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FINAL REPORT

SAN LORENZO RIVER SALMONID ENHANCEMENT PLAN

Fisheries Enhancement Strategy for the San Lorenzo River

submitted to

Santa Cruz County Environmental Health Services

by

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March 2004

EXECUTIVE SUMMARY

BACKGROUND AND INTRODUCTION

In order to update the fisheries section of the San Lorenzo River Watershed Management Plan Update, the County of Santa Cruz, with funding from the California Coastal Conservancy, contracted with Swanson Hydrology & Geomorphology, D.W. ALLEY and Associates, and Dr. Jerry Smith to develop a technical document that outlines the primary impacts to salmonid resources within the San Lorenzo River and tributaries and outlines a set of measures and recommendations needed to enhance the existing steelhead population and restore the coho salmon population.

Over the last several years, a considerable amount of attention has been paid to salmonid populations and habitat conditions on the San Lorenzo River due to historical accounts that suggest a rapid decline in fish numbers since the 1960's. The California Department of Fish and Game (CDFG) estimated that 20,000 adult steelhead were present in the San Lorenzo River prior to 1965 (Johansen, 1975). In the mid-1960's, CDFG estimated that 19,000 adult steelhead occurred in the San Lorenzo River. Recent estimates by the NOAA Fisheries, made in 1996, put the number of adults spawning in the San Lorenzo River at 500.

Unfortunately, estimates of historic adult steelhead numbers were based on conjecture and lack supportable scientific data. Most of the estimates were based on creel census data, which are inadequate to obtain accurate estimates of adult numbers and are more reflective of the extensive planting program in the San Lorenzo River rather than natural production. Scientifically supportable juvenile population and density estimates did not occur on the San Lorenzo until 1981 when Dr. Jerry Smith, with assistance from Donald Alley, conducted habitat surveys and sampling site density estimates on steelhead-bearing streams throughout Santa Cruz County (Smith, 1982). Comprehensive habitat condition and population estimates were continued in 1994 by D.W. ALLEY and Associates and have been monitored every year since (Alley, 1995-2001). These data suggest fairly stable steelhead populations between 1981 to present with year-to-year variations dependent upon sedimentation, streamflow, and habitat conditions in the River. Recent population estimates indicate declines in key reaches such as the Middle River.

Historic and present population estimates suggest an even darker picture for coho salmon. Though little data exist on watershed-wide adult numbers, coho salmon were sampled and identified in the San Lorenzo River at least until 1981 (Smith, 1982). Recent surveys of fish numbers, conducted since 1994 have not reported a single coho salmon individual (Alley, 1994-2001). According to NOAA Fisheries, coho salmon are thought to have been extirpated from the San Lorenzo River through a combination of habitat loss and drought conditions in the late 1980's, and early 1990's (J. Ambrose, NOAA Fisheries, personal comm.). The severe drought of 1976-77 also had impacts.

Based on these estimates of declining fish numbers over the last 35 years the NOAA Fisheries designated San Lorenzo River steelhead and coho salmon (as part of the Central Coast Evolutionarily Significant Unit) as two species that are experiencing a significant decline in numbers, enough to warrant the federal government to list them as threatened under the Endangered Species Act. Coho salmon is state listed as an Endangered Species south of the San Francisco Bay.

The federal listing of steelhead and coho salmon in the San Lorenzo River occurred as a result of regional concerns about the decline of these two species in a wide geographic region. Prior to the listing, research, data collection and monitoring of these populations and the physical conditions that affect their habitat have occurred since the early to mid-1990's (Alley, 1994-2002; Hecht and Kittleson, 1998; Swanson and Dvorsky, 2001). The focus of this research has been to understand population dynamics in relation to habitat conditions, and erosion and sedimentation patterns throughout the watershed. Following the listing of steelhead and coho salmon, development of a document that synthesizes existing biological and physical data into comprehensive plan for enhancement and restoration of these populations became a top priority. Through this analysis, key limiting factors contributing to the decline of steelhead and coho salmon could be identified, with recommendations made for habitat improvement.

HABITAT AND POPULATION ASSESSMENT EFFORTS

Limited standardized historical data existed prior to 1981 to describe habitat conditions and populations for salmonids on the San Lorenzo River. In 1994, the City of Santa Cruz Water Department and San Lorenzo Valley Water District initiated funding for a long-term monitoring program designed to assess the status of salmonids in the San Lorenzo River. Santa Cruz County joined in funding the effort in 1998. Based on habitat evaluation and fish sampling conducted through this program, data are available from 1994 to 2001 in the mainstem (Alley, 1995-2002) along with data collected in 1981 (Smith, 1982) with expanded data collection beginning in 1998 to include sampling in the tributaries. Random and non-random sampling was conducted in 2002 by H.T. Harvey and Associates (2003).

Methods: Values and Limitations

The methods used in assessing habitat and fish populations are described in Appendix A and in the referenced literature. Habitat conditions were surveyed by representative subsampling of the total available habitat. Sampling sites were selected from habitat-typed segments of reaches using a field-based determination of "average habitat conditions". This approach is called the Average Habitat Quality method (AHQ). Fish density estimates in specific habitat types of representative subsamples were then used to extrapolate fish numbers for the rest of the reach, using the habitat proportions determined from the habitat-typed segments. Sampling sites were repeated from year to year, except in cases where average habitat conditions changed considerably, based on annual habitat typing. This sampling protocol is based on the following assumptions (discussed further in Appendix A):

- It is the density of smolt-sized steelhead within the juvenile population that primarily determine the return of adult steelhead to the stream,
- There is a positive relationship between habitat quality and juvenile steelhead numbers,
- The density of smolt-sized juvenile steelhead (and less so for smaller juveniles), in relation to habitat quality (i.e.-poor, average, high), is approximately linear and, therefore, average habitat (in terms of water depth and escape cover) supports an average number of smolt- sized juvenile fish, and
- The available habitat is saturated with smolt-sized juvenile steelhead in most years and most stream reaches.
- Most juveniles captured during fall sampling reside at the site of capture for most of the dry season.

The representative reach approach using AHQ was selected over the random sampling approach to maximize sampling coverage throughout the watershed with limited funding and to provide a consistent dataset from year to year to assess population trends. Due to the lack of a statistically based random sampling effort, the statistical significance and degree of confidence in the estimated fish numbers is difficult to assess. Given these limitations, the same-site, year to year comparisons of fish density, size and age class are useful to assess trends in juvenile production, evaluate reach to reach variability, assess limiting factors, and evaluate the relative effects of changes in habitat conditions to guide watershed management efforts. In addition, when the same sites are sampled between years, the statistically powerful t-test has been performed to evaluate statistical significance of year-to-year variations in fish densities at sampling sites.

The fish population estimates contained in this report could possibly be further refined or modified through more detailed assessments, random sampling, adult monitoring, and/or downstream migrant monitoring, although many of these methods also have limitations of cost and/or effectiveness.

In 2002, the City of Santa Cruz hired H.T. Harvey and Associates to conduct salmonid sampling in the San Lorenzo River and tributaries. Sampling in the mainstem and tributaries used non-random sampling, which was intended to be comparable to methods used by D.W. ALLEY & Associates (1998-2001). In addition, random sampling was conducted in the middle segment of the mainstem San Lorenzo River. A comparison of the non-random and random methods used by H.T. Harvey and Associates suggests that their non-random sites underestimated juvenile steelhead density and abundance in runs, pools and combined, and overestimated density and abundance in riffles. Estimates from both methods for smolt sized fish (>= 85 mm Fork Length) were very close for riffles and runs, but numbers estimated for larger fish in pools were six times greater for the random method. While the non-random method used in 2002 by H.T. Harvey estimated abundance for all sizes of juvenile steelhead as somewhat lower than the random method for the middle River (18,880 versus 20,716), the estimated number from the non-random method fell within the 95% confidence interval of the random method (H.T. Harvey, 2003). The 95% confidence limits were approximately 16-23% for all estimates, suggesting that any observed variations within those ranges might not be statistically significant. The cause of the differences in estimates for the two methods was not definitive, but may be due to differences in (1) the true proportion of mesohabitat units determined in the random method versus the assumed proportion based on subsampling in the non-random method, (2) the exclusion of "non-response areas" in the random method, and (3) differences in how deep pools were included or excluded in sampling.

Population Trends

The San Lorenzo River can be generally divided into two functional regimes based on spawning, rearing, and smolt production. The lower and middle mainstem River (downstream of the Boulder Creek confluence) produces a substantial portion of the watershed's smolt-sized (=> 75 mm Standard Length) juveniles that are mostly fast growing young-of-the-year YOY fish. Unpublished work by Smith (1988-89) indicated that a sizeable portion of returning adult steelhead come from these fast growing YOY's. The upper River and tributaries produces mostly small, slower growing YOY juveniles and some yearling fish that have required two growing season to reach smolt size. The lower and middle River, though degraded due to heavy sedimentation of pools and riffles, support high growth rates of juvenile steelhead where many young-of-the-year juveniles may reach smolt size in one growing season. Despite higher water temperatures, higher growth rate results from higher streamflow, more food production and faster digestive rates. Conversely, the tributaries and the upper River experience less sedimentation, with better spawning habitat. However, more shading and lower streamflow in the tributaries and upper mainstem result in slower juvenile growth rates and usually lower densities of smolt-sized juveniles.

Tables ES.1 and ES.2 show annual estimates of steelhead juvenile numbers by size and age class for the mainstem and tributaries along with the proportion from each size and age class. Juvenile steelhead in the mainstem are evenly divided between size class 1 and size class 2 & 3 fish, apparently reflecting the rapid growth of YOY fish and recruitment of YOY fish from the cooler tributaries. The tributaries have a much higher proportion of size class 1 fish than size class 2 & 3, reflecting slow YOY growth rates and high fry production. These results suggest that smolts leaving the system (out-migrating to the ocean) each year are mostly a combination of large YOY's from the middle and lower River and yearlings from the tributaries and upper mainstem River.

Trends in mainstem and tributary juvenile steelhead production since 1996 (in the mainstem) and 1998 (in the tributaries) have been highly variable. In the lower and middle River there has been a steady decline in juvenile production through 2000 that can be attributed directly to the decline in YOY numbers (Table ES.2). The decline has been attributed to a reduction in rearing and spawning habitat due to sedimentation from tributaries in the wake of the 1998 floods as evidenced by increased embeddedness in fastwater feeding habitat.

In the tributaries and the upper River combined, juvenile production has fluctuated from year to year with an overall decline in size class 1 numbers from 1998 to 2000 and a rebound in 2001 (Table ES.1). Tributaries such as Zayante, Boulder, and Bear have shown a precipitous decline in size class 1 and YOY numbers from 1998 to 2000, presumably due to sedimentation of pool habitat and a reduction in spawning success (Tables ES.3 and ES.4). In 2001, all three tributaries increased in size class 1 and YOY numbers due to improved escape cover, though growth rate was reduced presumably due to reduced streamflow. Other tributaries, such as Branciforte, Bean, and Fall Creeks have remained fairly stable with some year to year fluctuation reflective of annual fluctuations in streamflow, habitat quality, and storm conditions that occurred each of those years.

The H.T. Harvey report (2003) presented findings for 2002, but was published after the majority of the data analysis and preparation had been completed for the present study. The specific data were not incorporated into this report, but it is useful to note that the data from the somewhat comparable (non-random sampling) method indicate that density and abundance of juvenile steelhead increased in 2002 relative to prior years. They also noted an improvement in substrate quality, which may have contributed to the increased production. The combined estimated abundance for the San Lorenzo River mainstem and all sampled tributaries was 168,278 juvenile steelhead. This value is the highest since 1998, which had similar abundance estimates. No coho salmon were encountered during sampling in 2002.

Table ES.1. Estimated Number of Juvenile Steelhead by Size-Class (rounded to the nearest 500) in the mainstem and tributaries (Size classes 2 and 3 are smolt-sized).

Year	# of Size Class 1	Class 1 Percentage	# of Size Class 2 & 3	Class 2 & 3 Percentage	Total Number of Juveniles
1981 Mainstem	37,000	54	31,500	46	69,000
1994 Mainstem	24,500	54	23,000	46	45,000
1995 Mainstem	37,000	49	38,000	51	75,000
1996 Mainstem	40,000	55	32,500	45	72,500
1997 Mainstem	63,000	72	25,000	28	88,000
1998 Mainstem	31,000	53	26,000	47	58,000
1999 Mainstem	17,500	42	24,000	58	41,500
2000 Mainstem	12,500	50	12,500	50	25,000
2001 Mainstem	23,500	67	11,500	33	35,000
1998 Tributaries	91,500	82	19,000	18	110,500
1999 Tributaries	73,500	72	28,500	28	102,000
2000 Tributaries	59,000	75	19,500	25	78,500
2001 Tributaries	70,000	81	16,500	19	86,500
1998 Watershed	122,500	73	45,000	27	168,500
1999 Watershed	91,000	63	52,500	37	143,500
2000 Watershed	71,500	69	32,000	31	103,500
2001 Watershed	93,500	77	28,000	23	121,500

Table ES.2. Estimated Number of Juvenile Steelhead Produced by Age-Class (rounded to the nearest 500) in the Mainstem and Tributaries. (The capture depletion method of density estimates was applied separately for size classes and age classes, yielding different total number of juveniles when adding size classes compared to age classes).

Year	# of YOY	YOY Percentage	# of Yearlings	Yearling Percentage	Total Number of Juveniles
1996 Mainstem	62,000	87	9,500	13	71,500
1997 Mainstem	81,500	91	8,500	9	89,500
1998 Mainstem	52,500	91	5,500	9	58,000
1999 Mainstem	34,500	82	7,500	18	42,000
2000 Mainstem	18,000	75	5,500	25	24,000
2001 Mainstem	30,500	86	5,000	14	35,500
1998 Tributaries	103,500	92	9,500	8	113,000
1999 Tributaries	74,500	73	28,000	27	102,500
2000 Tributaries	61,000	78	17,500	22	78,500
2001 Tributaries	69,500	80	17,000	20	86,500
1998 Watershed	156,000	91	15,000	9	171,000
1999 Watershed	109,000	75	35,500	25	144,500
2000 Watershed	79,000	78	23,000	22	102,500
2001 Watershed	100,000	82	22,000	18	122,000

Table ES.3. Estimated Number of Juveniles in Tributaries to the San Lorenzo River by Size-Class.

Creek	1998 Size Class 1	1998 Size Classes 2 & 3	1999 Size Class 1	1999 Size Class 2 & 3	2000 Size Class 1	2000 Size Class 2 & 3	2001 Size Class 1	2001 Size Class 2 & 3
Branciforte	13,300	3,300	9,500	3,100	11,300	2,800	11,700	2,000
Carbonera	5,000	2,500	4,900	1,600	3,500	2,000	4,100	1,200
Zayante	17,900	3,800	21,100	7,500	7,900	5,000	15,000	3,500
Bean	17,800	1,600	6,100	4,200	14,900	2,400	8,300	2,900
Fall	5,300	1,000	5,800	1,400	3,500	700	3,900	1,000
Newell	3,200	700	1,000	1,100	1,100	500	2,000	300
Boulder	10,000	2,200	5,800	3,100	5,300	1,800	7,900	1,900
Bear	17,200	2,300	16,700	5,500	7,700	3,700	13,300	2,600
Kings	2,000	1,700	2,700	1,200	3,800	600	3,700	1,100
Total Production	91,700	19,100	73,600	28,700	59,000	19,500	69,900	16,500

Table ES.4. Estimated Number of Juveniles in Tributaries to the San Lorenzo River by Age-Class. (The capture depletion method of density estimates was applied separately for size classes and age classes, yielding different total number of juveniles when adding size classes compared to age classes.)

Creek	1998 YOY	1998 Yearling	1999 YOY	1999 Yearling	2000 YOY	2000 Yearling	2001 YOY	2001 Yearling
Branciforte	14,800	2,000	9,500	3,100	11,300	2,800	11,700	2,000
Carbonera	6,900	600	4,900	1,500	3,500	2,000	4,100	1,200
Zayante	19,800	1,700	22,000	6,700	9,300	3,700	15,100	3,500
Bean	17,900	1,500	6,100	4,200	15,000	2,300	8,300	3,000
Fall	5,800	600	5,800	1,400	3,500	700	3,900	1,000
Newell	3,600	400	1,000	1,100	1,300	400	2,000	300
Boulder	13,400	1,300	5,800	3,100	5,300	1,800	7,900	1,900
Bear	18,100	1,200	16,700	5,500	8,300	3,000	13,000	2,900
Kings	3,300	300	2,700	1,200	3,800	600	3,400	1,300
Total Production	103,600	9,600	74,500	27,800	61,300	17,300	69,400	17,100

HISTORIC FLOW CONDITIONS AND IMPACTS FROM WATER DIVERSIONS

Flow Record at Big Trees

Historic daily flow data from the San Lorenzo River at Big Trees provide a record of daily values dating back to 1937. Based on an analysis of trends in flow conditions for each month at the Big Trees gage from 1937 to 1997, the results suggest that during most months there has been a significant reduction in baseflow over the last 60 years. Potential factors for changes in flow conditions can be observed in the months of October and December. October is typically the month of lowest streamflow prior to winter rains. Mean and minimum streamflow trends for October show a 17.2% and 32.1% decrease between 1937 and 1997. On the other hand, the trend in maximum streamflow for the month of October increases 25.5%. The increase in maximum streamflow in October can most likely only be explained by climatic conditions that have resulted in a slight shift in the wet season that brings more storms early in the year with a reduction in late winter storms. This is supported by a significant drop in maximum streamflow in April and May (68.8% and 31% respectively). The reduction of mean and minimum baseflow conditions in October is likely due to water extraction from both surface diversions and well pumping in addition to a possible reduction in late season rainfall (e.g. – April and May results) that would carry through the summer into fall.

The impact of surface diversions, reservoir construction, and well pumping becomes clearer after reviewing the December trends. Mean and maximum streamflow falls 36.2% and 46.2%, respectively. The magnitude of these reductions, particularly for the mean value, is significantly higher than all other months except for April. A viable explanation for the observed flow reductions is that groundwater pumping has reduced groundwater storage to a level where the response time between winter rains and release of water to stream channels has increased. Historically, rains in October and November would percolate into groundwater reservoirs, allowing rains in December through March to contribute more directly to runoff. The capture of initial runoff in Loch Lomond before it spills would also contribute partially to a reduced December maximum flow after 1960.

Streamflow and Steelhead Density Relationships

Linear regression relationships were calculated for annual dry season streamflow (late spring, summer, and fall) versus annual estimates of juvenile steelhead density, by size class, at sampling sites on the San Lorenzo River and tributaries. At mainstem San Lorenzo River sites, the annual average of mean monthly streamflow for May through September at the Big Trees Gage and the annual minimum baseflow at the sites were compared to the average density of young-of-the-year (YOY) steelhead that grew into yearling, smolt-size fish the first year. At tributary sites (where YOY's seldom grew to smolt size the first year), annual densities of YOY steelhead were compared to annual minimum baseflow. For reaches where the regression analysis has a significant correlation coefficient, the relative reduction in steelhead smolt production resulting from flow reductions can be estimated by comparing differences between fish density predicted under existing flows and density under unimpaired flows. Net extraction rates were determined with allowance for water recycling through septic systems.

Regression analysis was restricted to 1981 and 1994-97 in the middle River and to 1994-97 in the lower River to evaluate effects of streamflow on juvenile growth rate. At the two lower River sites, 1981 data were not used because there were considerable geomorphic changes between 1981 and 1994. Mainstem data from 1998 onward were not used because El Nino storms in 1998 brought considerable sediment into the mainstem with substantially degraded habitat in the middle River. In 1981 and 1994-97, much faster growth rates of YOY steelhead occurred in the mainstem River in wetter years as summer baseflow increased. This relationship was determined by plotting densities of YOY's reaching smolt size in the first growing season at traditional sampling sites as a function of several measures of streamflow (averaged mean daily flow for each month during May-September at the Big Trees Gage; minimum daily flow at the

Big Trees Gage in September; baseflow measured or estimated at sampling sites during sampling). The largest impacts of streamflow on juvenile steelhead growth in the mainstem River were seen in the middle River (between the Zayante Creek and Boulder Creek confluences) where there was generally a higher proportion of smolt-sized YOY's as annual summer streamflow increased as well as higher densities of these fish during wetter years compared to drier years. Annual densities of YOY's at sampling sites in tributaries also increased substantially with increasing baseflow.

