – Peak flow estimates for Horse Creek at the existing dam.

Method	2yr Flow (cfs)	5yr Flow (cfs)	10yr Flow (cfs)	25yr Flow (cfs)	50yr Flow (cfs)	100yr Flow (cfs)
Regional Peak Flow Equations:	193	797	1,607	3,592	5,716	8,152
Local Gaged Streams:						
Average	99	432	839	1,579	2,280	3,093
Minimum Estimate	22	104	223	489	800	1,232
Maximum Estimate	266	898	1,487	2,328	3,466	4,807

Table 3 – Flow records used in probabilistic analysis to estimate peak flows for Horse Creek.

USGS Site Name	Drainage Area (mi^2)	Record Length (years)	Distance from Horse Creek Dam (mi)
ZACA C NR BUELLTON CA	32.8	32	16.2
ZACA C A BUELLTON CA	39.4	24	18.3
ALAMO PINTADO C NR SOLVANG CA	29.4	29	16.1
SANTA CRUZ C NR SANTA YNEZ CA	74.0	62	17.8

Conclusions

The removal of the Horse Creek dam will likely cause the upstream channel to incise as stored sediments are mobilized and transported downstream to the Sisquoc River. The channel below the dam has incised nearly 5 feet since the dam was constructed, likely due to changes occurring in the Sisquoc River. For this reason, following removal the channel bed above the dam is expected to incise below the pre dam level and the channel may regrade upstream beyond the depositional areas caused by the dam. The anticipated volume to be release following dam removal (15,400 yd^3) may result in some localized aggradation of the Horse Creek channel below the dam. However, the volume released is likely less than 4-6% of the sediment volume transported annually by the Sisquoc River. Also, the mobilized sediment will likely be relatively course (gravels and cobbles).

Results from this study suggest removal of the dam will produce minimal to no negative impacts to the downstream stream and river channels. The upstream channel will experience some incision as the channel becomes wider and deeper. This will increase the overall grade of the stream above the dam, likely creating more channel complexity (i.e. pools and undercut banks). Additionally, dam removal and the resulting incision of the upstream channel will reduce the amount of flow becoming subsurface, maintaining surface flow later into the spring and summer.