The most significant correlations came from linear regression representing average densities of YOY's reaching smolt size at the 4 low-gradient, middle River sites versus the averaged mean monthly flow (May-September) (R-squared = 0.99) and the annual minimum daily flow (R-squared = 0.86) at the Big Trees Gage. Using the middle River's 4-site composite regression equation of minimum daily flow at the Big Trees Gage versus average density of YOY's => 75 mm SL, an estimated average of 1.51 cfs lost in September from estimated average net extraction rates lead to the predicted reduction of 9% in larger YOY's => 75 mm SL in a wet year (1995) (Table ES.5). In the drier year 1994, the estimated net extraction rate would be 1.35 cfs, leading to a 27% reduction in the estimated total density of larger YOY's (Table ES.5).

LIMITING FACTORS ASSESSMENT

For an anadromous (ocean and freshwater living) salmonid to survive to adulthood and then successfully reproduce, a variety of habitat requirements must be satisfied. Interruptions in any phase of the salmonid life cycle can devastate the entire population. When a salmonid fry emerges from an egg, the long process of rearing, migration to the ocean, growing large and returning to spawn has begun. If poor quality habitat, high predation, starvation, or barriers to migration exist, the salmonid life cycle will be cut short. Each risk to the salmonid life cycle can be a limiting factor for the entire population.

Table ES.6 summarizes the limiting factors by reach or tributary of the San Lorenzo River. The table was developed through review of existing habitat and population data and group discussions with the project team and County staff members to reach a consensus on the primary and secondary limiting factors. Factors were considered limiting regardless of their likelihood for improvement or remediation. Limiting factors that can be addressed through management measures and restoration plans are denoted by a closed circle in Table ES.6. In most cases, those factors are limiting due to anthropogenic influence or disturbance.

Spawning and Sediment

Based on qualitative observations, the quality of spawning habitat varies greatly throughout the San Lorenzo River. Generally, spawning gravel quality is high enough to allow returning fish to saturate the available habitat with fry due to the high reproductive capacity of adult salmonids and the ability of YOY's produced in the tributaries to move down into the mainstem to saturate rearing habitat where survival from egg to fry may be less. Though this is the general rule and spawning may not be the primary limiting factor in most reaches of the watershed, spawning conditions are sub-optimal. Most tributaries have less than optimal spawning conditions, but juvenile production is more limited by restricted rearing conditions resulting from low summer streamflow, shallow pool conditions, and the absence of good escape cover, rather than spawning success.

The primary causes of poor quality spawning habitat or limited success of emerging fry are:

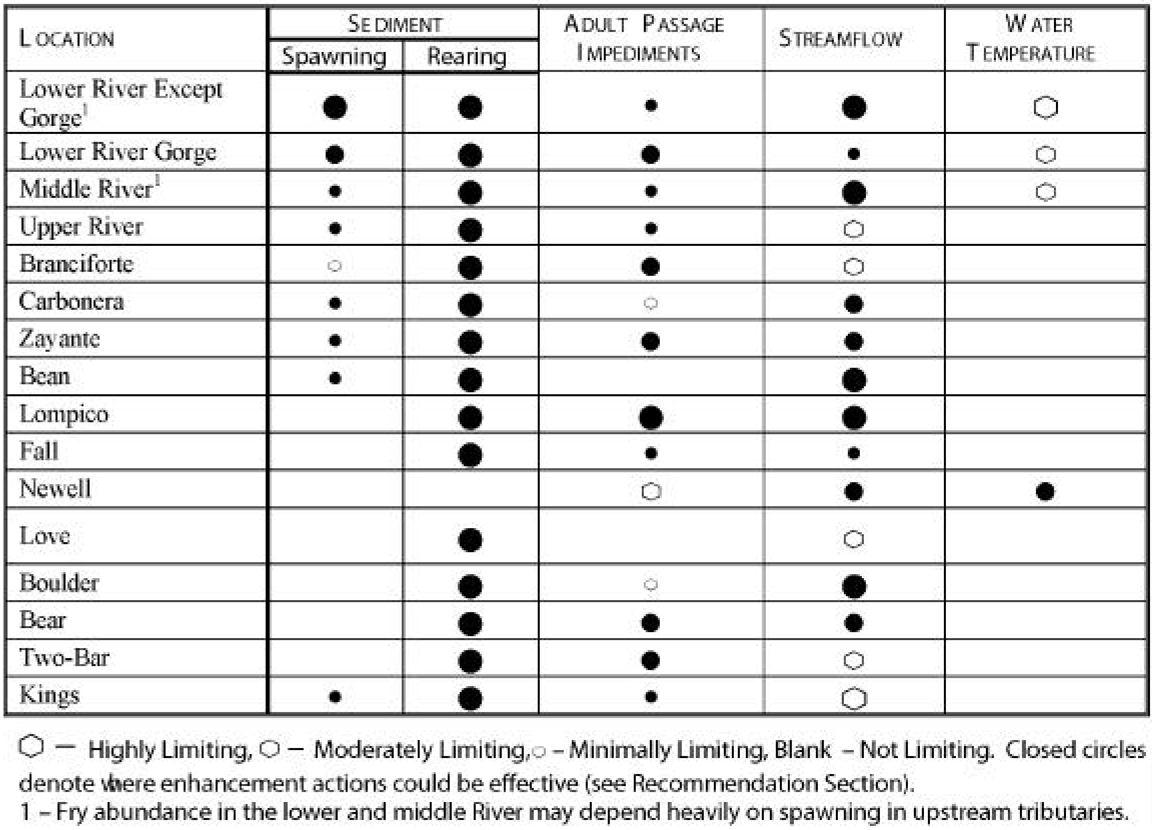
- Excessive fine sediment in spawning gravels that limit use of impaired areas by adult fish or cause egg or alevin mortality after spawning has occurred.
- Mobile bed conditions that result in loss of redds after spawning has already occurred.

Table ES.5. Estimated instantaneous flow extractions in September and associated estimates of reduced density for yearling-sized YOY's at mainstem River sites and reduced total YOY density at tributary sites where linear regression relationships were developed between: 1) annual minimum streamflow at mainstem sites versus YOY steelhead => 75 mm SL for mainstem sites, 2) annual minimum daily flow at the Big Trees Gage versus average density of YOY steelhead => 75 mm SL for the Middle River 4-site composite and 3) annual minimum streamflow at tributary sites versus density of YOY steelhead at tributary sites. Instantaneous flow extractions were determined by using the maximum diversion rates from Fall Creek and Lompico Creek, 0.5 cfs extraction rate from Bean Creek and for San Lorenzo Valley Water District diversions, both average September diversion rates and measured diversion rates in 1994 and 1998 provided by Nick Johnson. Water recycling through septic systems was factored in.

Site		**Annual Minimum Flow Wet/Dry Year Wet Year ('95) Extraction (%) Dry Year ('94) Extraction (%) cfs.**	**Correlation Coefficient (R2) of Linear regression of flow to fish density***	**Estimated % Reduction of Age/Size Category due to Water Extraction and Estimated Density with Unimpaired flows (fish/ 100 ft)***			
				YOY's => 75 mm SL		**All Juveniles => 75 mm SL**	
				1994 dry	**1995 wet**	**1994 dry**	**1995 wet**
Middle River	4-Site Composite	18 / 9 1.51(_9_%) 1.35 (8%	0.86 (YOY=>75mm to annual min. Flow at Big Trees)	27% (9.4)	9% (30.2)	17% (14.4)	6% (44.3)
	Below Fall Creek	14.6 / 5.1 0.9 (6%) 0.8 (16%	0.85 (YOY=>75mm to annual min. Flow at Big Trees)	13% (6.2)	8% (11.8)	12% (6.8)	5% (19.7)
	Ben Lomond	5.8 / 2.5 0.36(6%) 0.2 (8%)	0.89 (YOY=>75mm to annual min. Flow at Big Trees)	22% (12.2)	7% (65.8)	11% (25.4)	5% (90.6)
	Brookdale	4.6 / /1.8 0.36 (8%); 0.2 (11%))	0.87 (YOY=>75mm to annual min. Flow at Big Trees)	36% (4.7)	10% (29.4)	15% (11.7)	8% (40.0)
	Below Boulder Creek	4.2 / 1.1 0.26 (6%) 0.15 (14%)	0.42 (YOY=>75mm to annual min. Flow at Big Trees)	3% (10.0)	3% (11.8)	2% (17.8)	1% (23.0)
Estimated Flow: Wet (1998) Dry (1994) Average Extraction (% reduction)				**1994 (dry) YOY's**	**1998 (wet) YOY's**		
Lower Boulder	Above Hwy 9	2.2 / 0.6 0.26 (12-43%)	0.77 (Total YOY to Minimum Measured flow)	28% (30.9)	24% (186.3)		
Bean Creek	Below Lockhart Gulch	6.7 / 2.1 0.5 (7 – 24%)	0.59 (Total YOY to Mean summer flow@ Mt. Hermon)	67% (42.3)	20% (132.7)		
Zayante Creek	Below Bean Creek	8.8 / 3.8 0.65 (9-17%)	0.58 (Total YOY to Minimum Measured flow)	19% (38.8)	9% (87.5)		

* Calculated reductions in fish density were for specific, historical sampling sites and are not necessarily intended to represent reach-wide reductions. The significant correlation coefficients (>= 0.7) indicate that there is a meaningful direct linear relationship of flow to fish density at those sites. Based on available data, the relationship is less direct in other sites with lower correlation coefficients.

Table ES.6. Assessment of Limiting Factors for the San Lorenzo River.



LOCATION	SEDIMENT		ADULT PASSAGE IMPEDIMENTS	STREAMFLOW	WATER TEMPERATURE
	Spawning	Rearing			
Lower River Except Gorge[1]	⬤	⬤	•	⬤	◯
Lower River Gorge	●	⬤	●	•	○
Middle River[1]	•	⬤	•	⬤	○
Upper River	•	⬤	•	○	
Branciforte	◦	⬤	●	○	
Carbonera	•	⬤	◦	●	
Zayante	•	⬤	●	●	
Bean	•	⬤		⬤	
Lompico		⬤	⬤	⬤	
Fall		⬤	•	•	
Newell			○	●	●
Love		⬤		○	
Boulder		⬤	◦	⬤	
Bear		⬤	●	●	
Two-Bar		⬤	●	○	
Kings	•	⬤	•	◯	

◯ – Highly Limiting, ○ – Moderately Limiting, ◦ – Minimally Limiting, Blank – Not Limiting. Closed circles denote where enhancement actions could be effective (see Recommendation Section).
1 – Fry abundance in the lower and middle River may depend heavily on spawning in upstream tributaries.

In the lower and middle River, poor spawning conditions exist due to the input of high fine sediment loads from tributary streams such as Boulder, Bear, Kings, Zayante, and Bean Creeks. Fine sediment from these tributaries is deposited in the lower gradient reaches, increasing the fraction of fine sediment at the terminus of pools where spawning gravels are typically found. High fine sediment deposition in the lower and middle River forces spawning adults to use areas dominated by sand that become mobile during late winter and early spring high flow events.

In the case of tributaries, the variability of gradient and structural elements such as bedrock outcrops and large woody material may allow for good quality spawning habitat to exist in localized patches even if high fine sediment loads are present. Hydraulic variability created by these flow separators or constrictors allows fine sediment to be sorted and removed from certain locations, leaving higher quality gravel beds in their place that can be sought out by adult fish.

Rearing and Sediment

The quality of rearing habitat in the San Lorenzo River and tributaries affects the growth and survival of salmonids from the time they emerge from the gravels as fry to the time they leave for the ocean as smolts. Rearing salmonid juveniles can take up to two years to reach smolt size depending upon growth rates. The primary variables that determine the quality of rearing habitat for salmonids are food availability, fast water feeding areas, escape cover from predators, adequate water depth, water clarity, and water temperature. The quality of rearing habitat in the mainstem San Lorenzo River and tributaries is directly linked to streamflow and the presence of excessive fine sediment loads.

In the middle and lower River, excessive fine sediment loads have resulted in pool filling, high embeddedness in riffles and runs and a general loss of total habitat area. Rearing conditions in these reaches remain adequate to support a high proportion of the watershed's fast growing juveniles that are large enough to smolt within one year during high streamflow years in the middle River and in all years in the lower River. Faster growth of juvenile fish in the lower and middle River can be attributed partly to the wider river, allowing primary productivity to increase as the result of higher solar input. Higher primary productivity results in higher production of macroinvertebrates that salmonid juveniles feed upon. Higher water velocity resulting from higher streamflow increases the insect drift rate for juvenile salmonids, allowing for them to feed throughout the summer. However, the warmer water increases the metabolic rate of juveniles and their food demand. Therefore, they are restricted to primarily fastwater habitat (heads of pools, riffles and runs) and cannot utilize much of the slow water pool and glide habitat, which constitutes between 30 and 60% of the stream length in lower River reaches and between 50 and 75% in middle River reaches. Although the mainstem produces a significant portion of the watershed's smolt-sized juveniles, warm water may limit overall production.

Passage

Passage impediments include man-made features such as flashboard dams, diversion dams, culverts, low-water crossings and reduced streamflow conditions that limit migration past critical riffles. They also include natural features such as bedrock shelves, waterfalls, and high-gradient riffles. Passage impediments can also range from complete barriers that limit upstream migration under all flow conditions (e.g. – a 20-foot high waterfall) as well as partial barriers that may only limit migration under certain flow conditions. Passage impediments on the lower and middle mainstem of the San Lorenzo River are potential limiting factors for the entire River since they can restrict access to important spawning habitat in the tributaries. Good quality spawning habitat may be limiting in the lower and middle River, so access to higher quality tributary spawning habitat is important to steelhead abundance in both the mainstem and the tributaries.

Survey work in the San Lorenzo River gorge through Henry Cowell State Park identified approximately 12 natural passage impediments that may restrict salmonid passage, consisting of high gradient riffles or boulder falls (Alley, 1993). The study concluded that 35 cfs was probably an adequate streamflow to allow adult salmonid passage through the Gorge using the criteria of 0.6 feet minimum depth across 5 contiguous feet of channel width, except at 2 locations: a falls created by a boulder field just above Four Rock (Site #2A) and another boulder field just upstream, which was no longer present in 2002. After the El Nino storms of 1998, a critically wide riffle developed in the Rincon area that was a significant passage impediment and was still present in 2002. Flows for passage at these two remaining barriers were roughly estimated to be approximately 50-70 cfs in 2002. In the middle River, the Felton Diversion Dam (Site #3) may have caused passage difficulties at certain streamflows. Difficulty in locating the fish ladder when streamflow is spilling over the inflatable dam may be a problem at certain intermediate flows when fish cannot jump over the dam. The City and Fish and Game have developed operating procedures to reduce those impacts.

Funded in part by the California Department of Fish and Game, the Community Action Board of Santa Cruz identified, inventoried, and ranked all man-made passage impediments on the mainstem of the San Lorenzo River. Of the 24 sites identified, 21 consisted of current or abandoned flashboard dams. Numerous flashboard dams also occur on tributaries but were not mapped as part of this project. Even though many of the dams are no longer in use, the abutments or concrete sills can prove to be significant impediments to passage for adults in low water years under a range of flow conditions.

Smolt out-migration of both coho and steelhead occurs primarily from March through May. The primary limiting factor on movement of smolts from their rearing habitat to the ocean would be excessive dewatering of the stream channel resulting in very shallow riffles or dry sections, which would create physical barriers to migration. From March through May, complete dewatering of the channel or early closure of the lagoon mouth could occur during a year, or period of years, under drought conditions.

Streamflow

Streamflow as a limiting factor has been discussed in the context of other limiting factors such as rearing habitat for juveniles and passage barriers for adults. It is the primary element that defines total available habitat for salmonids with other limiting factors affecting the quality of the habitat and the ability to reach available habitat.

In the San Lorenzo River, the disparity in timing that exists between the seasonal availability of water and the demand for its use has resulted in a complicated system of water storage systems, groundwater pumping, winter and summer diversion systems and cross-basin transport of water. Multiple agencies distribute water to residents in the San Lorenzo Valley and other local communities. The largest agencies are the City of Santa Cruz Water Department, California American (formerly Citizen's Utilities), the San Lorenzo Valley Water District, and the Scotts Valley Water District.

The primary water diverter on the lower mainstem of the River is the City of Santa Cruz. The City of Santa Cruz Water Department has three primary facilities that divert and store water. The systems include Loch Lomond Reservoir on Newell Creek, the Felton Diversion Dam a half-mile downstream of the Zayante Creek confluence, and the Tait Street Diversion near Santa Cruz, which includes streamside wells that can be used in the place of the diversion. The use of these facilities varies greatly depending upon the season, water turbidity, availability, and demand. The Tait Street Diversion is the primary source of water for the City, particularly during the summer. Flow reductions at Tait Street can be significant, especially during summer low-flow months. Although the City is not required to bypass flow, it currently adjusts pumping rates to maintain a minimum flow downstream. During past drought years when the well pumps were also in operation, a cone of depression seemed to develop that dewatered the river downstream before it reached the lagoon, as occurred in 1988.

Water diversions also occur on tributaries to the San Lorenzo River. A significant diversion on Fall Creek, operated by California American Water Company, provides water for municipal use to the Felton area. Additionally, significant diversions occur from tributaries of Boulder Creek and Clear Creek by the San Lorenzo Valley Water District and Lompico Creek by the Lompico County Water District. Loch Lomond Reservoir, operated by the City of Santa Cruz, captures a portion of Newell Creek's flow, but provides some augmentation of dry season flows with a required year round release of 1.0 cfs. Each of these diversions collectively has an impact not only on local tributary stream conditions but has a cumulative impact on the middle and lower mainstem of the San Lorenzo River. There are also more than 130 individual private diversions in the watershed. The potential impact of these is estimated to be relatively small (0.2-0.4 cfs.), given the small size of the properties and limited amount of irrigation where water is used (Ricker, 1979). This could present some impact, particularly on smaller streams during dry years.

Another significant source of flow reduction that is much more difficult to monitor and quantify is the use of groundwater through well pumping. Groundwater basins support springs and seeps that are a significant source of summer baseflow for the San Lorenzo River and its tributaries, especially in Bean, Zayante, and Carbonera Creeks. Much of the pumping of significant groundwater resources occurs in the Zayante and Bean Creek watersheds by the Scotts Valley Water District and the San Lorenzo Valley Water District. These groundwater basins are formed in the highly permeable, porous Santa Margarita sandstone formation and underlying Lompico formation.

Synthesis of Limiting Factors

The three major factors limiting salmonid production on the San Lorenzo River are shortage of high quality rearing habitat, low quality spawning habitat in the lower and middle River, and barriers to migration. The primary question that remains, regarding limiting factors to salmonids in the San Lorenzo River, is which limiting factors have the most impact, and, ultimately what factors should enhancement efforts focus on. It is fairly clear from data and discussions presented in the preceding sections, that the primary limiting factors throughout the watershed are related to available streamflow and excessive delivery of fine sediment to stream channels from poor land use practices in the watershed. Since production of smolt-sized juveniles in reaches of the middle River appears to be the most sensitive to sediment and streamflow, we have attempted to assess the degree to which each of these factors are limiting. Table ES-7 presents the results of this analysis.

Though the data were not analyzed statistically, there is a clear inverse relationship between juvenile steelhead numbers of all size classes and embeddedness. The results suggest that higher embeddedness values, presumably due to increased delivery of fine sediment from upland sources (Alley, 2000;Swanson and Dvorsky, 2001), coincided with a decrease in steelhead juvenile numbers, on the order of a 35-40% reduction in the middle River. Though there may have been additional factors such as number of returning adults, spawning success, overwinter survival of juveniles and annual differences in summer baseflow, sedimentation, with a resulting increase in embeddedness, appears to have a significant impact on juvenile numbers.

Streamflow impacts on steelhead juvenile numbers in the middle reaches of the San Lorenzo River are also reported in Table 3.6, based on data developed and analyzed in Section 2.5 of this report. After combining the results for all four reaches of the middle River, the results show anywhere from a 6% to 27% reduction in fish numbers due to streamflow reductions from extractions, depending on the flow year and size classes analyzed.

Generally, the results from this analysis suggest that sedimentation due to excessive erosion of fine sediment from the watershed, may be having more of an impact on juvenile production in the middle River than reductions in streamflow (except possibly in drought years)), though both are clearly important factors when considering management recommendations to improve conditions for salmonids in the middle mainstem of the San Lorenzo River. The analysis presented in Table ES-7 should be considered a rough preliminary analysis that should direct resource managers to consider erosion control measures to reduce sedimentation in the near-term with an eye at long-term maintenance and/or enhancement of streamflow to improve juvenile rearing habitat.