References

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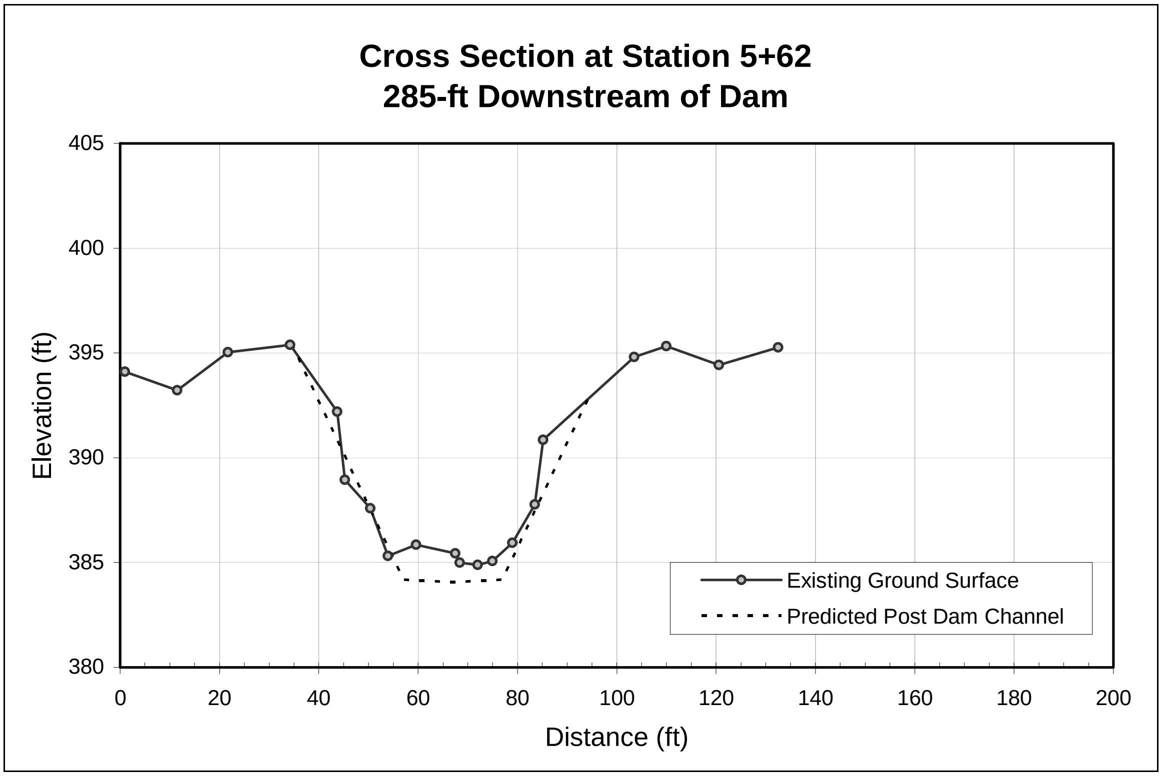
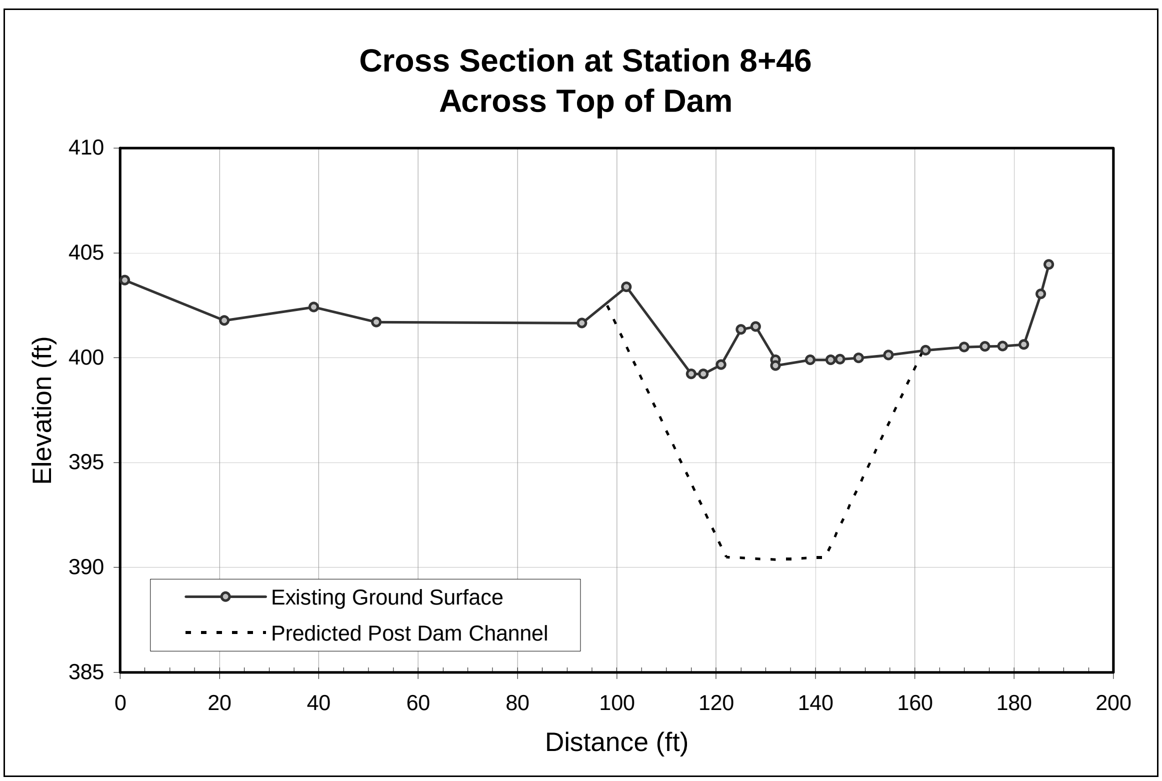
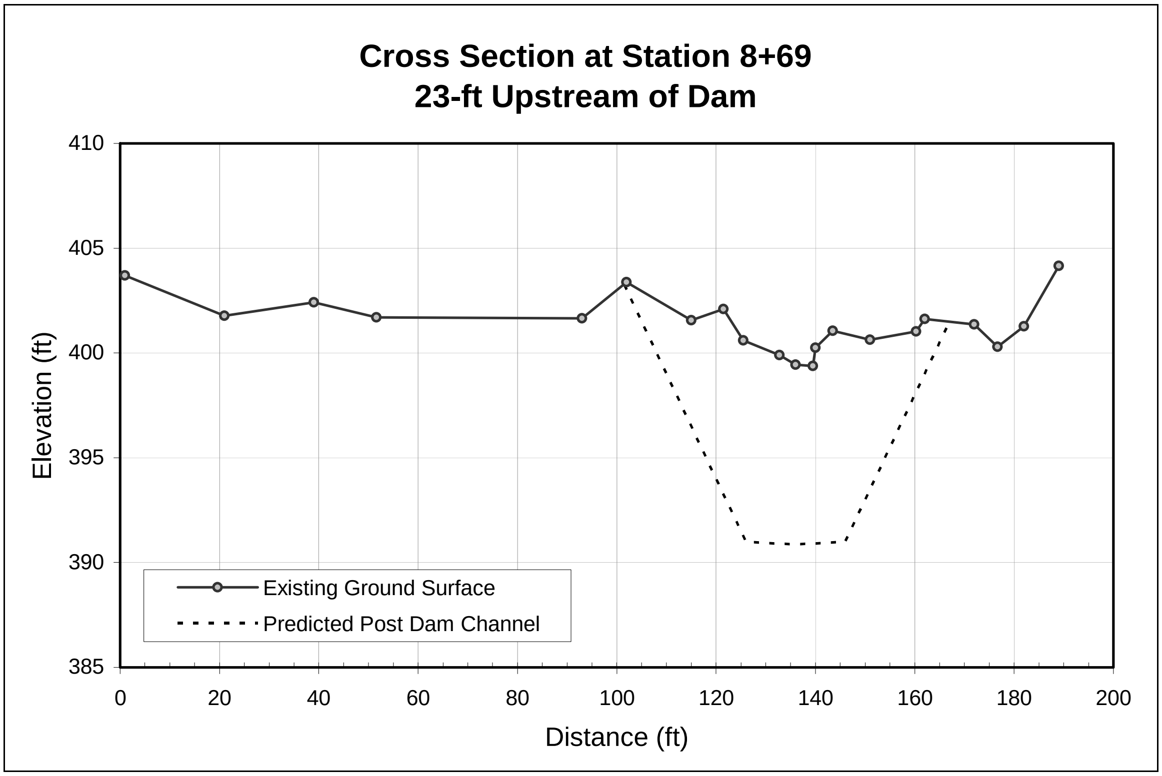
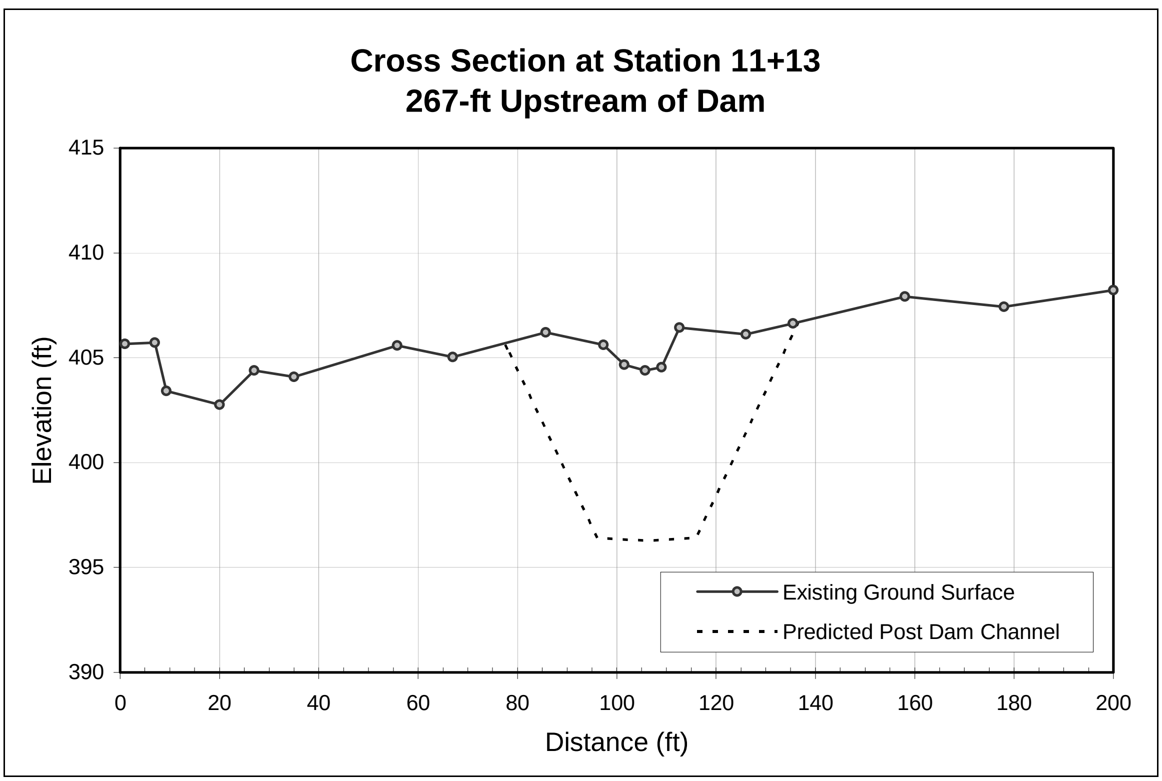
Appendix A