Unless appropriate protective measures are taken, erosion, sedimentation and habitat degradation are expected to increase in association with increased road building in suburban areas, increased impermeable surfaces, higher stormflow from increased runoff and less percolation, logging without adequate protection of the riparian corridor and lack of maintenance of erosion control measures during re-entry periods, increased clearing of forested areas for development, increased use of unpaved road surfaces, continued clearing of streamside vegetation by streamside residents and continued removal or cutting of instream large woody material.

Increased development and demand for water supply from surface and groundwater within the San Lorenzo River watershed will result in further declines in streamflow and fish habitat, unless measures are implemented to mitigate those impacts through 1) timing of winter diversions to minimize impact on adult passage during dry winters, 2) increased basin groundwater storage, 3) reduced summer stream extractions, 4) reduced overall demand for extraction through water conservation, desalination and/or water reuse and 5) locating and timing of stream extractions to minimize impacts on spawning and rearing fish habitat.

In order to protect and enhance salmonid production in the lower and middle River, the focus should be on streamflow maintenance and enhancement, reducing fine sediment production, and improving passage conditions. Since spawning and rearing habitat in the mainstem has been degraded by the input of excessive fine sediment, a long-term goal would be to reduce fine sediment input in the watershed through erosion control efforts and sediment detention basins at important non-fish-bearing locations identified in the watershed. Passage impediments should be identified and remedied at locations where a considerable amount of high quality spawning and rearing habitat exists upstream.

Table ES.7. Estimated reduction in fish numbers in the middle reaches of the mainstem San Lorenzo River due to sedimentation (A) and streamflow (B). To assess sedimentation effects, fish population and embeddedness data was compared between 1995 and 1999 since summer baseflow conditions were similar in those years. To assess reductions in fish numbers due to streamflow, the results of the analysis presented in Section 2.5 of the main report, was used.

A - Sedimentation Data and Results

Year	Reach	Size Class 1	Size Class 2&3	All Juveniles	Riffle Embeddedness	Pool Embeddedness
1995	6	8,042	22,606	30,648	38	35
	7	14,484	30,117	44,601	30	35
	8	20,322	32,676	52,998	30	40
	9	24,423	35,695	60,118	45	95
1999	6	7,397	17,107	24,504	45	100
	7	8,029	18,416	26,445	43	50
	8	10,007	19,268	29,275	43	60
	9	11,856	20,183	32,039	48	65
Percent Change from 1995 to 1999	6	-8.0	-24.3	-20.0	18.4	185.7
	7	-44.6	-38.9	-40.7	43.3	42.9
	8	-50.8	-41.0	-44.8	43.3	50.0
	9	-51.5	-43.5	-46.7	6.7	-31.6
Average % Change		-38.7	-36.9	-38.1	27.9	61.7

B - Streamflow Data and Results

		Estimated Dry Year % Reduction due to Flow Extractions			Estimated Wet year % Reduction due to Flow Extractions	
	Reach	YOY's => 75mm	All Juveniles => 75mm		YOY's => 75mm	All Juveniles => 75mm
	6	13%	12%		8%	5%
	7	22%	11%		7%	5%
	8	36%	10%		10%	8%
	9	3%	2%		3%	1%
	Combined	27%	8%		9%	6%

ENHANCEMENT GOALS AND OBJECTIVES

1. To reduce or remove limiting factors affecting juvenile steelhead.
2. To restore coho salmon habitat.
3. To establish and protect refugia where habitat conditions are particularly suitable for steelhead and/or coho.
4. To develop and promote implementation of management measures and projects that will promote the following objectives:
    a. Maximize baseflow and prevent stream reaches from drying out.
    b. Maintain water temperatures at levels suitable for steelhead throughout the watershed.
    c. Maintain temperatures suitable for coho in low gradient reaches of east side tributaries that they are most likely to inhabit.
    d. Restore and maintain riparian vegetation for proper floodplain/riparian function and stream cooling.
    e. Minimize sand content in spawning gravels and minimize sediment embeddedness in rearing areas.
    f. Restore and maintain adequate levels of large woody material in the channel to sort sediment and provide habitat structure.
    g. Reduce impediments to adult fish migration, particularly those caused by culverts, dams, and other structures.

RECOMMENDATIONS

(Note: These recommendations are summarized from the main body of the report. Additionally, the research recommendations are included in the main body.)

Sediment Recommendations

Recommendation S-1: Focus initial sediment reduction efforts on tributaries that have high habitat value and/or impact the middle and lower River. The focus of sediment reduction efforts should focus on tributaries such as Kings, Two-Bar, Boulder, Bear, Zayante, and Branciforte Creeks.

Recommendation S-2: Identify and repair bank failures or landslide toes that are a significant source of chronic fine sediment loads to the River. Repairs should be completed using bioengineering techniques and material, where appropriate. Habitat enhancement should be incorporated into the engineering design, where feasible.

Recommendation S-3: Locations for long-term sediment spoil sites should be identified and developed. A significant amount of sediment is removed from inside ditches and road surfaces during the winter months due to general erosion and removal of landslides. Establishing a site where removed sediment could be effectively disposed of would remove a significant source of fine sediment to adjacent stream channels.

Recommendation S-4: Locations for sediment catchment basins should be identified and developed, where appropriate. Though a limited number of areas may be suitable for sediment catchment basins, where feasible, they should be used to retain and remove potentially chronic fine sediment sources that significantly impacts primary stream channels.

Recommendation S-5: Increase the width of no-impact riparian buffers where appropriate to protect aquatic habitat from excessive sedimentation. There is a growing body of evidence that buffers that limit all land use activities from the riparian corridor protects aquatic ecosystems from potential disruption and degradation. All of these recommendations state that management activities such as logging, road building, clearing, and construction are to be avoided within riparian zones with a horizontal width on both sides of the stream of one to two tree height lengths for the maximum expected tree height unless those activities are compatible with restoration and preservation of riparian and aquatic function.

Recommendation S-6: Develop a County road database and emergency road repair fund. A database documenting the existing public road system in the County should be developed within a GIS framework. Grant funding should be pursued for existing road and culvert problems identified in the database. Repairs should be prioritized which will provide the greatest benefits for fish passage and sediment reduction. An emergency road repair fund should also be developed to supplement money available from FEMA for road repairs.

Recommendation S-7: Implement a sediment reduction program for private roads. Since many private roads are often substandard and numerous, a sediment reduction program for private roads should be designed as a cooperative effort between local governments and private landowners, reducing the need for enforcement actions.

Recommendation S-8: Reduce erosion from timber harvest roads. A series of recommendations have been outlined in the Zayante Area Sediment Study to reduce sediment from these sources and include the following measures:

- Surfacing of year-round access roads that are being used for timber harvest activities,
- Up to five years of maintenance and monitoring of unsurfaced roads and skid trails.
- Identify and fix problems associated with legacy roads during the initial THP process, and
- An engineering geologist should certify grading on inner gorge slopes.

Large Woody Material Recommendations

Recommendation WD-1: Large woody material should be retained, not removed, in all streams. Since wood is an important feature in developing good salmonid rearing and spawning habitat, attempts should be made to retain wood that is recruited to the channel unless there is an impending threat to life and property.

Recommendation WD-2: Implement an outreach program to educate agencies and private landowners about the benefits of large woody material.

Recommendation WD-3: When bridges require replacement, use free-span designs with increased flow capacity to allow for passage of large woody material.

Recommendation WD-4: Incorporate large woody material into stream bank protection projects, where appropriate.

Recommendation WD-5: Encourage mixed stands of conifer and deciduous riparian forest. To meet the goal of encouraging mixed stands of riparian vegetation, all future streambank stabilization projects should include conifer species (primarily redwood) as a significant element in the revegetation work.

Passage Impediment Recommendations

Recommendation PI-1: Replace problematic culverts in Class I streams with bridges or appropriate cost effective designs. Existing culverts within the critical range of salmonids should be inventoried and assessed to determine their condition and the cost-effectiveness of their replacement. Identified culverts should be replaced with either a free-span bridge structure or an oversized culvert that is over-excavated into the bed of the channel to allow for natural channel substrate to develop through the culvert.

Recommendation PI-2: Modify or remove flashboard dams that create passage problems for adult fish. Additionally, specific recommendations with regards to flashboard dams should be followed, including:

- Flashboard dams that could create problems for fish movement should not be installed before June 15th.
- Bypass flows should be maintained during filling of the pools to prevent dewatering downstream.
- Removal of flashboard dams in the fall should be gradual enough to prevent stranding, displacement, or injury to fish.
- Evaluate and mitigate on a case-by-case basis other impacts of flashboard dams.

Recommendation PI-3: Inventory, maintain, and/or modify existing fish ladders to allow passage under most flow conditions. These existing fish ladders need to be inventoried and assessed for adequacy of passage, modified if necessary, and continually maintained to assure that they are allowing fish passage under most flow conditions.

Recommendation PI-4: Consider modifying natural passage impediments in the mainstem of the San Lorenzo River. Several of these potential passage impediments occur in the Lower River Gorge, potentially limiting or delaying salmonid access to a large majority of potential spawning and rearing habitat in drier winters. Allowing minor modifications to these natural impediments to provide passage under most flow conditions could mitigate for winter flow reduction impacts.

Recommendation PI-5: Support the City of Santa Cruz to provide adult and smolt passage through the Lower San Lorenzo River and the flood control channel on Branciforte Creek according to recommendations in the Lower San Lorenzo River and Lagoon Management Plan.

Streamflow Recommendations

Recommendation SF-1: Continue to prohibit new or increased summer diversions.

Recommendation SF-2: Conduct water supply pumping overnight to the extent feasible, particularly for upstream diversions. Streamflow is often the highest during the nighttime hours as evaporation and transpiration are reduced. This is also the period of time when fish are relatively inactive and are usually not feeding. During the low-flow summer months, water that is being stored off-channel for use during peak demand periods should be diverted between the hours of 9pm and 5am, where feasible.

Recommendation SF-3: Develop critical flow levels for stream reaches impacted by water diversions. Critical flow values would include minimum bypass flow requirements for upstream adult migration during winter months and rearing habitat conditions in the summer and fall months.

Recommendation SF-4: Use developed exceedence probability curves to predict late summer flow conditions. If predicted flows are below a level considered critical to maintain viable rearing habitat for salmonids, measures to reduce water consumption can be initiated by municipal water suppliers in the San Lorenzo Watershed through conservation programs.

Recommendation SF-5: Study the feasibility of reconfiguring the water supply system in the San Lorenzo River Watershed to increase summer flow. The focus of any future expansion of municipal water supplies extracted from the San Lorenzo River should be on storage of excess high winter flows, maintenance or enhancement of summer flow, and extraction of water at a low point in the water system. Options for wastewater reclamation should also be evaluated and utilized where feasible.

Recommendation SF-6: Operations at the Felton Diversion should be scheduled to minimize impacts to migrating salmonids. Operation of the Felton Diversion pumps during low flow years should be timed to allow an adequate bypass flow (or the natural flow if it is less than the recommended bypass flow) to pass through the Lower River Gorge during the nighttime hours to ensure opportunities for adult fish migration over documented passage. We recommend the following:

- Between January 1 and April 1 of each year, the Felton Diversion will allow a 70 cfs minimum bypass for three consecutive nights between the hours of 9pm and 9am.
- The minimum bypass of 70 cfs for three consecutive nights should occur at least monthly within the January 1 to April 1 timeframe.
- If natural flows do not exceed 70 cfs, the natural flow would be bypassed, without requiring the City to reduce the pool volume behind the diversion dam.
- Pursue measures to modify barriers to reduce the amount of flow need for migration through the Lower River Gorge. From April 1 to June 1 each year, allow sufficient bypass at Felton and Tait Street to maintain hydraulic continuity to the estuary and an open sandbar to the ocean.

Recommendation SF-7: Maximize the storage capabilities of Loch Lomond by protecting the existing pool volume through a land management program to reduce sediment input and through potential adjustments in the pumping and storage operations. Allow more flexible provisions for reservoir storage, use and pumping from Felton Diversion Dam to maximize the potential for storage and use of excess winter flows. Consider raising the level of Loch Lomond to allow for more storage of winter flow during moderate and wet years.

Recommendation SF-8: In conjunction with other measures to maintain and enhance water supply, seek to increase upstream baseflows and manage operations at the Tait Street Diversion to maintain a minimum bypass into the Lower River and Lagoon. Maintaining a minimum bypass flow in the Lower River is critical to out-migration of steelhead and coho salmon smolts, movement of young steelhead into the lagoon, and maintenance of a freshwater lagoon. From April 1 to June 1 each year, a sufficient bypass should be provided to maintain hydraulic continuity to the estuary and an open sandbar to the ocean. Protection of bypass flows could be done in conjunction with modifying City water rights for increased diversion of excess spring and winter flows at Loch Lomond and/or Tait Street. Measures to increase upstream baseflows will also facilitate an adequate bypass below Tait Street while maintaining City supply.

Recommendation SF-9: Provide for a healthy lagoon that will support large numbers of rearing steelhead through implementation of the Lower San Lorenzo and Lagoon Management Plan. Due to the high food production potential of coastal lagoons, they can act as high quality rearing habitat for juvenile steelhead, allowing them to grow quickly to larger smolt sizes that increase survival rates in the ocean. Pursue a strategy for maintaining a freshwater lagoon at water levels that are optimal for fishery habitat without creating other adverse impacts.

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CHAPTER 1 - INTRODUCTION

In the late 1970's the County of Santa Cruz foresaw the need to develop a comprehensive watershed management plan for the San Lorenzo River due to the rapid growth occurring in the San Lorenzo Valley. What became of this forward thinking was the San Lorenzo River Watershed Management Plan, the first of its kind in the nation, prepared in 1979, that describes and presents recommendations that were to guide future planning and County policy in the San Lorenzo Watershed for the next several decades. The plan includes a description of existing conditions and policy recommendations for a range of issues including water quality, geology, erosion, and fisheries.

Approximately 20 years later, the County of Santa Cruz embarked on an effort to update the Management Plan of 1979 to reflect changes that have occurred in the County in the last 20 years. Additionally, the updated management plan includes a component to revisit the recommendations and policies outlined in the 1979 Plan and assess their impact on improving the overall environmental health of the watershed relative to the increased impacts that have occurred due to population growth in the valley.

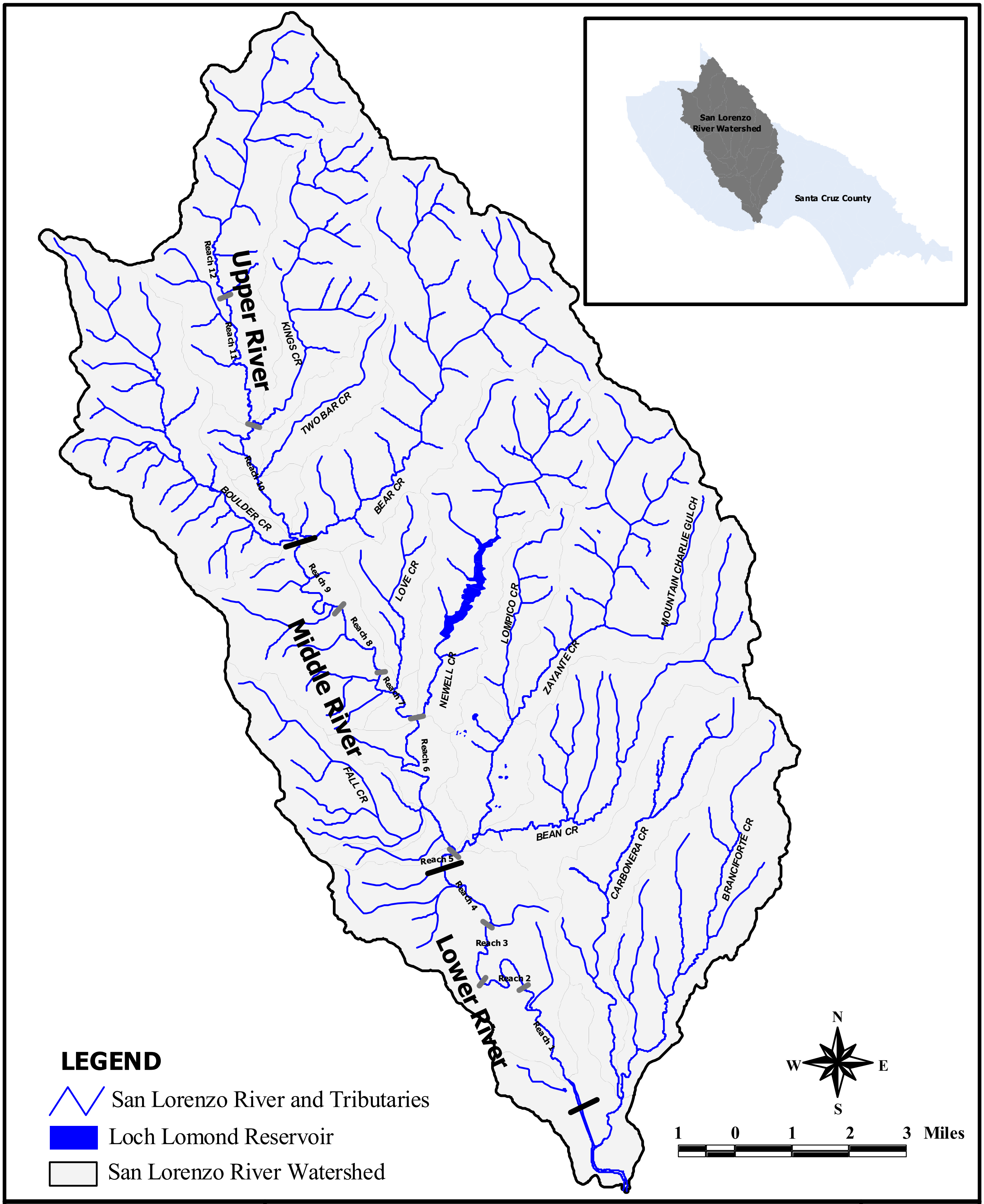
In order to update the fisheries section of the San Lorenzo River Watershed Management Plan , the County of Santa Cruz, with funding from the California Coastal Conservancy, contracted with Swanson Hydrology & Geomorphology, D.W. ALLEY & Associates, and Dr. Jerry Smith to develop a technical document that outlines the primary impacts to salmonid resources within the San Lorenzo River and tributaries and outlines a set of measures and recommendations that would be required to enhance the existing steelhead population and restore the coho salmon population. This document is meant to compliment a similar enhancement plan recently published for the lower portions of the San Lorenzo River and Branciforte Creek that flow through the City of Santa Cruz.

SECTION 1.1 - BACKGROUND

The San Lorenzo River is a 138 square mile watershed located in northern Santa Cruz County (Figure 1.1). It consists of a 25-mile long mainstem and 9 principle tributaries that include Branciforte, Carbonera, Zayante, Bean, Fall, Newell, Bear, Boulder, and Kings Creeks. Much of the watershed is forested with pockets of urban areas (e.g. – Santa Cruz, Scotts Valley, Felton, Ben Lomond, and Boulder Creek) and an increasing proportion of rural residential developments. Paved and unpaved roads occur in stream corridors, providing access to the small mountain communities and towns that occur throughout the San Lorenzo Valley (e.g. – Felton, Ben Lomond, Brookdale, Boulder Creek, Lompico, Zayante, and Mt. Hermon).

Since the late 1800's the Santa Cruz Mountains and the San Lorenzo River watershed have experienced a series of intensive land uses practices. Clear-cut logging in the turn of the century impacted most of the watershed, bringing with it road and rail line development. On the tributaries, small dams were built to support lumber mills and create splash dams to move logs down to the mills. Much of this activity continued into the 1920's when much of the timber resources were exhausted.

After the logging boom ended in the 1920's, most of the forest areas gradually recovered in stands of second growth conifers and evergreen hardwoods. Streams and wildlife habitat also generally recovered, but all were forever changed from pristine conditions. It is likely that salmonid populations were heavily impacted by watershed-wide logging impacts due to the cumulative effects they have on channel and habitat conditions. Though very little data exist to support these claims, the California Department of Fish and Game began monitoring salmonid populations in 1934 on the San Lorenzo River (Table 1.1) and had previously constructed a hatchery at Brookdale to hatch eggs collected on the San Lorenzo River and Scott Creek and rear juveniles for plantings throughout California (Table 1.2).