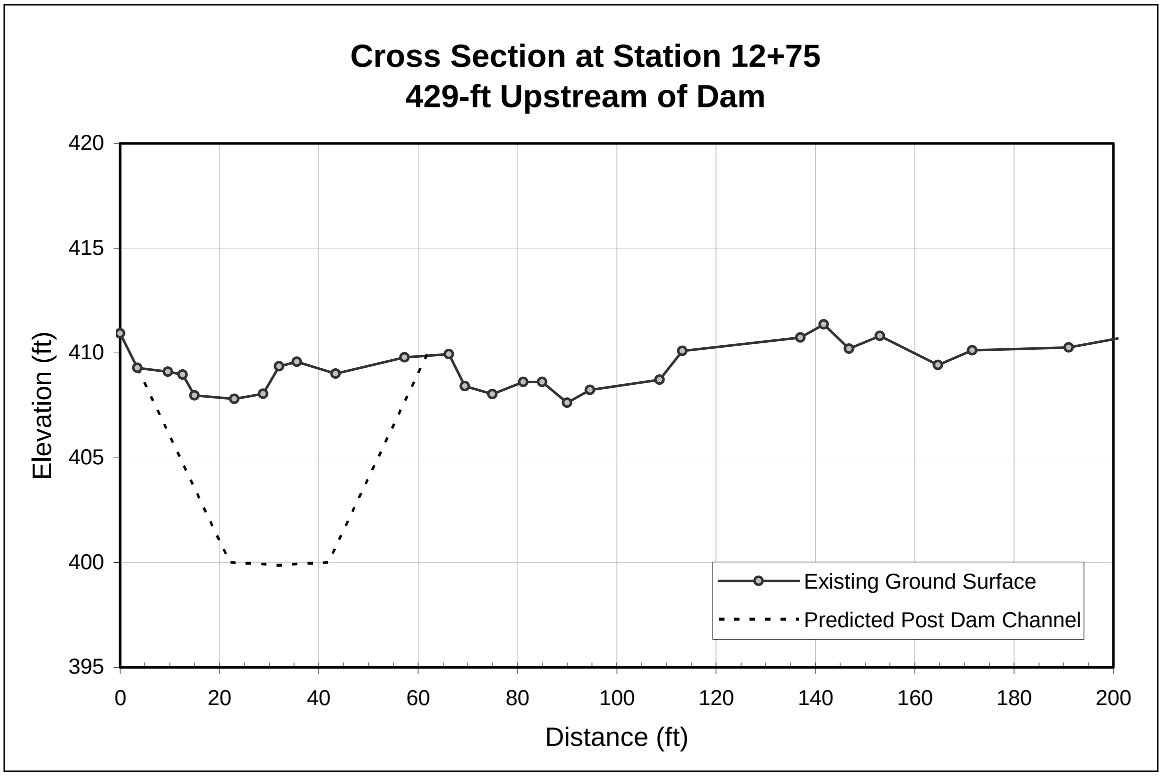
Existing and Predicted Post Dam
Channel Cross Sections


Cross Section at Station 5+62
285-ft Downstream of Dam
Elevation (ft)
Distance (ft)
405
400
395
390
385
380
0
20
40
60
80
100
120
140
160
180
200
Existing Ground Surface
Predicted Post Dam Channel

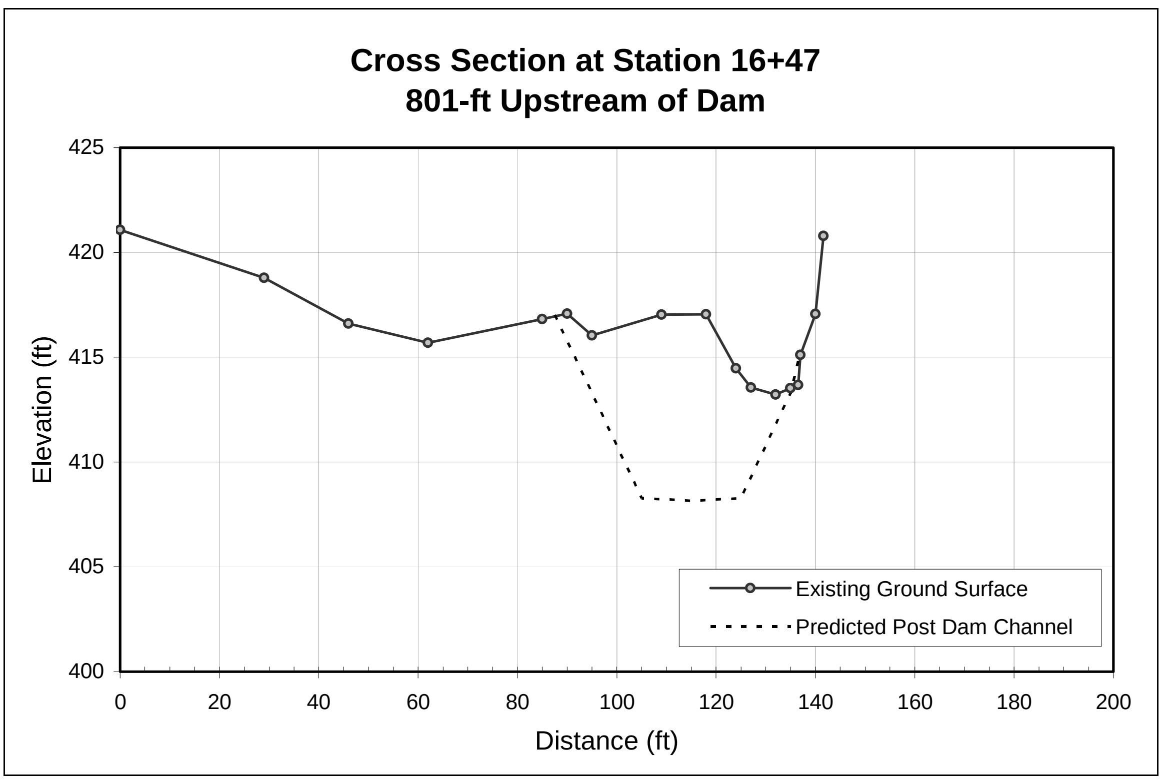

Cross Section at Station 8+46
Across Top of Dam
Elevation (ft)
Distance (ft)
410
405
400
395
390
385
0
20
40
60
80
100
120
140
160
180
200
Existing Ground Surface
Predicted Post Dam Channel


Cross Section at Station 8+69
23-ft Upstream of Dam
410
405
400
395
390
385
Elevation (ft)
0
20
40
60
80
100
120
140
160
180
200
Distance (ft)
Existing Ground Surface
Predicted Post Dam Channel


Cross Section at Station 11+13
267-ft Upstream of Dam
415
410
405
400
395
390
Elevation (ft)
0
20
40
60
80
100
120
140
160
180
200
Distance (ft)
Existing Ground Surface
Predicted Post Dam Channel



Cross Section at Station 12+75
429-ft Upstream of Dam
Elevation (ft)
Distance (ft)
Existing Ground Surface
Predicted Post Dam Channel
420
415
410
405
400
395
0
20
40
60
80
100
120
140
160
180
200



Cross Section at Station 16+47
801-ft Upstream of Dam
Elevation (ft)
Distance (ft)
Existing Ground Surface
Predicted Post Dam Channel
425
420
415
410
405
400
0
20
40
60
80
100
120
140
160
180
200

Estimated volumes of sediment to be released following dam removal.