Swanson Hydrology and Geomorphology

D.W. Alley & Associates

Jerry Smith, PhD

Figure 1.1: Location map for the San Lorenzo River showing the approximate boundaires of the Lower, Middle and Upper River Reaches and survey reaches of the mainstem river from fish habitat assessment work (Alley, 2000).

Figure 1.1
April 2002

Table 1.1. Summary of past trapping efforts conducted on the San Lorenzo River.

Year	Trapping Period	# of Adults	Location	Reference	Notes
1934-35	?	973	Below Brookdale	Fish and Game	
1938-39	?	412			
1939-40	?	1,081			
1940-41	?	671	Boulder Creek		
1941-42	Dec 24 – Apr 11	827			
1942-43	Dec 26 – Apr 22	624			
1976-77	Jan – Apr	1,614	Felton Diversion	Kelley and Dettman, 1981	
1977-78	Nov 21 – Feb 6	3,000			Estimate
1978-79	Jan – Apr	496			After Drought
1994-95	Jan 6 – Mar 21 (48 of 105 days Jan – Apr)	311		Dave Strieg, pers. comm., 1995	
1999-00	Jan 17 – Apr 10	532			Above Felton

Table 1.2. Number of stocked steelhead and coho smolts in the San Lorenzo River mainstem as reported by CDFG.

Year	Coho	Steelhead
1959	35,800	55,000
1961	300	1,200
1963	40,169	1,396
1964	40,056	0
1965	20,330	0
1967	0	11,791
1969	25,000	0
1970	25,008	29,364
1971	25,008	30,000
1972	20,007	40,250
1973	25,005	185,795
1974	25,008	0
1975	25,009	50,000
1976	25,002	36,840
1977	0	116
1978	0	10,070
1979	25,011	26,070
1980	0	10,500
1981	0	50,040
1982	0	20,250
1983	19,770	21,000
1984	17,160	37,146
1985	0	24,606
1986	15,991	29,200
1987	0	48,510
1988	20,445	23,256
1990	34,500	52,487
1991	19,880	98,337
1992	1,872	107,515
1993	11,808	93,974
1994	4,047	47,247
1995	0	49,238
1996	0	28,800
1997	0	31,986
1998	0	2,210
1999	0	30,599
2000	0	21,328

Tourism expanded in the early 20th century, leading to the construction of many summer cabins and camps in the Santa Cruz Mountains. With the expanded urban growth of the 1950's and 1960's, many seasonal residences were converted to year-round residences and urbanization of the San Lorenzo Valley increased. Growth brought more rural roads and more disturbed lands and greater erosion and sediment production to a watershed that was still recovering from the turn of the century logging. Aggregate quarries in the watershed expanded to supply building materials to the region and timber production occurred in predominately second growth forests.

Over the last several years, a considerable amount of attention has been paid to salmonid populations and habitat conditions on the San Lorenzo River due to historical accounts that suggest a rapid decline in fish numbers since the 1960's. The California Department of Fish and Game (CDFG) estimated that 20,000 adult steelhead were present in the San Lorenzo River prior to 1965 (Johansen, 1975). In the mid-1960's, CDFG estimated that 19,000 adult steelhead occurred in the San Lorenzo River. Recent estimates by the NOAA Fisheries made in 1996, put the number of adults spawning in the San Lorenzo River at 500.

Unfortunately estimates of historic adult steelhead numbers were based on conjecture and lack supportable scientific data. Most of the estimates were based on creel census data, which are inadequate to obtain accurate estimates of adult numbers and is more reflective of the extensive planting program in the San Lorenzo River rather than natural production. Scientifically supportable juvenile density estimates did not occur on the San Lorenzo River until 1981 when Dr. Jerry Smith, with assistance from Donald Alley, conducted habitat surveys and measured juvenile steelhead densities on steelhead-bearing streams throughout Santa Cruz County (Smith, 1982). Comprehensive estimates of habitat conditions and population estimates were continued in 1994 by D.W. ALLEY & Associates and continued for 8 consecutive years (Alley, 1995-2002). These data suggest fairly stable steelhead populations between 1981 to 2001, with year-to-year variations affected by ocean conditions, sedimentation, streamflow, and habitat conditions in the River. Recent population estimates indicate declines in key reaches such as the Middle River.

Historic and present population estimates suggest an even darker picture for coho salmon. Though little data exist on watershed-wide adult numbers, coho salmon were sampled and identified in the San Lorenzo River at least until 1981 (Smith, 1982). Recent surveys of fish numbers, conducted since 1994 have not reported a single coho salmon individual (Alley, 1994-2001). According to NOAA Fisheries, coho salmon are thought to have been extirpated from the San Lorenzo River through a combination of habitat loss and drought conditions in the late 1980's and early 1990's (J. Ambrose, NOAA Fisheries, personal comm.). The severe drought of 1976-77 also had impacts.

Based on these estimates of declining fish numbers over the last 35 years, the NOAA Fisheries designated San Lorenzo River steelhead and coho salmon (as part of the Central Coast Evolutionarily Significant Unit) as two species that are experiencing a significant decline in numbers, enough to warrant the federal government to list them as threatened under the Endangered Species Act. Coho salmon are state listed as an Endangered Species south of the San Francisco Bay.

The result of the listing has led to increased efforts to assess the current status of both steelhead and coho salmon on the San Lorenzo River. NOAA Fisheries issued technical memo status reviews for steelhead and coho that briefly summarize the conditions of steelhead and coho populations along the central coast of California from the Russian River south to Aptos Creek. Throughout these descriptions the San Lorenzo River was listed as one of the largest steelhead producing rivers in the region, making it an important watershed to pursue restoration and enhancement measures that will improve conditions for steelhead and coho salmon.

The San Lorenzo River has also been designated an impaired waterway under the Federal Clean Water Act for sediment, pathogens, and nutrients affecting drinking water, fisheries and recreational beneficial uses. This designation requires the preparation of a plan that specifies the allowable Total Maximum Daily Load (TMDL) for these constituents to restore the health of the system.

SECTION 1.2 - ENHANCEMENT PLAN GOALS

The federal listing of steelhead and coho salmon in the San Lorenzo River occurred as a result of regional concerns about the decline of these two species in a wide geographic region. For steelhead, the area that stretches from the Russian River in the north to Aptos Creek in the south constitutes the range defined as the California Central Coast Evolutionarily Significant Unit. For coho salmon, the geographic region stretches from Punta Gorda in the north to the San Lorenzo River in the south. Research, data collection, and monitoring of the San Lorenzo steelhead population and the physical conditions that affect their habitat have been occurring since the early to mid-1990's (Alley, 1994-2001; Hecht and Kittleson, 1998; Swanson and Dvorsky, 2001). The focus of this research has been to understand population dynamics in relation to habitat conditions and detect erosion and sedimentation patterns throughout the watershed.

Following the listing of steelhead and coho salmon, development of a document that synthesizes existing biological and physical data into a comprehensive plan for enhancement and restoration of these populations became a top priority. Through this analysis, key limiting factors contributing to the decline of steelhead and coho salmon could be identified with recommendations made for habitat improvement.

The primary tasks for the San Lorenzo River Salmonid Enhancement Plan include the following:

- Review historic and existing salmonid population estimates to determine the magnitude and extent of their decline.
- Assess trends in habitat conditions and their relation to population estimates.
- Review and incorporate recent reports that describe and quantify potential impacts, such as erosion and sedimentation, which may be detrimental to salmonid populations.
- Collect baseline data describing channel morphology, bank, and woody material densities at monitoring reaches that overlap locations where habitat and population data is collected.
- Assess historic and present streamflow conditions and potential reductions in summer baseflow due to water use and extraction.
- Identify limiting factors to the decline in salmonid numbers at key life cycle stages.
- Provide recommendations for improving habitat conditions and restoring and maintaining viable numbers of steelhead trout and coho salmon populations.
- Develop a monitoring plan to assess the effectiveness of implemented recommendations.

In addition to the Enhancement Plan document, an additional report will be prepared that will include a list of potential projects that should be pursued to improve conditions in the watershed for steelhead and coho salmon. The list will include a range of enhancement options from outreach programs to in-channel habitat restoration projects. The list of projects will be ranked and prioritized based on their potential for habitat improvement, feasibility, and cost effectiveness. Projects designated as high priority will be developed further into conceptual designs for implementation in the near-term.

SECTION 1.3 - LIFE CYCLES AND HABITAT REQUIREMENTS OF SALMONIDS

Though a wealth of information about steelhead (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*) resides in many textbooks and was eloquently described by Shapovalov and Taft (1954), a brief description and definition of terms used in the remainder of this report is included. The general life cycle and habitat requirements of steelhead and coho salmon are functionally similar but differ considerably in the timing and duration of life cycle stages and specific habitat needs.

Steelhead

Steelhead are genetically indistinct from rainbow trout and differ only in their behavior and the size of the adults. Steelhead exhibit a life-cycle strategy similar to other salmonids, known as anadromy, where they spend their adult life in the ocean and swim to their natal stream to reproduce (Figure 1.2). The hatched young, known as fry, spend up to 2 years in these freshwater streams, growing large enough to survive ocean conditions. Once large enough, they make their way to the ocean and undergo physiological changes, a process known as smolting, which allows them to adapt to salty ocean conditions.

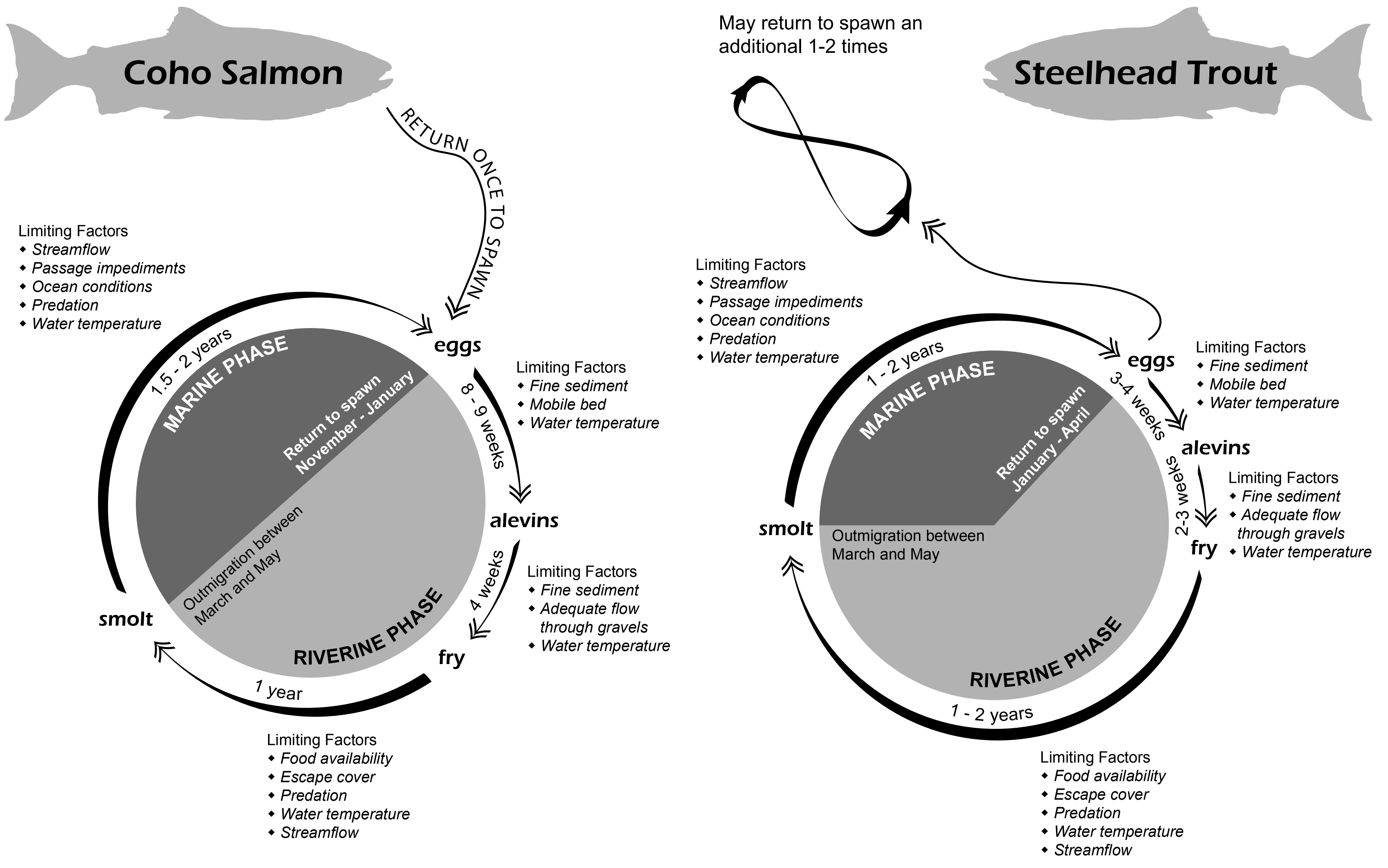


Figure 1.2: Life cycles of the Coho salmon and Steelhead trout showing duration of each stage and critical environmental factors affecting survival and reproduction. Coho salmon live for approximately 3 years before they spawn and die. Steelhead may live for up to 5 years and spawn as many as three times.

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Steelhead differ from other salmonids in their unique ability to spawn and return to the ocean with the intention of returning the following year to spawn again, unlike other salmonids, which die after spawning. This unique life-cycle pattern makes steelhead more resilient to diverse ecological conditions such as a drought or flood because they can return the following year if conditions are not adequate to reach their spawning grounds. Also, their young grow at different rates in different portions of the watershed, allowing some to smolt in 1 year while others require two years in freshwater. Thus, adult steelhead returning to spawn are from multiple years of spawning (unlike coho salmon, whose spawners come from only one year class). In addition, if lower reaches of the mainstem leading to the ocean become dry during smolting, some juveniles may remain and survive in freshwater an additional year or even spawn without ever entering the ocean. Due to these adaptations, steelhead were historically known to occur as far south as Baja California in Mexico and presently range as far south as Malibu Creek in Los Angeles County. Unfortunately, water extractions, dams, and prolonged drought have all but extirpated steelhead from their southern range.

Steelhead enter streams and rivers to prepare for migration to spawning grounds as soon as streamflow is adequate and summer sand bars at the mouths of coastal lagoons have breached. This typically occurs in November or December, depending upon the frequency and magnitude of late fall storms. Migration to spawning grounds typically begins in December and can last well into May if late spring storms provide adequate flow to negotiate potential passage barriers.

Spawning occurs within gravel deposits (in the range of 5 to 90 mm) situated at the end or tail of pools and head of riffles. When females dig a nest (termed a redd) in the gravel, significant clearing of fine sediment in the gravel deposit occurs (Cordone and Kelley, 1961). Excessive fine sediment (sand and silt) in spawning beds can be detrimental and has been shown to diminish the reproductive success of salmonids by reducing the permeability of gravels, intragravel water flow, and availability of dissolved oxygen for developing embryos (Terhune, 1958; McNeil and Ahnell, 1964; Vaux, 1962; Cooper, 1965; Daykin, 1965). Several researchers have also found an inverse relationship between fine sediment and fry survival (Bjornn, 1968; Phillips et al, 1975). Fine sediment deposited on the streambed also negatively impacts aquatic macroinvertebrate survival and production, a main food source for salmonids (Williams and Mundie, 1978).

The incubation period for steelhead eggs may take up to two months along the central Coast, depending on water temperature. During that time there must be adequate water circulation to oxygenate the eggs and carry away metabolic wastes. Once hatched, the fish remain in the gravel as sac fry or alevins and have very limited mobility within the gravel deposits. After emerging from the gravel, the juvenile fish become very active in swimming to avoid being swept downstream, to seek refuge from predators, and to find food for growth.

The quality of streambed habitat for these life cycle stages can become seriously disrupted by an influx of fine sediments. Coarse substrate and redds can be buried by influxes of fine sediments that move along the bed, even during summer low flow periods. The degree to which substrate is buried by fine sediment is known as embeddedness. Fine sediment can clog redds, reduce water circulation and kill or force early emergence of sac fry thereby decreasing survival. Fine sediment can also significantly reduce rearing habitat and places to hide, known as escape cover, by burying cobble and boulder areas on the streambed. Water depth is also a form of cover. When sediment shallows pools, rearing habitat quality is reduced.

Young steelhead spend 1 to 2 years in freshwater streams before heading to the ocean as smolts. The time spent by juveniles in freshwater depends primarily on food availability and metabolic rates. Each of these factors is highly dependent upon water temperature. As water temperature increases, fish become more active and require more food to support higher metabolic rates. Higher water temperatures allow for more primary and secondary productivity that make more food available to fish. The result is a delicate balance between food availability, water temperature, growth rates, and metabolic rates.

Streamflow also plays an important role in the balance between food availability and growth for steelhead. The quantity of streamflow on a given stream not only dictates the amount of habitat available to fish and production of aquatic macroinvertebrates (the major source of food in the juvenile steelhead diet along with adult insects that fall into the channel from streamside vegetation) but also acts as a "conveyor belt" for delivery of food to feeding steelhead. The more streamflow that is available in spring and summer, the more food that is available to be delivered to the fish. As summer flows recede and less habitat becomes available to fish and aquatic macroinvertebrates, the conveyor belt of food slows down. Water temperatures also rise as flows recede in the summer months, causing higher metabolic rates for fish and increasing their food requirements.

The result of interactions between streamflow, habitat availability, and the conveyor belt of food is higher growth rates for fish in the spring months and maintenance or reductions in fish size in the summer and fall months. Differences also occur between colder, smaller tributaries and the warmer, larger mainstem San Lorenzo downstream of the Boulder Creek confluence. Steelhead juveniles reared in the lower and middle mainstem of the San Lorenzo can grow at a fast enough pace to allow them to reach smolt-size (typically => 75 mm Standard Length (SL)) within 1 year, whereas juveniles in the tributaries and upper San Lorenzo require two years to reach smolt-size due to their slower growth rates. The size a fish reaches when it smolts plays an important role when they reach the ocean. Larger smolts tend to have higher survival rates in the ocean because they are often stronger, can swim faster, and have reduced predation.

In addition to requiring adequate food for growth, juvenile steelhead have specific habitat requirements essential to their survival. These include fast-water feeding areas to take advantage of food moving along the "conveyor belt" and locations to hide from predators (escape cover) and find shelter from high winter flows (overwintering refuge). Escape cover and overwintering refuge may include deep pools, undercut banks, side channels, large unembedded cobbles and boulders, rootwads, large woody material, and overhanging vegetation. Streams that lack adequate escape cover will often have low fish densities, regardless of the amount of food available.

Coho Salmon

Generally speaking, the life-cycle stages and habitat requirements of coho salmon (*Oncorhynchus kisutch*) and steelhead are similar. Both fish species are anadromous, build nests at the tail of pools in gravel substrate, require fast-water feeding areas to supply adequate food for growth, and require adequate escape cover to avoid predators and high winter flows. The primary differences lie in the timing and length of their life-cycle stages and specific habitat requirements that are unique to both.

Coho salmon typically return from the ocean to spawn from November through February along the central Coast (Figure 1.2). During drought years this life-cycle pattern can be detrimental since streamflow may not be adequate for coho to negotiate natural or man-made low flow barriers such as high gradient riffles or culverts. Additionally, early winter spawning of coho make their nests much more susceptible to high winter scouring flows that occur January through March. Unlike steelhead, coho are segregated into distinct year classes and are unable to wait an additional year for streamflow conditions to improve. During severe drought years when the lagoon sandbar does not breach, an entire year class could be lost indefinitely. This makes coho much more susceptible to environmental conditions and less adaptable than steelhead.

Coho eggs and alevins develop more slowly than steelhead, requiring a total of 12 to 13 weeks to emerge from the gravel compared to 5 to 8 weeks for steelhead. Juvenile coho then spend one year in freshwater before migrating to the ocean between March and May (Figure 1.2).

Coho salmon also require a more narrow range of habitat conditions compared to steelhead. Coho salmon prefer lower gradient habitat consisting of deep pools, cool water temperatures, and an abundance of escape cover. Prime coho salmon habitat often occurs in the mainstem and lower reaches of the tributaries within the San Lorenzo watershed. These areas also tend to be the reaches experiencing the most impact from sedimentation from road development, upstream timber harvest and urban/rural residential development.

CHAPTER 2 - CURRENT RESEARCH

SECTION 2.1 - OVERVIEW

In order to understand the primary factors that are limiting salmonid populations within the San Lorenzo River watershed, data must be available on habitat conditions, population trends, and the overall health of the watershed. This information provides the framework for determining reach-specific changes in fish numbers, the habitat conditions that drive fluctuations in population numbers, and the potential source of watershed impacts such as increases in fine sediment supply or lack of hydraulic complexity in the channel.