Cross Section	Location	Area New (sf)	Area Existing (sf)	Difference (sf)	Average Area between Sections (sf)	Distance between Sections (ft)	Volume (cf)	Volume (cy)
8+46	Across Dam Crest	589	191	397				
					398	22	8,832	**327**
8+69	Above Dam	555	157	398				
					381	244	92,865	**3,439**
11+13	Above Dam	401	38	363				
					351	162	57,059	**2,113**
12+75	Above Dam	462	123	340				
					272	372	101,035	**3,742**
16+47	Above Dam	567	364	204				
					102	1,523	155,118	**5,745**
31+70	Upstream end of Regrade	-	-	0				
							Total Estimated Volume to be Mobilized =	**15,367**

Appendix B

Peak Flow Calculations for Horse Creek

Horse Creek

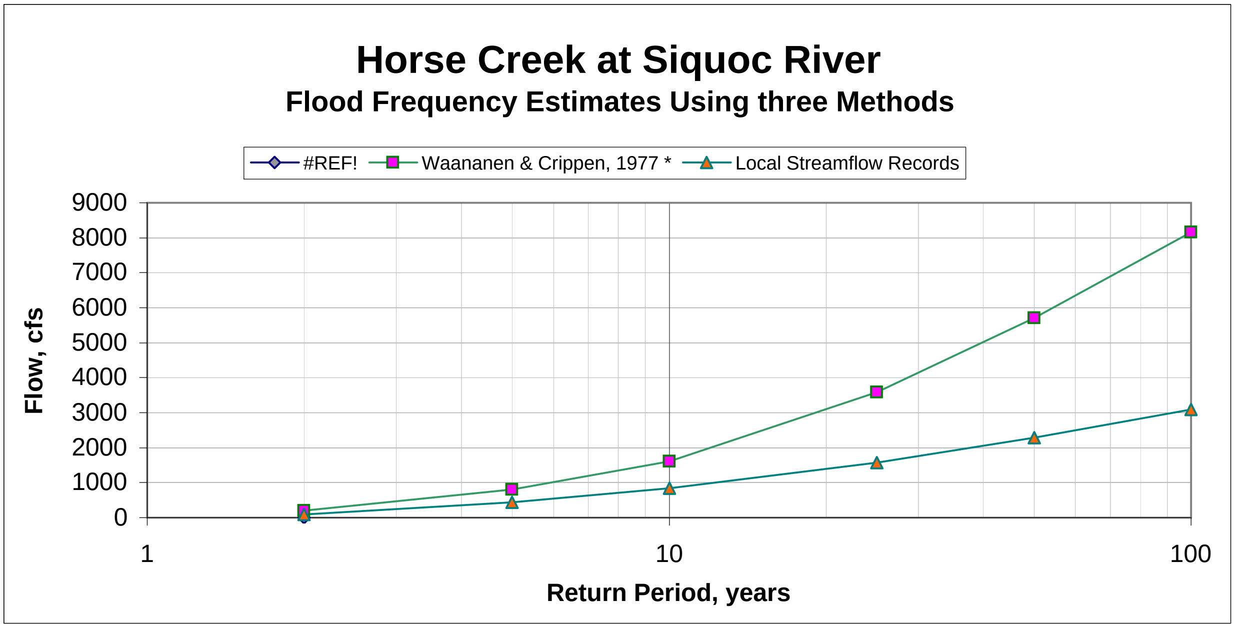
Summary of Peak Flow Calculations

Horse Creek at Siquoc River

Drainage Area (mi^2) = **21.8**

Mean Annual Precip. (in/yr) = **22.0** 20-24

Method	Q-2yr (cfs)	Q-5yr (cfs)	Q-10yr (cfs)	Q-25yr (cfs)	Q-50yr (cfs)	Q-100yr (cfs)
Waananen & Crippen, 1977 *	193	797	1,607	3,592	5,716	8,152
Local Streamflow Records						
Average	99	432	839	1,579	2,280	3,093
Mimium Estimate	22	104	223	489	800	1,232
Maximum Estimate	266	898	1,487	2,328	3,466	4,807



* Estimates using regional regression equations developed for the South Coast Region of California by the USGS (Waananen and Crippen, 1977):

South Coast Region (SC)

$Q_2 = 0.14 * A^{0.72} * p^{1.62}$

$Q_5 = 0.40 * A^{0.77} * p^{1.69}$

$Q_{10} = 0.63 * A^{0.79} * p^{1.75}$

$Q_{25} = 1.10 * A^{0.81} * p^{1.81}$

$Q_{50} = 1.50 * A^{0.82} * p^{1.85}$

$Q_{100} = 1.95 * A^{0.83} * p^{1.87}$

A = drainage area (mi2),

p = mean annual precipitation (in/yr),

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Flood Frequency Analysis Based on Local Streamflow Records

Peak flows associated with the 2-yr, 25-yr, 50-yr, and 100-yr recurrence intervals were estimated using a Log-Pearson type **III** distribution as described in Bulletin 17B (Guidelines for Determining Flood Flow Frequency, USGS, 1982).

Site Name	Location		Drainage Area (mi^2)	Record Length (yrs)	Recurrence Interval of Peak Flows 2-yr (cfs/mi^2)	5-yr (cfs/mi^2)	10-yr (cfs/mi^2)	25-yr (cfs/mi^2)	50-yr (cfs/mi^2)	100-yr (cfs/mi^2)
USGS ZACA C NR BUELLTON CA	34°38'55"	120°11'00"	32.80	32	1	10	24	55	86	125
USGS ALAMO PINTADO C NR SOLVANG CA	34°37'06"	120°07'11"	29.40	29	4	23	51	106	159	220
USGS SANTA CRUZ C NR SANTA YNEZ CA	34°35'48"	119°54'28"	74.00	62	12	41	68	107	136	165
USGS ZACA C A BUELLTON CA	34°36'50"	120°11'30"	39.40	24	1	5	10	22	37	57

	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
Min	1	5	10	22	37	57
Max	12	41	68	107	159	220
Average	5	20	39	72	105	142