Though very little historical data are available on habitat, populations, and channel conditions in the San Lorenzo River, the federal listing of both steelhead and coho salmon provided the impetus to develop a monitoring program to assess these factors. The most recent monitoring of fish populations began in 1994 by D.W. ALLEY & Associates and has been monitored consistently every year since (Alley, years 1995-2001). Random and non-random sampling was conducted in 2002 by H.T. Harvey and Associates (2003).

Several studies have also been conducted in recent years to assess erosion and sedimentation (Hecht and Kittleson, 1998; Swanson and Dvorsky, 2001) occurring in the watershed as part of an effort to develop a TMDL by the Regional Water Quality Control Board. These studies have included establishment of point monitoring locations for bed conditions, sampling and identification of erosion source problems. Additionally, as part of research conducted under this project, reach-scale monitoring sites were established to develop a baseline dataset of channel morphology, bank conditions, and densities of woody material to monitor the effectiveness of future enhancement and restoration measures.

SECTION 2.2 - HABITAT AND POPULATION ASSESSMENT EFFORTS

Limited, standardized historical data exist prior to 1981 to describe habitat conditions for salmonids on the San Lorenzo River. Past reports by the Department of Fish and Game (CDFG) usually only included a narrative description of sediment, spawning, and rearing conditions based on general impressions from the survey team. More recent CDFG surveys included habitat typing of selected reaches of the River, but these surveys were not coordinated with fish sampling and do not provide additional information about past population trends.

During the period 1994-2001, a long-term monitoring program designed to assess the status of salmonids in the San Lorenzo River was funded by the City of Santa Cruz Water Department, San Lorenzo Valley Water District, Santa Cruz County Environmental Planning, and the National Marine Fisheries Service (NOAA Fisheries). Based on habitat evaluation and fish sampling conducted through this program, data are available from 1994 to 2001 (Alley, 1995-2002) along with data collected in 1981 (Smith, 1982). Because the scope increased through the years, the dataset is unequal between years. Changes in the sampling protocol and expansion of the scope to include a more thorough evaluation of tributaries reduces the number of years of data that are available when looking for trends in watershed conditions and juvenile numbers across the entire watershed.

This section is intended to express the general patterns of juvenile production and growth rates. It identifies the environmental conditions and impacts that have affected juvenile densities and growth rates. Methods used to census the juvenile population are described briefly in the next section.

Methods: Values and Limitations

The methods used in assessing habitat and fish populations are described in Appendix A and in the referenced literature. The watershed was divided into reaches with boundaries based on changes in geomorphology, habitat proportions, shading and streamflow, primarily. Habitat conditions were surveyed by representative subsampling of the total available habitat in designated reaches. Representative population sampling sites were selected from habitat-typed segments of reaches using a determination of "average habitat conditions". This was termed the Average Habitat Quality method (AHQ). Fish density estimates in specific habitat types of representative subsamples were then used to extrapolate fish numbers for the rest of the reach, using the habitat proportions determined from the habitat-typed segments. Sampling sites were repeated from year to year, except in cases where habitat conditions in the reach changed considerably based on habitat typing. To justify this sampling protocol, several assumptions were made, including:

- It is the density of smolt-sized steelhead within the juvenile population that primarily determine the return of adult steelhead to the stream,
- There is positive relationship between habitat quality and juvenile steelhead numbers,
- The density of smolt-sized juvenile steelhead (and less so for smaller juveniles), in relation to habitat quality (i.e.-poor, average, high), is approximately linear and, therefore, average habitat (in terms of water depth and escape cover) supports an average number of juvenile fish, and
- The available habitat is saturated with smolt-sized juvenile steelhead in most years and most stream reaches.
- Most juveniles captured during fall sampling resided at the site of capture for most of the dry season.

The representative reach approach was selected over the random sampling approach to maximize sampling coverage throughout the watershed with limited funding and to provide a consistent dataset from year to year to assess population trends. Due to the lack of a statistically based random sampling effort, the statistical significance and degree of confidence in the estimated fish numbers is difficult to assess. Given these limitations, the same-site or representative site, year-to-year comparisons of fish density by size and age class are useful to assess trends in juvenile production, evaluate reach-to reach-variability, assess limiting factors, and evaluate the relative effects of changes in habitat conditions to guide watershed management efforts. In addition, when the same sites were sampled between years, the statistically powerful t-test was performed to detect year-to-year trends in fish densities at sampling sites.

The conclusions contained in this report could possibly be further refined or modified through more detailed assessments, random sampling, detailed streamflow-habitat modeling (IFIM), adult monitoring, and/or downstream migrant monitoring, although many of these methods also have limitations of cost and/or effectiveness.

In 2002, the City of Santa Cruz hired H.T. Harvey and Associates to conduct salmonid sampling in the San Lorenzo River and tributaries. Sampling in the mainstem and tributaries used non-random sampling that was intended to be comparable to methods used by D.W. ALLEY & Associates (1998-2001). In addition, random sampling was conducted in the middle segment of the mainstem San Lorenzo River. A comparison of the non-random and random methods suggests that the non-random method underestimated juvenile steelhead density and abundance in runs, pools and combined, and overestimated density and abundance in riffles. Estimates from both methods for smolt sized fish (>= 85 mm Fork Length) were very close for riffles and runs, but estimated numbers for larger fish in pools were six times greater for the random method. The cause of the differences in estimates for the two methods was not definitive, but may be due to differences in (1) the true proportion of mesohabitat units determined in the random method versus the assumed proportion based on subsampling in the non-random method, (2) the exclusion of "non-response areas" in the random method, and (3) differences in how deep pools were included or excluded in sampling. H.T. Harvey eliminated deeper (and usually longer) pools from those from which censused pools were randomly chosen. These were considered unsampleable. Therefore, pool selection was not purely random. Since juvenile steelhead primarily use the heads of pools and leave the remainder of the habitat unutilized, long pools have much lower fish densities. The elimination of longer deeper pools, differs from previous assessments by Alley, who snorkel-censused long and short pools. Finally, while the non-randomly estimated abundance for all sizes of juvenile steelhead was somewhat lower for the middle River (18,880 versus 20,716), the estimated number from the non-random method fell within the 95% confidence interval of the estimate generated from the random method (H.T. Harvey, 2003). The 95% confidence limits were approximately 16-23% for all estimates, suggesting that any observed variations within those ranges might not be statistically significant.

Coho Salmon Status and Potential for Re-Introduction

In fall 1981, juvenile coho were found at only Bean and Fall Creek sites out of 32 electrofished sites sampled in the San Lorenzo River watershed (Smith, 1982). None have been captured in recent years, 1994-2001 (D.W. Alley, 1995-2002) and 2002 (H.T. Harvey, 2003).

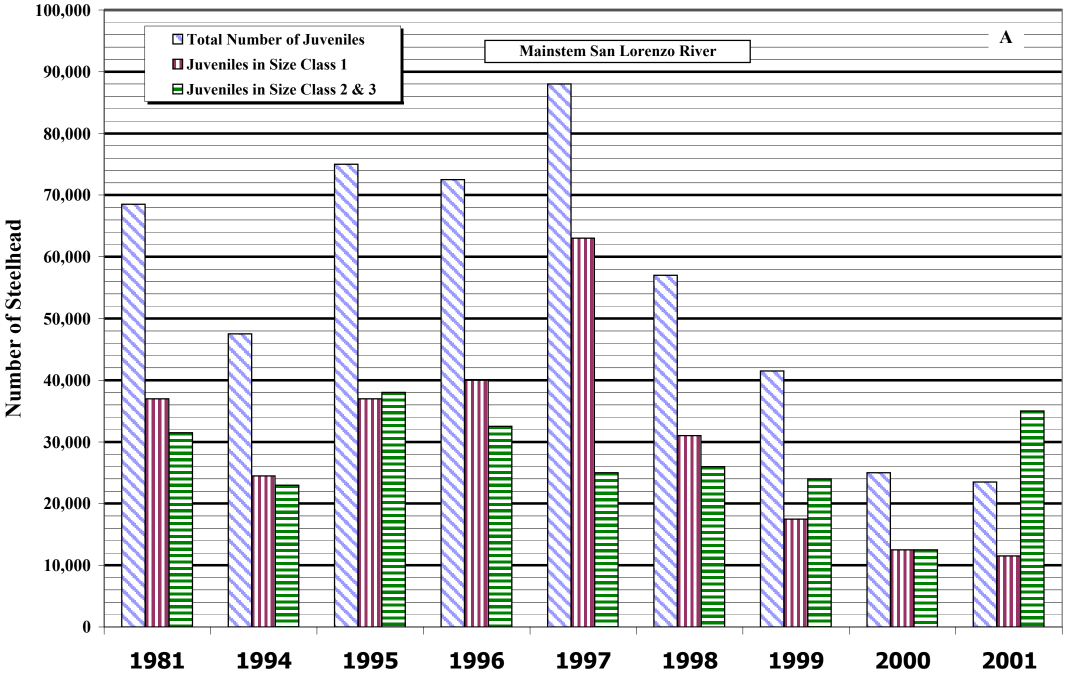
Whether the San Lorenzo River drainage can support a sustaining coho population without hatchery stocking is a matter of conjecture. Watershed conditions that hinder the recovery of coho include difficult passage conditions in the Gorge, land practices that increase sedimentation and reduce spawning success, removal of woody material necessary for cover, water diversions, and warm water temperatures in lower gradient reaches that coho prefer.

In some years, coho might successfully spawn and rear in cooler, low gradient tributaries on the east side of the watershed (lower Branciforte, lower Zayante, Bean, lower Bear and Kings creeks), as well as in the low gradient mainstem reaches above Boulder Creek. Here, more food would be available in the pools that coho could utilize. In the Mattole River system (northern California) coho were found only in tributaries where the maximum weekly average water temperatures were 16.7ºC (62ºF) or less and the maximum weekly maximum temperatures were 18.0ºC (64ºF) or less (Welsh et al., 2001).

Because of the dominance of sandy substrate in the San Lorenzo River system and the presence of steelhead, the temperature limits found in the Mattole River are probably the appropriate goal for re-establishing coho in San Lorenzo tributaries and the mainstem, upstream of the Boulder Creek confluence.

Juvenile Steelhead Production in the Mainstem River

For the mainstem River, juvenile numbers in the size class I (< 75 mm Standard Length (SL)) and combined size classes II and III (=> 75 mm SL) were lower in 1994 compared to 1981, presumably due to the drought of 1987-92 (Figure 2.1). Refer to Appendix A for a description of censusing methods. In 1995 and 1996, with increased streamflow from wetter conditions, mainstem juveniles increased beyond 1981 levels in all size classes, and most importantly, in the larger size classes (Table 2.1). More young-of-the-year (YOY) steelhead grew into the larger sizes classes in the mainstem in 1995 and 1996 compared to earlier years because of increased summer baseflow (Figure 2.1). The reason for dividing juveniles into size classes was because those => 75 mm SL during fall sampling would likely smolt the following winter and spring without spending another year in freshwater. It is these smolts that are critical in determining the number of adult returns. The size at smolting was based on data collected from smolt trapping on the San Lorenzo River in the mid 1980's (Smith and Alley, unpublished), scale analysis of returning adults (Smith, unpublished), and previous trapping on Waddell Creek (Shapovalov and Taft, 1954). Also, densities of these larger fish are more sensitive to habitat quality than the smaller YOY fish, whose densities fluctuate more from year to year.



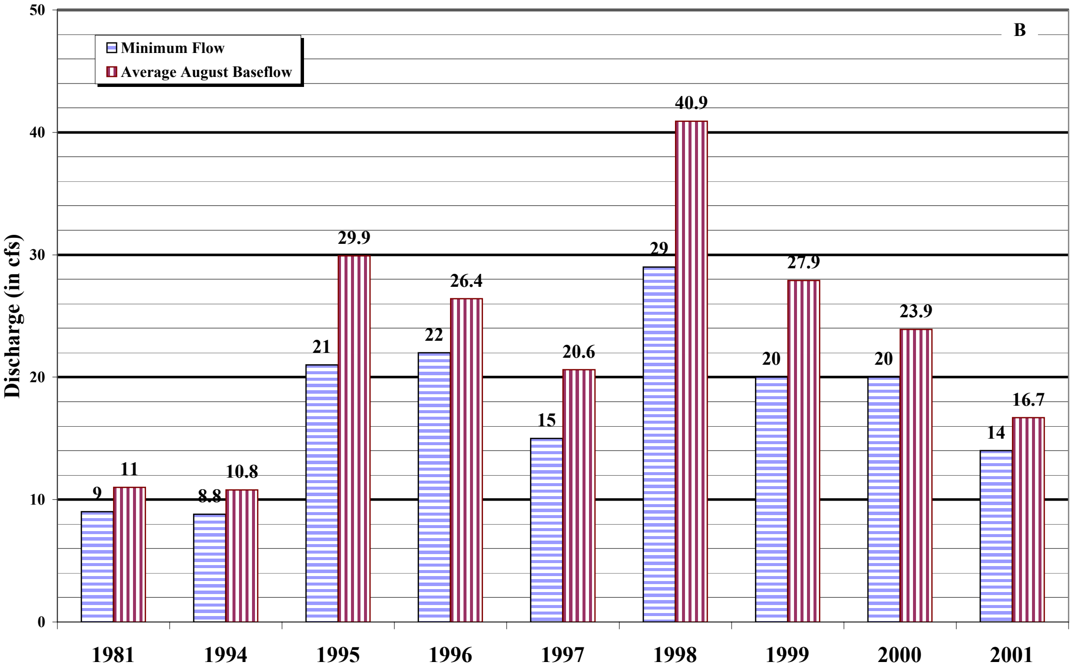


Figure 2.1: A) Estimated number of juvenile steelhead by size-class in the San Lorenzo River mainstem from Highway 1 to above Waterman Gap in the Fall of 1981, 1994-2001. Tributaries to the San Lorenzo River were only surveyed from 1998 t 2001 and are not included in these data. B) Minimum flow between May and October from 1981, 1994 to 2001 and average flow for the month of August (assumed to be average baseflow) for the Big Trees streamflow gage on the San Lorenzo River (USGS Gage #11160500).

Table 2.1. Estimated Number of Juvenile Steelhead by Size-Class (rounded to the nearest 500).

Year	# of Size Class 1	Class 1 Percentage	# of Size Class 2 & 3	Class 2 & 3 Percentage	Total Number of Juveniles
1981 Mainstem	37,000	54	31,500	46	69,000
1994 Mainstem	24,500	54	23,000	46	45,000
1995 Mainstem	37,000	49	38,000	51	75,000
1996 Mainstem	40,000	55	32,500	45	72,500
1997 Mainstem	63,000	72	25,000	28	88,000
1998 Mainstem	31,000	53	26,000	47	58,000
1999 Mainstem	17,500	42	24,000	58	41,500
2000 Mainstem	12,500	50	12,500	50	25,000
2001 Mainstem	23,500	67	11,500	33	35,000
1998 Tributaries	91,500	82	19,000	18	110,500
1999 Tributaries	73,500	72	28,500	28	102,000
2000 Tributaries	59,000	75	19,500	25	78,500
2001 Tributaries	70,000	81	16,500	19	86,500
1998 Watershed	122,500	73	45,000	27	168,500
1999 Watershed	91,000	63	52,500	37	143,500
2000 Watershed	71,500	69	32,000	31	103,500
2001 Watershed	93,500	77	28,000	23	121,500

The H.T. Harvey report (2003) was published after the majority of the data analysis and presentation had been completed for the present study and the specific data was not incorporated into this report. However, it is useful to note that the data from non-random sampling indicates that density and abundance of juvenile steelhead increased in 2002 relative to prior years. The combined estimated abundance for the San Lorenzo River mainstem and all sampled tributaries was 168,300 juvenile steelhead. This value is the highest since 1998, which had similar abundance estimates. No coho salmon were encountered during sampling in 2002.

When the watershed was divided into two basin subdivisions (one grouping of mainstem sites up to the Boulder Creek confluence and the other grouping of sites in the upper mainstem above Boulder Creek combined with tributary sites) and statistically analyzed (paired t-test) in terms of reach production by size class between adjacent years (1997-2001), some changes were found to be significant. Mainstem production of size class 1 juvenile steelhead significantly decreased from 1997 to 1998 (p-value= 0.01246), consistent with faster growth rates of YOY's occurring from high baseflows in 1998. In tributaries, size class 2 and 3 juvenile production significantly declined from 1999 to 2000 (p-value= 0.0087), indicating fewer yearlings present. Size class 2 juveniles also declined in the mainstem from 1999 to 2000 at a level of significance of $p = 0.05743$ due likely to reduced YOY production in 2000 (El Niño effects of fewer adult returns). Mainstem production of size class 1 juveniles increased significantly from 2000 to 2001 (p-value= 0.00914), consistent with increased YOY production in 2001 and slower growth rates of YOY's from lower baseflows (Refer to Appendix A for statistical results).

When steelhead densities at sampling sites were statistically compared between 2000 and 2001, both size class 1 and age class 1 densities increased over the entire watershed in 2001 (Alley 2002). These differences were highly significant, statistically (p-values of 0.00129 and 0.00049, respectively). The same was true when the watershed was divided into two subdivisions, yielding significant increases in Size Class 1 and Age Class 1 from 2000 to 2001.

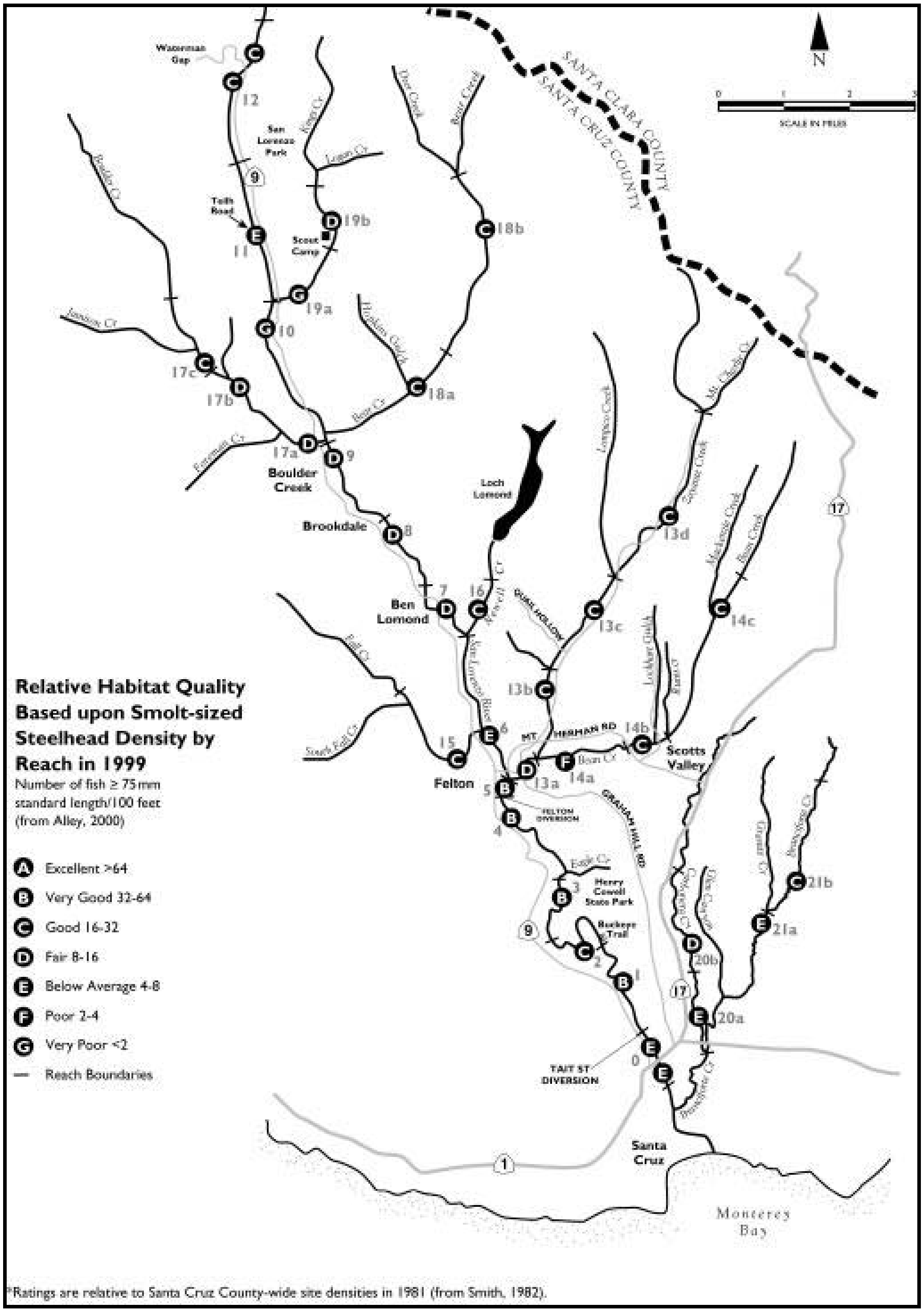
Most of the YOY's inhabiting the lower River grow into smolt-size (Size Class 2 => 75 mm SL) the first year. Yearlings are also quite large, but in lower densities. The middle River also may produce a high proportion of smolt-sized YOY's when streamflow is sufficient. Therefore, YOY growth rates and production of smolts in the middle River may be highly impacted by streamflow diversions. Since the El Niño winter of 1997-98, the habitat in the middle River has been seriously impacted by sedimentation resulting from erosion in upper tributaries (especially Kings and Bear creeks). Streamflow in the upper River, above the Boulder and Bear creek confluences, is much less than downstream. Therefore, YOY's in the upper River grow at a rate similar to those in tributaries. In tributaries, most YOY's must spend two years in freshwater and smolt as yearlings because streamflow in spring and summer is much less than in the middle and lower River. Growth rate in tributaries and upper River is less because of lower streamflow, less food available and cooler water temperature. The tributaries are undoubtedly an important source of YOY's to the Middle and Lower River, where they can expand into and grow more quickly. In conclusion, the smolts leaving the system (out-migrating to the ocean) each year are mostly a combination of large YOY's from the middle and lower River and yearlings from the tributaries and mainstem River. Unpublished data (Smith 1988-89) indicate that a high proportion of the adults returning to the San Lorenzo came from these large, fast-growing YOY's.

The middle River has been substantially impacted by sedimentation and fluctuations in baseflow, causing fluctuations in the growth rate of YOY juveniles and production of larger juveniles. The middle River is warm, as is the lower River, requiring juveniles to seek out fastwater habitat that greatly increases with higher summer baseflow. The middle River potentially produces many smolt-sized juveniles in wetter years.

The great value of the mainstem River is its production of larger, smolt-sized juveniles. Figure 2.2 rates the various reaches of the mainstem and tributaries according to their production of smolt-sized juveniles in 1999, prior to the downturn in smolt production in 2000. Presumably because of the high stormflows of the El Niño winter of 1997-98, many would-be yearlings were washed out of the system (Tables 2.1-2.3), but spawning success was adequate enough in spring to produce high numbers of YOY fish that grew rapidly to smolt size in the lower and middle River with the especially high streamflows. However, since 1998, the contribution of the mainstem River to smolt production has diminished from 26,000 (1998) to 24,000 (1999) to 12,500 (2000) to 11,700 (2001). This decline primarily resulted from fewer YOY's utilizing the mainstem with 52,500 in 1998 to 34,500 (1999) to 18,000 (2000) (Table 2.1, Figure 2.3) and slower growth rate of the estimated 30,500 YOY's in 2001.

Table 2.2. Estimated Number of Steelhead by Location on the Mainstem River. (The capture depletion method of density estimates was applied separately for size classes and age classes, yielding different total number of juveniles when adding size classes compared to age classes).

Location / Year	# of Size Class 1	# of Size Class 2 & 3	# of YOY's	# of Yearlings	Total # of Juveniles
Lower SLR - 1996	6,200	17,900	22,700	1,200	23,900
Lower SLR – 1997	9,000	14,400	22,500	1,400	23,900
Lower SLR – 1998	2,100	14,700	15,700	1,100	16,800
Lower SLR – 1999	1,700	15,900	15,000	2,100	17,100
Lower SLR – 2000	1,000	4,500	4,900	1,200	6,200
Lower SLR – 2001	4,000	6,400	9,100	1,000	10,100
Middle SLR - 1996	19,000	9,400	24,400	2,900	27,300
Middle SLR – 1997	28,500	7,000	33,000	3,600	36,600
Middle SLR – 1998	24,300	8,500	31,100	2,100	33,200
Middle SLR – 1999	10,200	4,300	12,600	1,800	14,400
Middle SLR – 2000	1,800	2,100	3,200	700	3,900
Middle SLR – 2001	9,300	1,400	10,000	500	10,500
Upper SLR - 1996	15,000	5,200	15,000	5,200	20,200
Upper SLR – 1997	25,800	3,400	25,800	3,400	29,200
Upper SLR – 1998	4,800	3,500	5,800	2,200	8,000
Upper SLR – 1999	5,800	3,900	6,800	3,400	10,200
Upper SLR – 2000	9,600	4,500	10,000	3,800	13,800
Upper SLR – 2001	23,600	11,700	30,600	4,800	35,400



*Ratings are relative to Santa Cruz County-wide site densities in 1981 (from Smith, 1982).

Figure 2.2: Relative habitat quality by reach based on smolt-sized steelhead densities in 1999.

Table 2.3. Estimated Number of Juvenile Steelhead by Age-Class (rounded to the nearest 500). (The depletion method of density estimates was applied separately for size classes and age classes, yielding different total number of juveniles when adding size classes compared to age classes).

Year	# of YOY	YOY Percentage	# of Yearlings	Yearling Percentage	Total Number of Juveniles
1996 Mainstem	62,000	87	9,500	13	71,500
1997 Mainstem	81,500	91	8,500	9	89,500
1998 Mainstem	52,500	91	5,500	9	58,000
1999 Mainstem	34,500	82	7,500	18	42,000
2000 Mainstem	18,000	75	5,500	25	24,000
2001 Mainstem	30,500	86	5,000	14	35,500
1998 Tributaries	103,500	92	9,500	8	113,000
1999 Tributaries	74,500	73	28,000	27	102,500
2000 Tributaries	61,000	78	17,500	22	78,500
2001 Tributaries	69,500	80	17,000	20	86,500
1998 Watershed	156,000	91	15,000	9	171,000
1999 Watershed	109,000	75	35,500	25	144,500
2000 Watershed	79,000	78	23,000	22	102,500
2001 Watershed	100,000	82	22,000	18	122,000

We saw a precipitous decline in mainstem juvenile production in 2000 partially due to habitat sedimentation but also from other factors. We suspect that poor spawning success and/or fewer spawners resulting from events associated with the 1997-99 El Niño period explain the fewer YOY's in the lower and middle River and much of the watershed in 2000. Fewer spawners than usual may have entered the River in winter of 1999-2000 due to the El Niño storm pattern and associated oceanic conditions. There was likely high mortality of wild smolts in winter of 1997-1998 due to flood flows, causing fewer adult returns in 1999-2000 and less spawning. In addition, the Monterey Bay Salmon and Trout Project sustained flood damage during the 1997-98 El Niño and significantly reduced its steelhead smolt planting that year. These smolts would have returned as adults in 2000. Smolt planting numbers for spring, 1995-99, were 42,300, 28,800, 32,000, 2,200 and 30,600, respectively. In addition, oceanic conditions for juvenile survival to adulthood may have been abnormally difficult. El Niño began in summer 1997, peaked in fall and winter of 1997-98, and persisted through spring and summer of 1998. Unusually warm surface water temperatures (SST's), low macronutrient levels, and low chlorophyll and primary production characterized this event (Michisaki et al., 2001). Biological effects were particularly strong during spring and summer of 1998. Survival of steelhead smolts entering the ocean during the winter and spring of 1997-1998 may have had poor survival due to high competition for food under warm water conditions. This may have additionally contributed to low adult returns in 2000. The same reduction in YOY's and yearlings was also observed in Soquel Creek in 2000 (Alley, 2001) from what we assume were similar reasons.

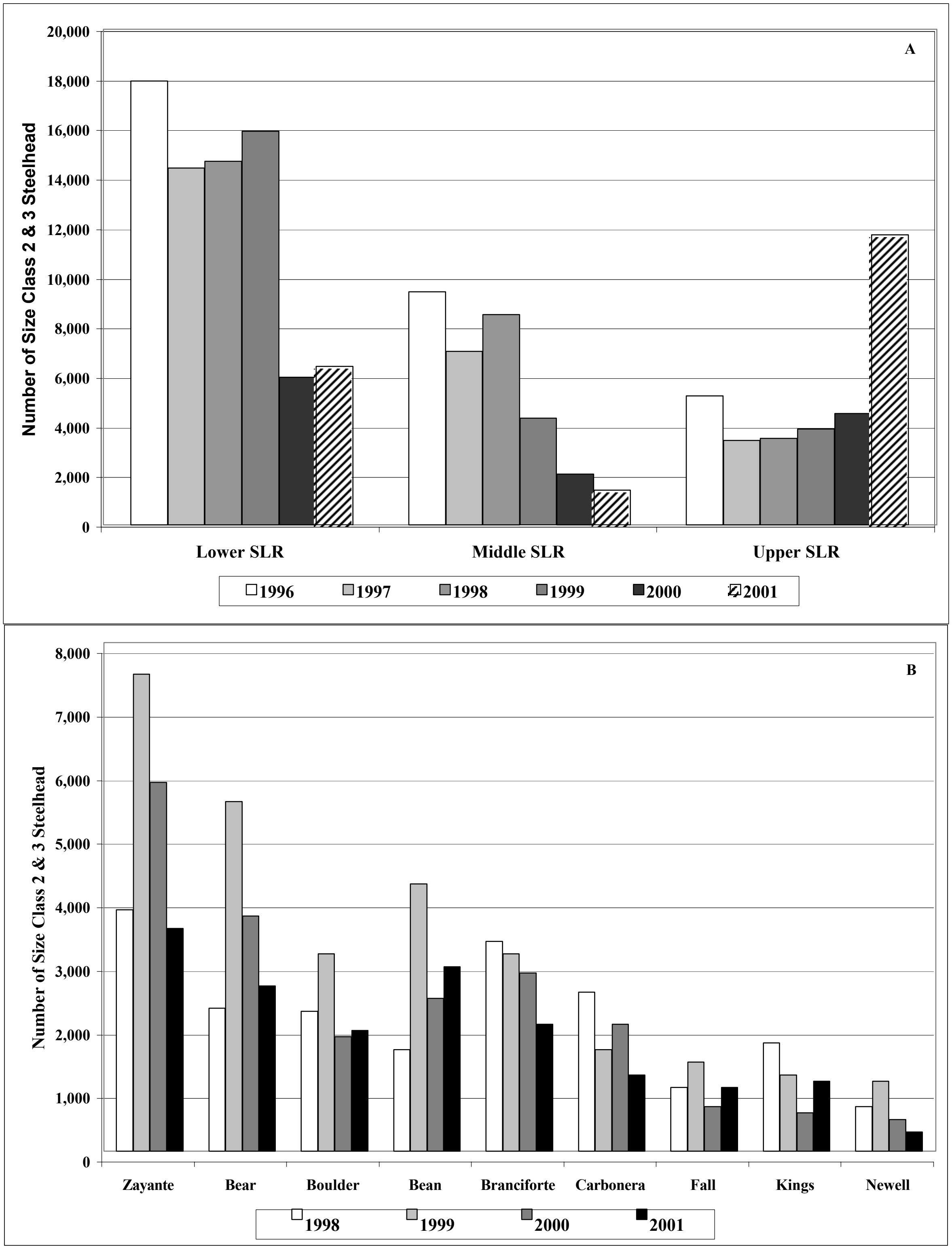


Figure 2.3: A) Estimated number of size class 2 & 3 juvenile steelhead in the mainstem of the San Lorenzo River from 1996 to 2000. B) Estimated number of size class 2 & 3 juvenile steelhead in the tributaries of the San Lorenzo River from 1998 to 2000.

In 2000, the timing of winter stormflows may have caused poor survival of overwintering juveniles, high egg mortality and a more constricted period of good spawning access and adequate flows to allow successful spawning. More sediment was in the system than prior to the large El Niño storms of 1998. During the mid-January and mid February storms, streamflow went from less than 150 cfs to peak flows between 5,000 and 7,500 cfs within 24 hours at the Big Trees Gage, undoubtedly causing rapid increases in sediment load and water velocity that would cause difficulty for overwintering juveniles to avoid being dislocated downstream.

The upper River, particularly upstream of the Kings Creek confluence, is the one portion of the watershed that has steadily improved its juvenile production since the El Niño storm events (Table 2.1). However, its YOY production in 1997, prior to El Niño, was substantially higher than afterwards.

Juvenile Production in the Tributaries

Regarding juvenile steelhead production in the tributaries, Zayante Creek is usually the most productive in terms of YOY's and smolt-sized fish (Tables 2.4 and 2.5; Figure 2.3). It is the largest tributary and is capable of producing YOY's of smolt-size because of its higher streamflow. It also produces the most yearlings. However, Zayante Creek YOY production was less than half the 1999 level in 2000, presumably due to similar reasons that YOY production was off in the mainstem River.

Bean, Bear, Branciforte and Boulder creeks are important producers of YOY's and yearlings, though Bean and Bear were seriously impacted by sedimentation resulting from El Niño storms (Tables 2.4 and 2.5). Bean Creek bounced back quickly to high production in 2000. Spawning success and overwintering by juveniles in Boulder Creek are vulnerable to high stormflows because of its vertical canyon walls that confine the channel and maximize water velocity. As a result, its YOY and yearling production are much reduced when winter stormflows rapidly increase or are sustained at high levels. Carbonera Creek is a good producer of yearlings despite its limited summer streamflow. Fall and Boulder Creeks are undoubtedly important sources of YOY's to the mainstem River. Newell Creek is not very productive because of its relatively short steelhead reach. Kings Creek is relatively unproductive despite its comparably long steelhead reach. This is because of high sediment impacts and relatively low spring and summer flow.

Table 2.4. Estimated Number of Juveniles in Tributaries to the San Lorenzo River by Age-Class. (The capture depletion method of density estimates was applied separately for size classes and age classes, yielding different total number of juveniles when adding size classes compared to age classes.)

Creek	**1998 YOY**	**1998 Yearling**	**1999 YOY**	**1999Yearling**	**2000 YOY**	**2000 Yearling**	**2001 YOY**	**2001 Yearling**
Branciforte	14,800	2,000	9,500	3,100	11,300	2,800	11,700	2,000
Carbonera	6,900	600	4,900	1,500	3,500	2,000	4,100	1,200
Zayante	19,800	1,700	22,000	6,700	9,300	3,700	15,100	3,500
Bean	17,900	1,500	6,100	4,200	15,000	2,300	8,300	3,000
Fall	5,800	600	5,800	1,400	3,500	700	3,900	1,000
Newell	3,600	400	1,000	1,100	1,300	400	2,000	300
Boulder	13,400	1,300	5,800	3,100	5,300	1,800	7,900	1,900
Bear	18,100	1,200	16,700	5,500	8,300	3,000	13,000	2,900
Kings	3,300	300	2,700	1,200	3,800	600	3,400	1,300
Total Production	103,600	9,600	74,500	27,800	61,300	17,300	69,400	17,100

Table 2.5. Estimated Number of Juveniles in Tributaries to the San Lorenzo River by Size-Class.

Creek	1998 Size Class 1	1998 Size Classes 2 & 3	1999 Size Class 1	1999 Size Class 2 & 3	2000 Size Class 1	2000 Size Class 2 & 3	2001 Size Class 1	2001 Size Class 2 & 3
Branciforte	13,300	3,300	9,500	3,100	11,300	2,800	11,700	2,000
Carbonera	5,000	2,500	4,900	1,600	3,500	2,000	4,100	1,200
Zayante	17,900	3,800	21,100	7,500	7,900	5,000	15,000	3,500
Bean	17,800	1,600	6,100	4,200	14,900	2,400	8,300	2,900
Fall	5,300	1,000	5,800	1,400	3,500	700	3,900	1,000
Newell	3,200	700	1,000	1,100	1,100	500	2,000	300
Boulder	10,000	2,200	5,800	3,100	5,300	1,800	7,900	1,900
Bear	17,200	2,300	16,700	5,500	7,700	3,700	13,300	2,600
Kings	2,000	1,700	2,700	1,200	3,800	600	3,700	1,100
Total Production	91,700	19,100	73,600	28,700	59,000	19,500	69,900	16,500

Overall Watershed Production of Juvenile Steelhead

Production of juvenile steelhead in the San Lorenzo drainage declined from 1998 to 2000 due to progressively less annual production of YOY fish (Table 2.3) (Alley, 2001). While yearling production was substantially greater in 1999 compared to 1998, in 2000 it was less than in 1999 (Table 2.3), leading to the lowest predicted total of smolt-sized juveniles of the three years (Table 2.4). The proportion of watershed smolt-sized production in the tributaries has increased from 1998 to 2000 with 42% in 1998 (19,100), 54% in 1999 (28,700) and 61% (19,500) in 2000.

In 2001, tributaries produced 75% of the Size Class 1 juveniles (83% in 2000; 80% in 1999; 75% in 1998), 69% of YOY fish (77% in 2000; 68% in 1999; 66% in 1998), 58% of the Size Class 2 and 3 juveniles (61% in 2000; 54% in 1999; 42% in 1998) and 78% of the yearlings (75% in 2000; 79% in 1999; 63% in 1998). These proportions imply that relatively less production has occurred in the mainstem in each succeeding year and that most of the slower growing requiring 2 years to reach smolt size inhabit the tributaries, which have less streamflow than the lower and middle mainstem in most years.

Index of Adult Steelhead Returns from Juvenile Production

The Dettman population model (Kelley and Dettman, unpublished, 1987) has been used to provide an index of adult returns on a reach-by-reach basis for the mainstem River since 1994 and for the watershed since 1998. The basic assumption of the model is that the survival rate from juvenile to a returning adult is positively related to the size of the juvenile. This has been confirmed by scale analysis of returning adults (Smith, unpublished). Results of the model suggest that future adult returns, resulting from juvenile production in 2000 and returning in 2002-2003 will stem from reduced smolt production in the lower and middle River where many of the larger fish are produced.

The adult index for mainstem juveniles steadily declined for 6 consecutive years, 1995-2000, and increased slightly in 2001 (Alley, 2002) (Table 2.6, Figure 2.4). Within the mainstem, the adult index declined most in the middle River, followed by the lower River. The upper River increased its relative contribution in 2000. Adult indices from mainstem juveniles for 1998-2001 were 1,260, 1,150, 560, and 610, respectively, representing a 51% decline from 1999 to 2000 and a 9% increase in 2001. The proportion of adults expected for the entire watershed from mainstem juvenile production in 1998-2001 was 52%, 43%, 35%, and 38%, respectively. Juvenile production from the lower River in 1998-2001 represented 26%, 27%, 14%, and 19% of the total watershed adult index, respectively. Juvenile production from the middle River in 1998-2001 represented 19%, 9%, 6%, and 6% of the watershed adult index, respectively. Therefore, the lower and middle River potentially contributes substantially to the index of adult returns, underscoring the importance of protecting instream flow and reducing sedimentation there.

The estimated number of returning adults from the Dettman model was probably high before the 50% reduction was factored in. We have no data to indicate the actual survival rates of smolts to adulthood or the percent of repeat spawners. But for comparison purposes, the model provides insight into comparing years of juvenile production and assessing the potential value of annual juvenile production to adult returns, assuming the return rate has not changed significantly from 1981 to the present. Based on trapping data from the 1930's, 1940's and 1970's, the model's index of adult returns for the late 1990's appear to be within the expected range of year-to-year variation in returning adults. However, the sharp decline in YOY numbers in portions of the mainstem and in most tributaries in 1999 and 2000 without substantial habitat deterioration may indicate an atypical drop in adult returns for those years. In 2001 the YOY production rebounded to pre-El Niño levels.

Adult indices from tributary juveniles from 1998-2001 were 1,200, 1,500, 1,050, and 980, respectively, representing a 30% decline in 2000 and a 9% decline in 2001 (Table 2.6). Zayante Creek (including Bean Creek) continued to be the most important sub-watershed in contributing to the adult index in 2000. The percent of the adult index expected from juveniles produced in various tributaries in 1998-2001 were as follows; Zayante sub-basin contributing 15%, 23%, 25% and 23.5%, Branciforte sub-basin contributing 13%, 10%, 16% and 12.5%, Bear Creek contributing 6.5%, 11%, 12% and 10%, Boulder Creek contributing 6%, 6%, 6% and 7%, Fall, Newell and Kings, combined, contributing 8%, 8%, 7% and 8%. Adult indices from mainstem and tributary juveniles for 1998-2001 were 2,470, 2,670, 1,650, and 1,580 adults, respectively, representing a 38% decline from 1999 to 2000 and a slight decline in 2001.