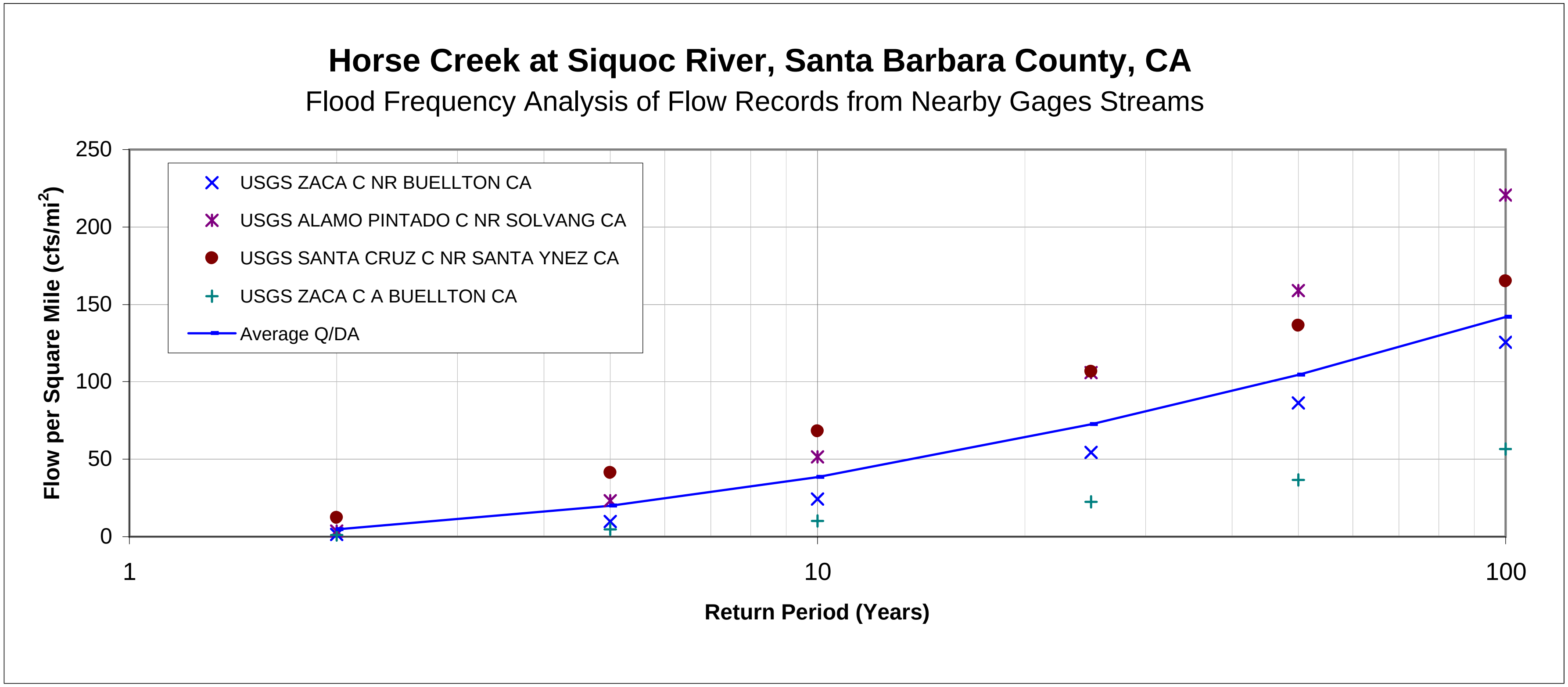
Peak Flow Estimates:

Peak flows for project site estimated from local streamflow records, adjusted by drainage area.

Horse Creek at Siquoc River

Drainage Area = 21.8 mi^2

	Q 2-yr	Q 5-yr	Q 10-yr	Q 25-yr	Q 50-yr	Q 100-yr
Average (cfs)	99	432	839	1,579	2,280	3,093
Minimum (cfs)	22	104	223	489	800	1,232
Maximum (cfs)	266	898	1,487	2,328	3,466	4,807



Horse Creek at Siquoc River, Santa Barbara County, CA
Flood Frequency Analysis of Flow Records from Nearby Gages Streams
Flow per Square Mile (cfs/mi²)
250
200
150
100
50
0
1
10
100
Return Period (Years)
USGS ZACA C NR BUELLTON CA
USGS ALAMO PINTADO C NR SOLVANG CA
USGS SANTA CRUZ C NR SANTA YNEZ CA
USGS ZACA C A BUELLTON CA
Average Q/DA

Flood Frequency based on Annual Maximum Series

USGS ALAMO PINTADO C NR SOLVANG CA

Station # 11128250

Drainage Area sq. mi **29.4**

Location: **34°37'06"** **120°07'11"** **NAD27**

WY	Date of Peak	Discharge (cfs)
	1/25/1969	10.32
	12/21/1970	12
	12/27/1971	0.75
	1/18/1973	466
	1/7/1974	93
	3/7/1975	40
	9/28/1976	8.8
	1/2/1977	7
	2/9/1978	724
	3/27/1979	106
	2/19/1980	397
	3/5/1981	139
	4/11/1982	42
	12/25/1982	900
	12/25/1983	126
	12/19/1984	40
	1990	0
	3/18/1991	865
	2/12/1992	615
	3/10/1995	863
	2/20/1996	486
	12/22/1996	180
	2/3/1998	3680
	3/20/1999	73
	2/23/2000	222
	3/5/2001	462
	11/24/2001	54
	12/19/2002	36
	2/26/2004	62

RANK	Recurrence Interval (years)	Dischage (cfs)	Discharge (cms)	log-discharge (cfs)
1	30.00	3680	104	3.57
2	15.00	900	25	2.95
3	10.00	865	24	2.94
4	7.50	863	24	2.94
5	6.00	724	21	2.86
6	5.00	615	17	2.79
7	4.29	486	14	2.69
8	3.75	466	13	2.67
9	3.33	462	13	2.66
10	3.00	397	11	2.60
11	2.73	222	6	2.35
12	2.50	180	5	2.26
13	2.31	139	4	2.14
14	2.14	126	4	2.10
15	2.00	106	3	2.03
16	1.88	93	3	1.97
17	1.76	73	2	1.86
18	1.67	62	2	1.79
19	1.58	54	2	1.73
20	1.50	42	1	1.62
21	1.43	40	1	1.60
22	1.36	40	1	1.60
23	1.30	36	1	1.56
24	1.25	12	0	1.08
25	1.20	10.32	0	1.01
26	1.15	8.8	0	0.94
27	1.11	7	0	0.85
28	1.07	0.75	0	-0.12
29	1.03	0.01	0	-2.00

Number of Years, n =	29		
Skewness =	4.02	4.02	-1.72
Mean=	369	10	1.90
Std Dev=	701	20	1.10

Peaks Flow Frequency

From USGS Data

Station # 11128250

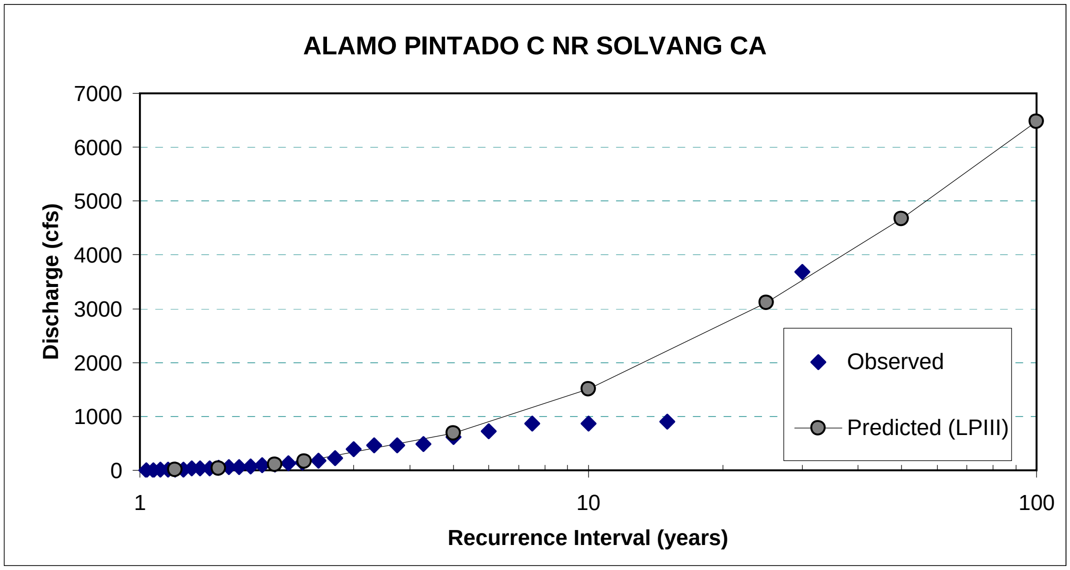
Generalized Skew=	**-0.30**	A=	-0.00283
Station Skewness (log Q)=	-1.72	B=	0.49178
Station Mean (log Q)=	1.90	MSE (station skew) =	0.58854
Station Std Dev (log Q)=	1.10		
Weighted Skewness (G_W)=	**-0.78**		

Log Pearson Type III Distribution

Return Period (years)	**Exceedence Probability**	**Log-Pearson K**	**Predicicted Discharge (cfs)**
1.2	0.833	-0.96636	7
1.5	0.667	-0.31879	35
2.0	0.500	0.12921	109
2.33	0.429	0.29714	167
5.0	0.200	0.85623	686
10	0.100	1.16878	1,512
25	0.040	1.45505	3,115
50	0.020	1.61584	4,675
100	0.010	1.74529	6,482

Values From K-Table for Linear interpolation

Weighted Skewnes	-0.80	-0.70	-0.78
P	K	K	K
0.9	-1.33640	-1.33294	-1.33581
0.8	-0.77986	-0.79022	-0.78163
0.7	-0.41309	-0.42851	-0.41573
0.6	-0.12199	-0.13901	-0.12490
0.500	0.13199	0.11578	0.12921
0.429	0.29961	0.28516	0.29714
0.200	0.85607	0.85703	0.85623
0.100	1.16574	1.18347	1.16878
0.040	1.44813	1.48852	1.45505
0.020	1.60604	1.66325	1.61584
0.010	1.73271	1.80621	1.74529



Michael Love Associates
P.O. Box 4477 Arcata CA 95518

Flood Frequency based on Annual Maximum Series

USGS ZACA C NR BUELLTON CA

Station # 11129800

Drainage Area sq. mi **32.80**
Location: **34°38'55"** **120°11'00"** **NAD27**

WY	Date of Peak	Discharge (cfs)	RANK	Recurrence Interval (years)	Dischage (cfs)	Discharge (cms)	log-discharge (cfs)
	5/16/1905	0	1	33.00	1390	39	3.14
	11/19/1963	8	2	16.50	1070	30	3.03
	11/12/1964	8	3	11.00	743	21	2.87
	2/6/1966	6	4	8.25	512	14	2.71
	12/6/1966	191	5	6.60	496	14	2.70
	3/13/1968	1	6	5.50	484	14	2.68
	2/24/1969	1390	7	4.71	246	7	2.39
	3/4/1970	9	8	4.13	233	7	2.37
	12/21/1970	3	9	3.67	205	6	2.31
	12/27/1971	5	10	3.30	191	5	2.28
	1/18/1973	205	11	3.00	142	4	2.15
	3/30/1974	16	12	2.75	103	3	2.01
	2/2/1975	48	13	2.54	96	3	1.98
	9/29/1976	45	14	2.36	52	1	1.72
	1/6/1977	14	15	2.20	48	1	1.68
	3/4/1978	743	16	2.06	45	1	1.65
	3/29/1979	28	17	1.94	32	1	1.51
	2/19/1980	96	18	1.83	28	1	1.45
	3/5/1981	142	19	1.74	28	1	1.45
	6/12/1905	0	20	1.65	16	0	1.20
	3/19/1991	233	21	1.57	14	0	1.15
	2/15/1992	512	22	1.50	12	0	1.08
	1/25/1995	496	23	1.43	9.8	0	0.99
	2/20/1996	103	24	1.38	9	0	0.95
	1/24/1997	52	25	1.32	8	0	0.90
	2/3/1998	1070	26	1.27	8	0	0.90
	2/9/1999	28	27	1.22	6	0	0.78
	2/23/2000	246	28	1.18	5	0	0.70
	3/5/2001	484	29	1.14	3	0	0.48
	11/24/2001	9.8	30	1.10	1	0	0.00
	12/20/2002	32	31	1.06	0.01	0	-2.00
	2/25/2004	12	32	1.03	0.01	0	-2.00

Number of Years, n =	32		
Skewness =	2.38	2.38	-1.35
Mean=	195	6	1.48
Std Dev=	331	9	1.21

Peaks Flow Frequency

From USGS Data

Station # 11129800

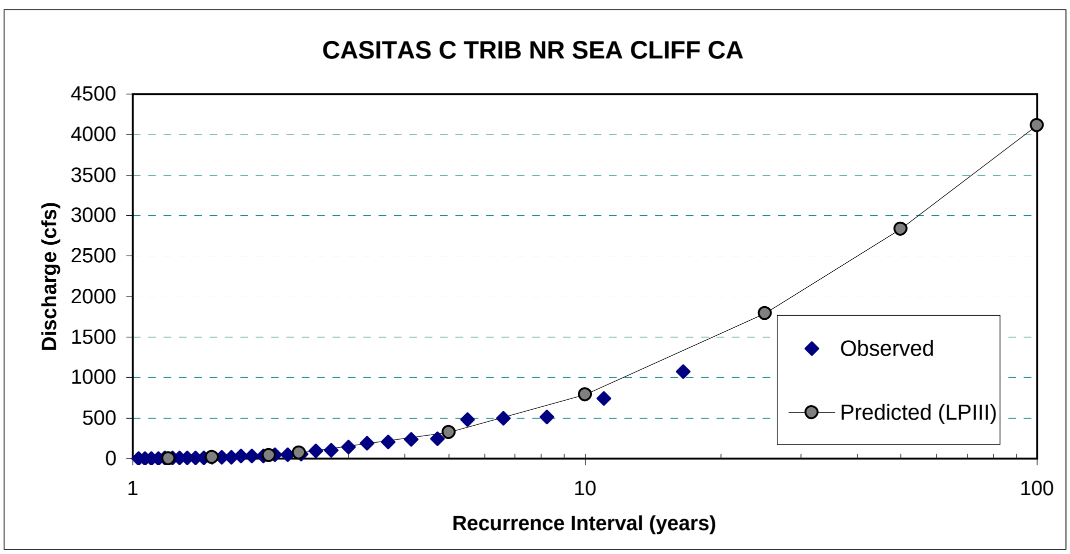
Generalized Skew=	-0.30	A=	-0.11601
Station Skewness (log Q)=	-1.35	B=	0.58988
Station Mean (log Q)=	1.48	MSE (station skew) =	0.38549
Station Std Dev (log Q)=	1.21		
Weighted Skewness (G_W)=	**-0.76**		