The percent of adults expected from tributary production of juveniles from 1998-2001 was 48%, 57%, 65%, and 62% of the total, respectively. This underscored the relative decline in juvenile production in the mainstem River.

Table 2.6. Estimated Index of Adult Steelhead Returns.

Year	# of First Time Spawners	Total # of Returning Adults
1981 Mainstem	1,250	1,500
1994 Mainstem	900	1,100
1995 Mainstem	1,500	1,800
1996 Mainstem	1,300	1,500
1997 Mainstem	1,100	1,300
1998 Mainstem	1,100	1,300
1999 Mainstem	950	1,150
2000 Mainstem	470	560
2001 Mainstem	500	610
1998 Tributaries	1,000	1,200
1999 Tributaries	1,300	1,500
2000 Tributaries	900	1,070
2001 Tributaries	800	1,000
1998 Watershed	2,100	2,500
1999 Watershed	2,250	2,650
2000 Watershed	1,350	1,650
2001 Watershed	1,300	1,600

Figure 2.4: Trends in the Index of Adult Steelhead Returns projected for the San Lorenzo River based on the year of juvenile production.

SECTION 2.3 - GEOMORPHIC SURVEYS

Introduction

As part of the San Lorenzo River Salmonid Enhancement Plan, 14 monitoring reaches were established on the San Lorenzo River and its major tributaries to assess streambed conditions (Figure 2.5). The sites were chosen to overlap existing fish population survey sites and are to be used as baseline information to monitor changes in watershed conditions above each site. As part of the initial data collection, each monitoring reach was surveyed in fall of 2000.

Stream channels, riparian corridors and aquatic systems have been shown to be good indicators of cumulative watershed impacts (Likens and Bormann, 1974; Allan et al, 1977; Hawkins et al, 1994). On the San Lorenzo River and major tributaries, the dominant impacts limiting steelhead spawning and rearing success have been caused by sedimentation and loss of channel complexity. Sedimentation results in pool filling, reductions in insect production, loss of escape cover, and loss in habitat quantity and quantity. Loss of channel complexity from channel straightening and road building within the inner gorge limits the ability of the channel to sort sediment, scour pools and provide a variety of habitat types.

The data collection design at each monitoring reach is meant to characterize the hydraulic and geomorphic conditions of the channel and banks through the entire monitoring reach. Since channel conditions tend to integrate upstream land-use changes and erosional processes, an assessment of channel and bank conditions, within a defined reach, can act as a proxy for changes in the watershed. An attempt was made to assess conditions at the reach scale but also provide monitoring at site-specific locations. With this goal in mind, a field method was developed to monitor variables that relate to pool development, human-induced changes to the channel, fine sediment deposition and fish habitat quality.

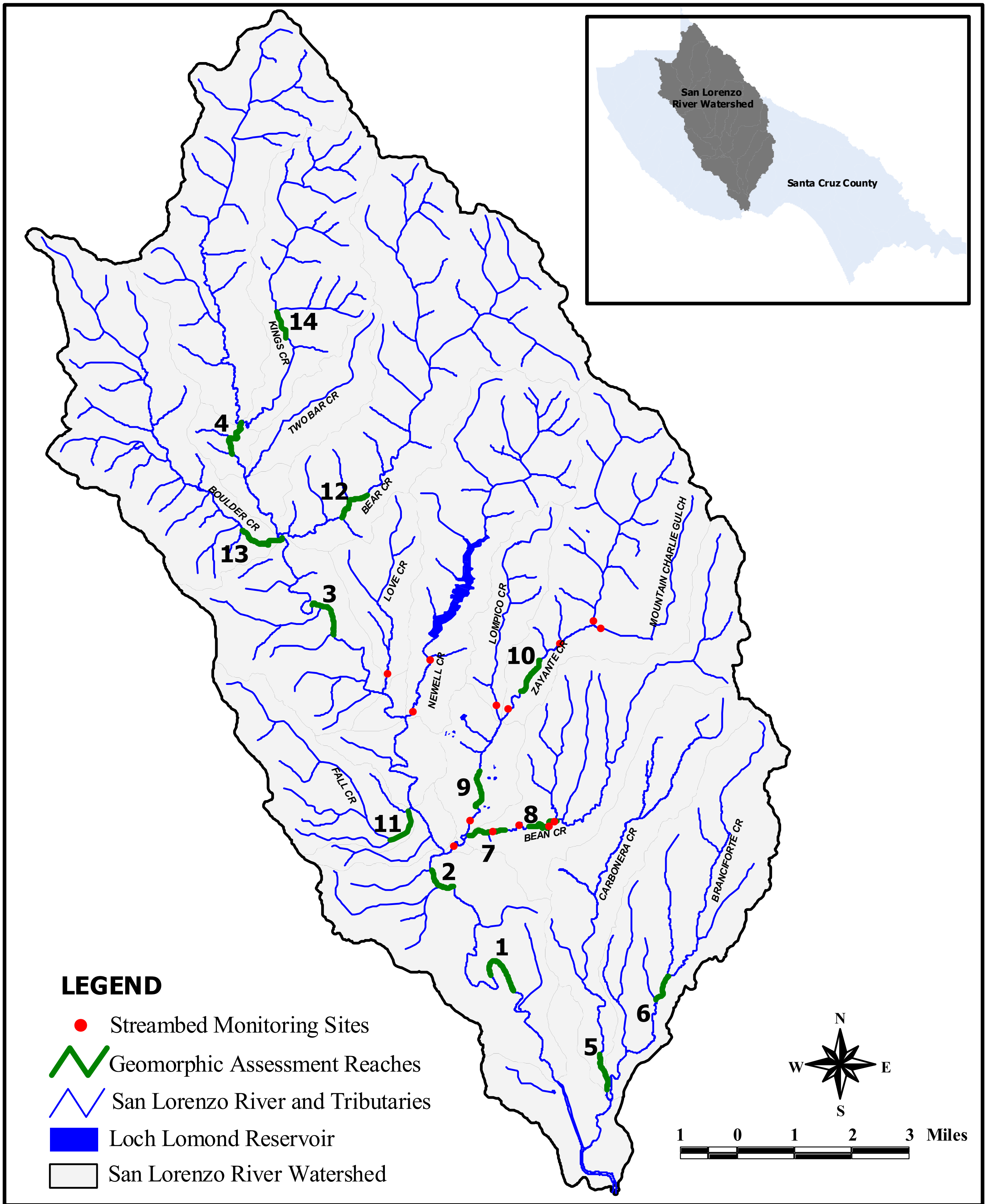
The primary objective of establishing the 14 monitoring reaches was to collect baseline data for comparison with future monitoring efforts. The survey was conducted in October and November of 2000 during low flow conditions. A secondary objective was to develop a set of geomorphic data that overlapped existing fish population data. Correlations between geomorphic conditions and population numbers could then be assessed to determine potential geomorphic controls on fish population numbers.

Monitoring Reaches

Selecting the number and location of each site to conduct long-term monitoring is often a crucial part of the initiation phase of a project. The first step involves identifying the problems that necessitate monitoring. The second step involves identifying key reaches where changes in future watershed management practices could be detected.

Identification of the problems occurring on the San Lorenzo River, that we are hoping to monitor, have been outlined and reiterated in several previous reports and supporting documentation (Swanson and Dvorsky, 2001; Nolan et al, 1993; Hecht and Kittleson, 1998; Ricker and Mount, 1979; Hecht and Enkeboll, 1980). The next step is to identify appropriate monitoring locations. To meet this goal, we met with a representative from the County to discuss appropriate monitoring locations. The following criteria were used for selection:

- The monitoring reach should be located on the mainstem or major tributary,
- The monitoring reaches on the mainstem should represent a variety of channel types and should be key reaches for steelhead production,
- Tributary reaches should be located downstream of reaches known to contribute significant sediment loads,



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Jerry Smith, PhD

Location and ID number of reaches surveyed during the channel geomorphic assessment in the Fall of 2000. Also shown are the Streambed Monitoring Sites established for the Zayante Area Sediment Study.

Figure 2.5
April 2002

- Reaches should overlap with current salmonid habitat and population surveys (Alley, 2000),
- If possible, the reaches should overlap monitoring sites established in the Zayante Area Sediment Study (Swanson and Dvorsky, 2001), and
- Reach boundaries should be set at known landmarks such as roads or tributary confluences for easy reference in future monitoring efforts.

Based on these criteria, 14 monitoring sites were established (Table 2.7 and Figure 2.5). Four sites were established on the mainstem of the San Lorenzo River with the remaining 10 on major tributaries. Zayante and Bean Creeks were the only tributaries where more than one monitoring reach was established (2 each). Multiple sites were established on these two creeks due to their importance to salmonid production in the San Lorenzo River watershed and the range of impacts affecting them.

Since the goal of establishing the monitoring reaches is to assess cumulative impacts and detect the level of improvement to channel conditions from changes in management policies and erosion control efforts, appropriate monitoring methods were selected based on defined variables. The selected methods are reproducible from one survey to the next with clearly defined results that are comparable and easily assessed quantitatively and statistically.

With this is mind, the variables that were measured in the survey reaches are bankfull depth, bankfull width, entrenchment, pool-riffle-run ratios, mean pool depth, maximum pool depth, pool type, embeddedness, bank condition, and the quantity and size of large woody material. These variables were measured along the entire reach to get a reach-averaged picture of the channel conditions. This was done to avoid site-specific, year-to-year changes in local morphology that may not be a good indicator of overall channel conditions. Reach-averaged conditions are assumed to be a better indicator of cumulative watershed impacts.

Additional parameters, describing general characteristics of the reach, were calculated through the use of topographic maps, digital terrain models and aerial photos. These parameters include stream class type, drainage area, average reach slope, and reach length.

In addition to the channel conditions assessed along each reach, pools were selected and monumented in order to determine changes in pool volume over time. Since one of the impacts of sedimentation is pool filling and loss of deep pool habitat, it is essential to conduct detailed monitoring of pool depths and volumes. By selecting key pools along each reach and monitoring them, the magnitude of sedimentation and potential habitat loss will be better understood.

The following section describes the methods used for measuring each parameter.

Methods

The methods used for the survey of channel conditions and pool volumes have been taken directly from standard methods. In some cases, standard methods have been adapted slightly to deal with the unique conditions found on the San Lorenzo River or to provide the specific information required for this study. Table 2.8 summarizes the parameters that were measured at each monitoring site. Several parameters were not measured in the lower mainstem of the San Lorenzo River based on their perceived lack of importance (pool habitat in the lower river), difficulty of collecting the data (large woody material counts) and existing information (flow from Big Trees gage).

Table 2.7: Location and description of Geomorphic Monitoring Reaches established in Fall, 2000. Also listed are reach numbers for overlapping fish monitoring sites (Alley, 2000).

Geomorphic Reach #	Fish Survey Reach	Description
M-1	**2**	*Lower River - Rincon* *Upstream end:* Downstream end of braided (channel split), downstream of Rincon Road from Hwy 9 *Downstream end:* At trail crossing that comes down from Graham Hill Road through Henry Cowell Park *Access Point:* Hwy 9 to Rincon Trail. Walk down river.
M-2	**4**	*Lower River - Henry Cowell Park* *Upstream end:* Big Treet Park Road *Downstream end:* At large bend in river downstream of Gold Gulch, adjacent to Beth Drive *Access Point:* Henry Cowell Bridge off Hwy 9
M-3	**8**	*Middle River - Brookdale* *Upstream end:* Pacific Street Bridge *Downstream end:* Larkspur Bridge *Access Point:* Bridge off Hwy 9
M-4	**10**	*Upper River* *Upstream end:* Pleasure Way bridge off Hwy 9 downstream of Kings Creek confluence *Downstream end:* adjacent to end of Shady Lane downstream of Spring Creek confluence *Access Point:* Pleasure Way bridge off Hwy 9
M-5	**20a**	*Branciforte Creek* *Upstream end:* Large pool in narrow canyon area upstream of County Hospital *Downstream end:* Lee Street bridge upstream of Hwy 1 bridge *Access Point:* Lee Street bridge off Emiline Avenue
M-6	**21a**	*Carbonera Creek* *Upstream end:* Confluence of Branciforte Creek and Granite Creek *Downstream end:* Flashboard dam structure adjacent to Happy Valley Conference Center *Access Point:* Branciforte Road bridge past intersection with Granite Creek Road
M-7	**14a**	*Lower Bean Creek* *Upstream end:* Just upstream of trail from Mt. Hermon Conference Center to the creek *Downstream end:* Foot bridge just upstream of confluence with Zayante *Access Point:* Trail down to Creek from Mt. Hermon Conference Center
M-8	**14b**	*Upper Bean Creek* *Upstream end:* Confluence of Lockhart Gulch *Downstream end:* Large bend just downstream of tributary coming from abandoned landing strip *Access point:* Lockhart Gulch Road bridge
M-9	**13b**	*Lower Zayante Creek* *Upstream end:* Adjacent to McEnery Road *Downstream end:* At East Zayante Road bridge near intersection with West Zayante Road *Access Point:* East Zayante Road bridge
M-10	**13d**	*Upper Zayante Creek* *Upstream end:* At bedrock chute adjacent to Zayante Road and end of Rosebloom Avenue *Downstream end:* Adjacent to Waner Way just downstream of old bridge (unusable) across creek *Access Point:* Waner Road off Zayante Road
M-11	**15**	*Fall Creek* *Upstream end:* Bennett Creek confluence *Downstream end:* Bridge for Fall Creek/Farmers Street *Access Point:* Henry Cowell - Fall Creek Unit parking lot. Take trail to tributary, then tributary to Fall Creek
M-12	**18a**	*Bear Creek* *Upstream end:* Just downstream of bridge at Forest Hill Drive *Downstream end:* Just downstream of confluence with Hopkins Gulch at bridge *Access Point:* 14780 Bear Creek Road. Down drive to bridge
M-13	**17a**	*Boulder Creek* *Upstream end:* adjacent to where St. Francis Drive intersects with Hwy 236 *Downstream end:* Hwy 9 bridge *Access Point:* From Schwanzbach Associates Realtors parking lot
M-14	**19b**	*Kings Creek* *Upstream end:* At bend in creek just downstream of Logan Creek *Downstream end:* Kings Creek Road bridge above Peterson Gulch *Access Point:* Kings Creek Road bridge

Table 2.8: Measured parameters for each geomorphic monitoring reach

Site	Channel Parameters	Pool Riffle Run Ratio	Mean Pool Depth	Max Pool Depth	Pool Type	Pool Tail Embedded ness	Riffle Embedd edness	Linear Distance of Eroded Banks	Linear Distance of Modified Banks	Large Woody Debris	Surveyed Pool Volumes (1 to 2 per reach)	Flow
1 – Lower San Lorenzo Below Zayante	X	X	X	X	X	X	X	X	X			
2 – Lower San Lorenzo @ Rincon	X	X	X	X	X	X	X	X	X			
3 – San Lorenzo River @ Brookdale	X	X	X	X	X	X	X	X	X		X	X
4 – San Lorenzo River below Kings Creek	X	X	X	X	X	X	X	X	X	X	X	X
5 – Kings Creek below Logan Creek	X	X	X	X	X	X	X	X	X	X	X	X
6 – Boulder Creek @ Hwy 9 Bridge	X	X	X	X	X	X	X	X	X	X	X	X
7 – Bear Creek upstream of Hopkins Gulch	X	X	X	X	X	X	X	X	X	X	X	X
9 – Fall Creek downstream of Bennett Creek	X	X	X	X	X	X	X	X	X	X	X	X
10 – Zayante Creek @ Zayante	X	X	X	X	X	X	X	X	X	X	X	X
11 – Zayante Creek near Olympia	X	X	X	X	X	X	X	X	X	X	X	X
12 – Bean Creek downstream of Lockhart	X	X	X	X	X	X	X	X	X	X	X	X
13 – Bean Creek near Mt. Hermon	X	X	X	X	X	X	X	X	X	X	X	X
14 – Branciforte below Granite Creek	X	X	X	X	X	X	X	X	X	X	X	X
15 – Carbonera @ Branciforte confluence	X	X	X	X	X	X	X	X	X	X	X	X

Channel and Bank Conditions

The ultimate goal in determining the geomorphic character of the channel and banks is to assess their condition in relation to fish habitat quality, production and rearing potential. Traditional fish habitat quality surveys often incorporate standard physical condition monitoring to define the controlling variables on fish presence or absence and total fish population numbers.

The geomorphic, channel and bank condition variables assessed in this project have been described well in habitat inventory manuals such as the California Salmonid Stream Habitat Restoration Manual (Flosi et al, 1998) and a variety of manuals used by the U.S. Forest Service. In addition, many of the methods are described in the stream classification literature outlined by Dave Rosgen (Rosgen, 1994; Rosgen, 1996). Some modifications were made to standard methods based on site conditions and necessity of obtaining certain types of data. The methods used are described below in detail and in some cases are adapted from the previously mentioned manuals.

Average bankfull depth: This variable is defined as the mean depth at bankfull discharge where bankfull discharge is the dominant channel forming flow. Bankfull discharge is estimated to be at the 1.5-year recurrence interval. This variable is averaged over the entire reach by taking multiple measurements during the course of the survey. Indicators of bankfull depth include breaks in slope between active channel and floodplain and the lowest elevation of perennial vegetation.

Average bankfull width: The channel width at bankfull discharge. This variable is measured in the same manner as bankfull depth. Both bankfull width and bankfull depth are important parameters for restoration, channel classification and in identifying land use changes.

Average channel width at two-times bankfull depth - Entrenchment Ratio: This variable is measured at the same locations as the previous two variables and is used to determine channel entrenchment. Channel entrenchment is defined as the channel width at two-times bankfull depth divided by the bankfull width. The entrenchment ratio describes the degree of vertical containment of a river channel.

Pool-riffle-run lengths and ratios: Each reach was measured for pool, riffle and run lengths. Standard definitions of pool, riffles and runs were used based on Department of Fish and Game methods (Level II categorization). Following data collection, the ratios of each habitat type were determined.

Mean pool depth: This parameter is estimated using a stadia rod by taking several measurements over the length of the pool. This parameter was averaged over the entire reach to determine average mean pool depth.

Maximum pool depth: This parameter is measured using a stadia rod by finding the deepest point in the pool. This parameter was averaged over the entire reach to determine average maximum pool depth.

Pool type: Pool type defines the form or function of the pool. Pools are the result of scour due to roughness objects or constrictions and obstructions in the channel. This parameter was determined at each pool and is important in determining the effectiveness of restoration activities such as adding woody material and other roughness objects. Fifteen pool types were identified in the fall 2000 survey (Table 2.9).

Pool and riffle embeddedness: Embeddedness is defined as the percent burial of bed substrate by fine-grained sediment. In the case of this survey, embedded cobbles and boulders impact available escape cover for salmonids and reduce insect productivity. Embeddedness is visually estimated by observing the line between the shiny buried portion and the duller exposed portion. The percent of the sampled substrate that is buried is termed the embeddedness. Several estimates are taken throughout the pool or riffle to obtain a unit averaged value.

Table 2.9 - Location and description of Pool Volumes established in Fall, 2000.