Log Pearson Type III Distribution

Return Period (years)	Exceedence Probability	Log-Pearson K	Predicicted Discharge (cfs)
1.2	0.833	-0.96769	2
1.5	0.667	-0.32248	12
2.0	0.500	0.12547	42
2.33	0.429	0.29380	68
5.0	0.200	0.85646	327
10	0.100	1.17287	792
25	0.040	1.46438	1,789
50	0.020	1.62906	2,835
100	0.010	1.76229	4,114

Values From K-Table for Linear interpolation

Weighted Skewness	-0.80	-0.70	-0.76
P	K	K	K
0.9	-1.33640	-1.33294	-1.33501
0.8	-0.77986	-0.79022	-0.78403
0.7	-0.41309	-0.42851	-0.41929
0.6	-0.12199	-0.13901	-0.12884
0.500	0.13199	0.11578	0.12547
0.429	0.29961	0.28516	0.29380
0.200	0.85607	0.85703	0.85646
0.100	1.16574	1.18347	1.17287
0.040	1.44813	1.48852	1.46438
0.020	1.60604	1.66325	1.62906
0.010	1.73271	1.80621	1.76229



Michael Love Associates
P.O. Box 4477 Arcata CA 95518

Flood Frequency based on Annual Maximum Series

USGS ZACA C A BUELLTON CA

Station # 11130000

Drainage Area sq. mi **39.40**

Location: **34°36'50"** **120°11'30"** **NAD27**

WY	Date of Peak	Discharge (cfs)
	3/3/1941	874
	12/28/1941	44
	1/22/1943	340
	2/22/1944	225
	2/2/1945	32
	3/29/1946	21
	11/20/1946	8
	3/24/1948	0.4
	3/4/1949	185
	12/8/1949	88
	10/26/1950	6.8
	1/15/1952	622
	12/30/1952	70
	1/19/1954	8
	1/9/1955	24
	1/26/1956	23
	5/11/1957	8.3
	4/3/1958	273
	2/21/1959	30
	2/1/1960	8
	1/26/1961	5
	2/11/1962	560
	3/28/1963	49
	1/26/1964	5

RANK	Recurrence Interval (years)	Dischage (cfs)	Discharge (cms)	log-discharge (cfs)
1	25.00	874	25	2.94
2	12.50	622	18	2.79
3	8.33	560	16	2.75
4	6.25	340	10	2.53
5	5.00	273	8	2.44
6	4.17	225	6	2.35
7	3.57	185	5	2.27
8	3.13	88	2	1.94
9	2.78	70	2	1.85
10	2.50	49	1	1.69
11	2.27	44	1	1.64
12	2.08	32	1	1.51
13	1.92	30	1	1.48
14	1.79	24	1	1.38
15	1.67	23	1	1.36
16	1.56	21	1	1.32
17	1.47	8.3	0	0.92
18	1.39	8	0	0.90
19	1.32	8	0	0.90
20	1.25	8	0	0.90
21	1.19	6.8	0	0.83
22	1.14	5	0	0.70
23	1.09	5	0	0.70
24	1.04	0.4	0	-0.40

Number of Years, n =	24		
Skewness =	2.03	2.03	-0.18
Mean=	146	4	1.57
Std Dev=	233	7	0.82

Peaks Flow Frequency

From USGS Data

Station # 11130000

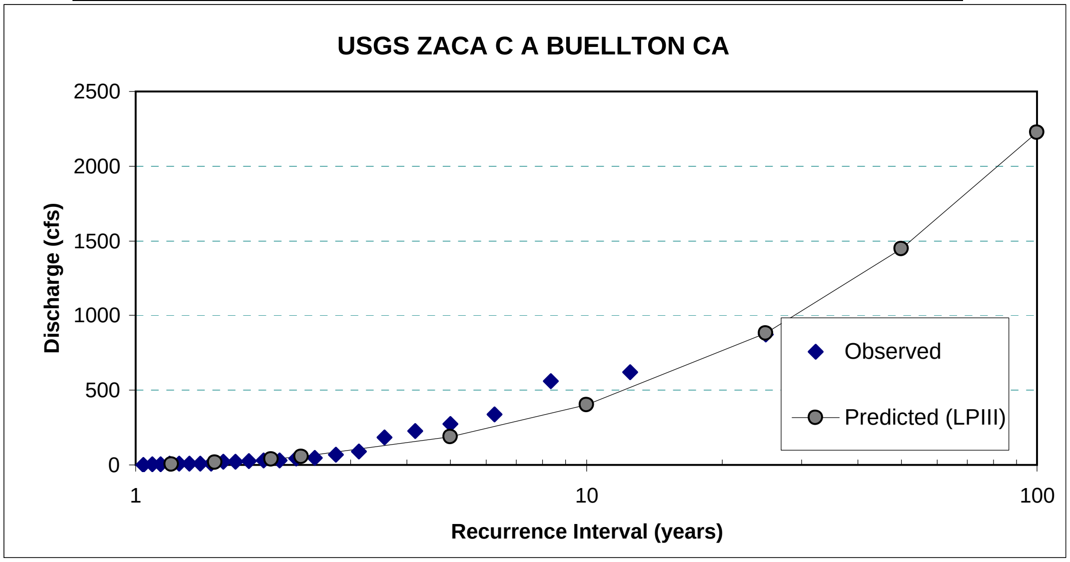
Generalized Skew=	**-0.30**	A=	-0.31574
Station Skewness (log Q)=	-0.18	B=	0.89366
Station Mean (log Q)=	1.57	MSE (station skew) =	0.22104
Station Std Dev (log Q)=	0.82		
Weighted Skewness (G_W)=	**-0.23**		

Log Pearson Type III Distribution

Return Period (years)	Exceedence Probability	Log-Pearson K	Predicicted Discharge (cfs)
1.2	0.833	-0.98681	6
1.5	0.667	-0.40251	17
2.0	0.500	0.03820	40
2.33	0.429	0.21390	56
5.0	0.200	0.85075	187
10	0.100	1.25436	402
25	0.040	1.66909	884
50	0.020	1.92854	1,446
100	0.010	2.15599	2,227

Values From K-Table for Linear interpolation

Weighted Skewnes	-0.30	-0.20	-0.23
P	K	K	K
0.9	-1.30936	-1.30105	-1.30352
0.8	-0.82377	-0.83044	-0.82846
0.7	-0.48600	-0.49927	-0.49533
0.6	-0.20552	-0.22168	-0.21688
0.500	0.04993	0.03325	0.03820
0.429	0.22492	0.20925	0.21390
0.200	0.85285	0.84986	0.85075
0.100	1.24516	1.25824	1.25436
0.040	1.64329	1.67999	1.66909
0.020	1.88959	1.94499	1.92854
0.010	2.10294	2.17840	2.15599



Michael Love Associates
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Flood Frequency based on Annual Maximum Series

USGS SANTA CRUZ C NR SANTA YNEZ CA

Station # 11124500

Drainage Area sq. mi **74.00**

Location: 34°35'48" 119°54'28" **NAD27**

WY	Date of Peak	Discharge (cfs)
	12/28/1941	472
	2/22/1944	2500
	2/2/1945	2700
	3/30/1946	1300
	11/20/1946	910
	4/10/1948	19
	3/11/1949	140
	2/6/1950	1160
	3/2/1951	1.5
	1/15/1952	2690
	1/13/1953	261
	1/24/1954	1540
	2/17/1955	168
	1/26/1956	2040
	1/13/1957	559
	4/3/1958	3580
	2/16/1959	930
	2/1/1960	918
	12/2/1960	35
	2/9/1962	4520
	2/9/1963	398
	4/1/1964	145
	4/9/1965	308
	12/29/1965	2030
	12/6/1966	5800
	3/8/1968	472
	2/24/1969	7050
	3/1/1970	910
	11/29/1970	1100
	12/25/1971	436
	1/18/1973	2160
	1/7/1974	648
	3/7/1975	1400
	2/9/1976	234
	5/9/1977	71
	2/9/1978	5060
	3/28/1979	673
	2/16/1980	2620
	3/4/1981	735
	4/1/1982	681
	3/1/1983	3960
	12/25/1983	1290
	2/9/1985	256
	2/14/1986	1650
	3/6/1987	203
	2/28/1988	1800
	2/9/1989	211
	2/18/1990	1.9
	3/19/1991	3100
	2/12/1992	4820
	2/23/1993	3200
	2/20/1994	313
	3/10/1995	3110
	2/20/1996	1690
	1/23/1997	2220
	2/23/1998	4360
	2/9/1999	272
	2/21/2000	595
	3/5/2001	3980
	12/30/2001	44
	3/15/2003	868
	2/25/2004	599

RANK	Recurrence Interval (years)	Dischage (cfs)	Discharge (cms)	log-discharge (cfs)
1	63.00	7050	200	3.85
2	31.50	5800	164	3.76
3	21.00	5060	143	3.70
4	15.75	4820	136	3.68
5	12.60	4520	128	3.66
6	10.50	4360	123	3.64
7	9.00	3980	113	3.60
8	7.88	3960	112	3.60
9	7.00	3580	101	3.55
10	6.30	3200	91	3.51
11	5.73	3110	88	3.49
12	5.25	3100	88	3.49
13	4.85	2700	76	3.43
14	4.50	2690	76	3.43
15	4.20	2620	74	3.42
16	3.94	2500	71	3.40
17	3.71	2220	63	3.35
18	3.50	2160	61	3.33
19	3.32	2040	58	3.31
20	3.15	2030	57	3.31
21	3.00	1800	51	3.26
22	2.86	1690	48	3.23
23	2.74	1650	47	3.22
24	2.63	1540	44	3.19
25	2.52	1400	40	3.15
26	2.42	1300	37	3.11
27	2.33	1290	37	3.11
28	2.25	1160	33	3.06
29	2.17	1100	31	3.04
30	2.10	930	26	2.97
31	2.03	918	26	2.96
32	1.97	910	26	2.96
33	1.91	910	26	2.96
34	1.85	868	25	2.94
35	1.80	735	21	2.87
36	1.75	681	19	2.83
37	1.70	673	19	2.83
38	1.66	648	18	2.81
39	1.62	599	17	2.78
40	1.58	595	17	2.77
41	1.54	559	16	2.75
42	1.50	472	13	2.67
43	1.47	472	13	2.67
44	1.43	436	12	2.64
45	1.40	398	11	2.60
46	1.37	313	9	2.50
47	1.34	308	9	2.49
48	1.31	272	8	2.43
49	1.29	261	7	2.42
50	1.26	256	7	2.41
51	1.24	234	7	2.37
52	1.21	211	6	2.32
53	1.19	203	6	2.31
54	1.17	168	5	2.23
55	1.15	145	4	2.16
56	1.13	140	4	2.15
57	1.11	71	2	1.85
58	1.09	44	1	1.64
59	1.07	35	1	1.54
60	1.05	19	1	1.28
61	1.03	1.9	0	0.28
62	1.02	1.5	0	0.18

	(cfs)	(cms)	log-discharge
Number of Years, n =	62		
Skewness =	1.35	1.35	-1.58
Mean=	1579	45	2.85
Std Dev=	1639	46	0.75

Peaks Flow Frequency

From USGS Data
Station # 11124500

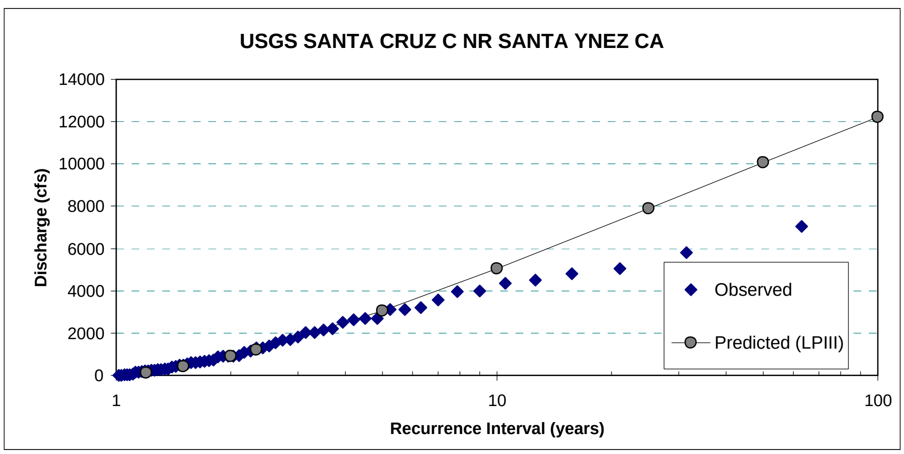
Generalized Skew=	**-0.30**	A=	-0.04747
Station Skewness (log Q)=	-1.58	B=	0.53047
Station Mean (log Q)=	2.85	MSE (station skew) =	0.34056
Station Std Dev (log Q)=	0.75		
Weighted Skewness (G_W)=	**-0.90**		

Log Pearson Type III Distribution

Return Period (years)	Exceedence Probability	Log-Pearson K	Predicicted Discharge (cfs)
1.2	0.833	-0.95903	135
1.5	0.667	-0.30034	418
2.0	0.500	0.14796	904
2.33	0.429	0.31358	1,203
5.0	0.200	0.85428	3,049
10	0.100	1.14726	5,049
25	0.040	1.40749	7,901
50	0.020	1.54926	10,084
100	0.010	1.66051	12,211

Values From K-Table for Linear interpolation

Weighted Skewness	-1.00	-0.90	-0.90
P	K	K	K
0.9	-1.34039	-1.33889	-1.33888
0.8	-0.75752	-0.76902	-0.76910
0.7	-0.38111	-0.39729	-0.39740
0.6	0.08763	-0.10486	-0.10621
0.500	0.16397	0.14807	0.14796
0.429	0.32740	0.31368	0.31358
0.200	0.85161	0.85426	0.85428
0.100	1.12762	1.14712	1.14726
0.040	1.36584	1.40720	1.40749
0.020	1.49188	1.54886	1.54926
0.010	1.58838	1.66001	1.66051



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