Geomorphic Reach #	Pool Volume Number	Description
3	**3.1**	*Middle River - Brookdale* *Access Point:* Larkspur Bridge *Location:* Upstream of Larkspur Bridge at old fish hatchery. *Benchmark:* On left bank at downstream end of pool adjacent to 8" diameter Alder
4	**4.1**	*Upper River* *Access Point:* From Hwy 9 to Spring Creek Rd to Shady Lane. Access through 320 Shady Ln *Location:* Walk upstream until you reach suspended cable (old bridge cable?) *Benchmark:* On right bank at downstream end below maple (Downstream end starts between 2 bedrock outcrops)
5	**5.1**	*Branciforte Creek* *Access Point:* From upper parking lot of county hospital down old dirt road to creek *Location:* Upstream approximately 1/4 mile *Benchmark:* Approximately 12 feet up on right bank to right of Maple (with green flagging)
6	**6.1**	*Carbonera Creek* *Access Point:* From turnout on N. Branciforte Dr. just downstream of Granite Creek Bridge *Location:* Downstream of access point. Long, narrow pool. Green flagging at top and bottom of pool on right bank *Benchmark:* Adjacent to downstream flag up on right bank next to redwood
7	**7.1**	*Lower Bean Creek* *Access Point:* From Conference Drive and Mt. Hermon Conference Center. Pull off road just past baseball fields. Take trail to river *Location:* Just upstream of trail junction with creek *Benchmark:* Downstream end of pool at top of left bank (below green flagging)
7	**7.2**	*Lower Bean Creek* *Access Point:* From Conference Drive and Mt. Hermon Conference Center. Pull off road just past baseball fields. Take trail to river *Location:* Approximately 250 feet upstream of Pool 13.1 at large log jam *Benchmark:* 10 feet up right bank adjacent to fallen tree at downstream end of pool (below green flagging)
8	**8.1**	*Upper Bean Creek* *Access Point:* Mt.Hermon Rd to Lockhart Gulch Rd. Park at bridge over Bean Creek. Walk downstream approximately 1/4 mile *Location:* Approximately 500 feet downstream of RCD log bank stabilization project (2 bends downstream) *Benchmark:* Downstream end of pool on right bank bar (with green flagging above benchmark)
8	**8.2**	*Upper Bean Creek* *Access Point:* Mt.Hermon Rd to Lockhart Gulch Rd. Park at bridge over Bean Creek. Walk downstream approximately 1/4 mile *Location:* Approximately 100 feet upstream of RCD log bank stabilization project (at shear bedrock wall) *Benchmark:* Downstream end of pool on top of left bank (below green flagging)
9	**9.1**	*Lower Zayante Creek* *Access Point:* From E. Zayante Rd take W.Zayante Rd approximately 1/4 mile. Park in turnout opposite horse corral. *Location:* Down to creek from parking spot *Benchmark:* At downstream end of pool on right bank, approximately 9 feet up bank above old large culvert in creek
10	**10.1**	*Upper Zayante Creek* *Access Point:* Off E.Zayante Rd, Warner Rd. Access through Matt McVeigh's property. *Location:* Large pool located upstream of old, unused bridge *Benchmark:* Downstream end of pool on right bank above several fallen tree limbs. Green flag on small redwood adjacent to maple
11	**11.1**	*Fall Creek* *Access Point:* From Henry Cowell Park - Fall Creek Unit parking lot. Hike down trail, follow Bennett tributary to mainstem *Location:* Approximately 500 feet downstream of confluence. Pool at large bedrock facr on right bank *Benchmark:* At downstream end of pool on left bank below scrub oak (with green flagging)
11	**11.2**	*Fall Creek* *Access Point:* From Henry Cowell Park - Fall Creek Unit parking lot. Hike down trail, follow Bennett tributary to mainstem *Location:* Approximately 500 feet downstream of Pool 9.1 next to large point bar on right bank *Benchmark:* On right bank at upstream end of plunge pool, 25 feet up bank to right of fern below scrub oak (with green flagging)
12	**12.2 and 12.2**	*Bear Creek* *Access Point:* Hwy 9 to Bear Creek Rd. Cross creek at road just before Hopkins Gulch. Park at bend just after bridge *Location:* Walk downto creek. Upper pool in bend with residences above. Lower pool below short riffle. *Benchmark:* On left bank at base of trail (same benchmark for 7.1 and 7.2)
13	**13.1**	*Boulder Creek* *Access Point:* Trail down to creek from north side of bridge over Hwy 9 *Location:* At the bottom of trail *Benchmark:* Downstream end of pool on right bank at base of single-trunked bay (with green flagging)
14	**14.1**	*Kings Creek* *Access Point:* From Hwy 9 to Kings Creek Road. Just after 2nd bridge crossing over Kings Creek *Location:* Pullout on left before road splits then walk to creek. *Benchmark:* At downstream end on left bank below Tan Oak (marked by green flagging)

* The pool volume maps generated as part of this project will also aid in identifying the location of the benchmark (coordinate 0,0 on the map). In addition, each banchmark has a stake with green flagging located next to the banchmark nail and green flagging located on an object above the benchmark such as a tree or shrub.

Bank conditions: Bank conditions were surveyed along the entire reach for both right and left banks. The length and height of locations of bank erosion were recorded to determine the total area affected by bank erosion. Modifications to natural bank conditions were also classified and measured to estimate the impact from man-made structural elements and channel straightening. The fall surveys identified eleven types of bank modifications occurring along the surveyed reaches (Table 2.10).

Table 2.10. Description and Classification of Pool and Modified Bank Types

Pool Type Code	Pool Type Description	Modified Bank Type Code	Modified Bank Description
1	Bridge Abutment Scour	1	Grouted Rock Wall
2	Log Scour	2	Boulder Revetment
3	Bank Scour	3	Gabion Revetment
4	River Bend Scour	4	Log Retaining Wall
5	Bedrock Scour	5	Wood Retaining Wall
6	Boulder Scour	6	Cinderblock Retaining Wall
7	Dam	7	Concrete Revetment
8	Plunge	8	Broken Concrete Revetment
9	Root Wad Scour	9	Concrete Bridge Abutment
10	Corner Scour	10	Concrete Abutment
11	Constriction	11	Sacked Concrete Wall
12	Concrete Block		
13	Log Jam Scour		
14	Confluence		
15	Mid-Channel		

Large woody material: Woody material was counted along each reach based on the criteria that it was greater than 6 feet long and occurred within the zone of the active channel and adjacent floodplain. Wood on the hillslope that was available for future recruitment was not counted. Wood that occurred in large logjams was not counted individually. Instead it was counted as an individual logjam. Root wads were also counted as a separate category. Counted wood was divided into categories according to its diameter (<6 inches, 6-12 inches, 12-24 inches, > 24 inches).

General Notes: Notes were also taken about the reach including riparian canopy type, observed gaps in the riparian canopy, access points, flagging locations for up and downstream markers, etc. Photos were also taken for future referencing of key features along the reach.

Pool Volumes

The greatest impact from land use changes and increased erosion has been shown to be loss of habitat quality from sedimentation of pools and riffles. Pool sedimentation reduces the total volume of habitat, results in loss of escape cover and decreases insect production. Under these impaired conditions, government agencies have been mandated to develop policies that will ultimately reduce erosion and sediment input into stream channels. To monitor the effectiveness of treatments to reduce stream sedimentation, detailed measurements of pool volume have been identified as being an important tool.

Unfortunately, developing a detailed topographic map of an area with modern, highly technical survey gear is a very expensive and time-consuming process that becomes intractable under poor site access and conditions where steep canyon walls are present. Our approach combines the benefits of fairly high-resolution bathymetry without the necessity for highly technical equipment. The result is an estimate of pool volume that can be returned to and resurveyed as often as necessary.

For each reach, one or two pools were chosen to survey in detail, depending on the overall size of the pool (Table 2.9). Pools were chosen based on their likelihood of persisting (bedrock scour pools, confluence pools, etc), accessibility, and size. Selected pools were chosen and flagged during the channel and bank surveys and returned to later to complete the topographic survey. Stream flow was measured at the same time the pool was surveyed to provide reference for future surveys.

At each pool, a benchmark was chosen out of the floodplain. In all cases, the benchmark is a large survey nail that is marked with a wooden stake pounded in adjacent to the nail with flagging marking the nail. An additional piece of flagging was placed near the nail in a tree or overhanging feature. A photo was also shot of the pool that was to be surveyed. Table 2.9 describes the location of each pool selected for monitoring along with the benchmark location.

The benchmark was assumed to be at an elevation of 100 feet. Using a hand level and stadia rod, the water surface elevation of the pool was determined. Since the water surface elevation is a flat surface across the pool, this value is fixed through the entire survey. Once these two elevations are known (benchmark and water surface), the remaining survey could be conducted with a compass, tape and stadia rod across a grid of points.

Survey points were chosen based on standard topographic survey methods. These locations include edge of water, thalweg and breaks in slope. Approximately 50-100 survey points were recorded at each pool depending on the size and complexity of the pool.

Based on compass angles, distances and water depths, calculations using standard spatial geometry produced values of x, y, and z for each point. This information was then input into a Geographic Information System (GIS) and contours were generated using triangulation with linear interpolation. From the contours and the water surface elevation, volumes for each pool were generated. A map of each pool was also produced that shows the pool surface, contours, benchmark location and direction of north (Appendix C). The map should aid in identifying the pool and benchmark locations for future monitoring.

Results and Discussion

Geomorphic Data

The results from the initial year of monitoring of geomorphic conditions and woody material densities are presented in Table 2.11. Each reach was assigned a Rosgen classification (Rosgen, 1994) to provide a reference for the channel type and allow comparisons to be made between reaches. This dataset will act as a baseline assessment, depicting the conditions of the channel, at representative reaches, for the fall of 2000.

As future datasets are collected along the same monitoring reaches, changes in reach conditions can be completed to assess improvements or benefits to a particular reach. This data can then be qualitatively compared to fish numbers to determine if there is a relationship between improved geomorphic, sedimentation, and woody material densities and habitat quality for fish.

One component that appears to be missing from the literature regarding salmonid habitat conditions is the lack of thresholds that define habitat quality. Reach averaged values of woody material density or pool-riffle ratio can be compared between reaches or from year to year, but targets have not been set to define appropriate conditions. Generally, we may assume that the more woody material left in the stream channel, the better. The San Lorenzo system is presently very lacking in large woody material compared to some northern, Central Coast streams containing coho salmon (e.g. Gazos, Waddell and Scott creeks. For example, Leicester (2002, draft report) had reach densities of large woody material (at least 1 foot in diameter) ranging between 18 and 65 pieces per thousand feet in the active (bankfull) channel of Gazos Creek. In surveyed reaches of the San Lorenzo and tributaries, the density range was only 2-32 pieces per 1000 feet. (One site, in Henry Cowell Park, had 65 pieces per 1000 feet.). Setting of threshold conditions would need to consider channel conditions (i.e. – channel form, gradient) and watershed conditions (i.e.-

Table 2.11: Results from Fall 2000 geomorphic monitoring surveys.

	Mainstem Reaches				Tributary Reaches										
Name	**Rincon**	**Cowell**	**Brookdale**	**Upper River**	**Carbonera**	**Branciforte**	**Lower Bean**	**Upper Bean**	**Lower Zayante**	**Upper Zayante**	**Fall**	**Bear**	**Boulder**	**Kings**	
Reach	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Average**
Drainage Area (mi^2)	112.9	109.4	55.1	20.0	7.2	7.1	9.8	9.2	16.4	10.9	4.4	14.7	11.4	6.2	NA
Average Reach Gradient	0.65%	0.35%	0.40%	0.20%	0.55%	0.74%	0.59%	0.57%	0.84%	2.40%	3.40%	0.90%	2.90%	1.80%	1.16%
Rosgen Channel Classification (1994)	C2/C3	C3/C4	C3	F1/F2	B3c	B1c/B2c	B1c/B2c	B3c/B4c	B1c/B2c	B1/B2	B2/B3	B1c/B3c	B1/B2	B1c/B2c	NA
Bankfull Depth (ft)	4.6	2.5	3.0	2.3	1.5	1.3	1.7	1.5	2.0	2.0	1.5	1.5	1.5	1.2	2.0
Bankfull Width (ft)	80	65	20	28	15	15	17	25	20	30	15	20	25	15	28
Width at 2X Bankfull Depth (ft)	165	130	35	35	25	25	25	40	30	40	20	25	35	25	47
Entrenchment Ratio	2.06	2.00	1.75	1.25	1.67	1.67	1.47	1.60	1.50	1.33	1.33	1.25	1.40	1.67	1.57
Total Reach Length (mi)	0.77	0.53	0.53	0.78	0.52	0.51	0.43	0.44	0.57	0.40	0.39	0.44	0.52	0.42	0.52
Percent Pool	63%	54%	61%	59%	50%	67%	42%	44%	70%	50%	28%	55%	50%	46%	53%
Percent Riffle	20%	9%	18%	5%	10%	11%	13%	13%	11%	8%	38%	10%	22%	15%	14%
Percent Run	17%	37%	21%	36%	39%	22%	45%	44%	19%	43%	34%	35%	29%	39%	33%
Average Pool Length (ft)	367	216	155	134	63	85	50	48	152	55	22	97	85	84	115
Average Mean Pool Depth (ft)	2.1	1.9	2.0	1.9	1.1	1.1	1.1	1.3	1.7	1.4	1.3	2.1	2.0	1.3	1.6
Average Max Pool Depth (ft)	4.3	3.2	3.4	2.9	2.2	1.9	2.3	2.0	3.0	2.3	2.0	3.4	3.3	2.5	2.8
Average Pool Embeddedness (%)	62	33	23	90	56	46	46	41	31	39	27	64	55	79	49
Average Riffle Length (ft)	135	51	50	27	20	26	41	23	29	21	39	29	46	30	40
Average Riffle Embeddedness (%)	26	19	11	9	24	15	18	10	10	14	12	21	18	11	16
Average Run Length (ft)	100	129	65	123	64	54	77	56	83	56	65	81	260	67	91
Percent Eroded Bank	4%	30%	2%	8%	17%	1%	6%	11%	0%	9%	10%	0%	1%	10%	8%
Percent Modified Bank	0%	35%	20%	22%	9%	27%	0%	12%	16%	1%	1%	10%	7%	3%	12%
Rootwad Density (per mile of channel)	1	28	40	41	58	20	21	52	17	13	76	57	44	60	38
Log Jam Density (per mile of channel)	10	4	2	1	8	0	7	5	3	5	41	0	6	2	7
Woody Material Density < 6in (per mile)	289	19	303	370	199	94	447	502	195	290	488	443	242	480	311
Woody Material Density 6-12in (per mile)	89	53	115	131	164	82	278	196	54	98	160	133	99	187	131
Woody Material Density 12-24in (per mile)	19	126	36	69	89	12	80	39	5	13	97	55	37	74	54
Woody Material Density > 24in (per mile)	18	217	8	35	21	16	92	34	5	23	56	21	31	34	43
Total Woody Material Density (per mile)	416	415	461	605	473	204	896	771	260	423	801	651	408	775	540

dominant vegetation, geology, soils) to develop a range of "habitat suitability" values that would be different for each creek. Unfortunately this is beyond the scope of this project.

These indices have been developed for several sediment variables such as pool embeddedness and percent fine sediment based on literature values that suggest a reduction in spawning and rearing success at values greater than the threshold. For the Zayante Area Sediment Source Study (Swanson and Dvorsky, 2001) a proposed target of less than 25% embeddedness was used for particles greater than 16 mm. A target of less than 30% fines was used as the threshold for fines less than 4mm. Further work should be encouraged with local universities to develop reasonable threshold values for streams within the Santa Cruz Mountains.

For embeddedness, most of the survey reaches met the target for embeddedness in riffles except for Reach 1 in the Rincon area of the Gorge (26%), most likely due to cumulative effects from the entire watershed. Carbonera also had fairly high riffle embeddedness (24%) due to the highly erosive Santa Margarita and increased urbanization in the Scotts Valley area that has increased impervious surfaces and has likely increased bank erosion. Pools, on the other hand, were highly embedded in almost all reaches surveyed with only Reach 3 in the vicinity of Brookdale (23%) meeting the embeddedness target. Extremely high embeddedness values were measured in the Upper River, Kings, Bear, and the Rincon area that is consistent with past findings made by Don Alley. The data suggests that high sediment loads are coming from Kings and Bear Creeks and in the urbanizing watersheds of Bean and Carbonera.

Though the primary use of the geomorphic survey was to establish baseline monitoring data that can be used to detect future trends, correlation coefficients were calculated to assess relationships between channel conditions, woody material density, and fish densities collected in fall of 2000. The correlation coefficient for each relationship is shown in Table 2.12. Low correlation values in geomorphic and biological data are common due to the many factors that influence biological populations and the inability to experimentally control certain variables. At best, trends in the data can be assessed with inferences made about the potential cause of high correlations between variables.

The results of the correlation analysis support several hypotheses about the relationship between geomorphic conditions, habitat, and fish densities. Negative correlations between channel geometry variables (e.g. – bankfull width, bankfull depth, and entrenchment) for Size Class 1 fish and positive correlations with Size Class 2 & 3 fish suggest that smaller channels, such as tributaries, either produce smaller fish or are acting as primary spawning and YOY rearing areas. The larger channels, such as the mainstem, are producing larger fish or are acting as rearing areas for fish that are about to smolt.

The results also suggest some level of habitat partitioning occurring between Class 1 and Class 2 & 3 fish. Class 1 fish show a negative correlation with pool variables such as mean pool depth and maximum pool depth. Conversely, Class 2 & 3 fish show a positive correlation with those variables. All size classes appear to be negatively correlated with riffle embeddedness, suggesting that this variable may be important to monitor since it may be a better indicator of the overall amount of sedimentation occurring in the reach.

The results from the woody material data do not show any significant correlations with fish densities. What is surprising is the consistency of the negative correlation found between woody material density and the occurrence of pools (The complete correlation matrix is presented in Appendix B). For example, logjams have a correlation coefficient of –0.68 with percent pools and 0.86 with percent riffles. The data also suggests that larger channels are able to maintain large pieces of wood but lack smaller pieces, whereas smaller channels contain small pieces but lack the larger pieces.

Table 2.12. Correlation coefficients between geomorphic survey data and fish densities from fall 2000.

	Fish Density (Size Class 1 / 100 ft)	Fish Density (Size Class 2 & 3 / 100 ft)	Fish Density (All Size Classes / 100 ft)
Bankfull Depth (ft)	-0.46	0.47	0.11
Bankfull Width (ft)	-0.45	0.30	-0.02
Width at 2X Bankfull Depth (ft)	-0.49	0.27	-0.07
Entrenchment Ratio	-0.45	0.17	-0.13
Percent Pool	-0.28	0.39	0.15
Percent Riffle	0.13	-0.23	-0.12
Percent Run	0.22	-0.26	-0.08
Average Pool Length (ft)	-0.57	0.42	0.00
Average Mean Pool Depth (ft)	-0.38	0.63	0.29
Average Max Pool Depth (ft)	-0.61	0.46	0.02
Average Pool Embeddedness (%)	-0.05	-0.05	-0.07
Average Riffle Length (ft)	-0.50	0.13	-0.19
Average Riffle Embeddedness (%)	-0.65	-0.24	-0.59
Average Run Length (ft)	-0.17	0.15	0.02
Rootwad Density (per mile of channel)	0.21	-0.14	0.01
Log Jam Density (per mile of channel)	0.16	-0.28	-0.13
Woody Material Density < 6in (per mile)	0.22	-0.29	-0.11
Woody Material Density 6-12in (per mile)	0.05	-0.40	-0.30
Woody Material Density 12-24in (per mile)	-0.18	0.15	0.01
Woody Material Density > 24in (per mile)	-0.20	0.27	0.10
Total Woody Material Density (per mile)	0.09	-0.23	-0.14

Pool Volumes

Monitoring of pool volume may provide a better indicator of the degree of sedimentation occurring within a particular reach. Research on Idaho streams found a decrease in fish density in direct proportion to the loss in pool volume (Stuehrenberg, 1975; Klamt, 1976). Pool filling and loss of habitat was also shown to result in changes in population and community structure of the affected stream. A study conducted by Bisson (unpublished data) in western Washington found that a decrease in the quality of pools caused a shift in the fish population from cutthroat, coho, and steelhead to predominately steelhead. This suggests that a reduction in pool volume and complexity created more homogeneous habitat conditions that excluded cutthroat and coho.

The results from our fall 2000, initial pool volume estimates are presented in Table 2.13. Contour maps, photos, and survey information are presented in Appendix B. At this time, the results can only be presented as a description of existing conditions. Future pool surveys at these locations would provide the information to discern changes in reach conditions based on changes in pool volumes.

SECTION 2.4 – HISTORICAL FLOW ANALYSIS AND DIVERSION REDUCTIONS

Introduction

In much of the discussion regarding salmonid populations and habitat conditions on the San Lorenzo River, streamflow is mentioned as an important limiting factor. The quantity of streamflow, especially during the low flow summer and fall months, directly influences the amount of habitat available for both fish and aquatic macroinvertebrates, a common food source for salmonids. The quality of rearing habitat is greatly influenced by the amount of streamflow by controlling important habitat parameters such as pool depth, riffle conditions, and potentially the amount of escape cover.

Table 2.13. Pool volume survey results, Year 2000.

Reach ID	Pool ID	Stream Name	Survey Date	Pool Volume (ft^3)	Flow (cfs)	Maximum Depth (ft)
3	3.1	San Lorenzo River	12/19/2000	11,823	8.86	5.9
4	4.1	San Lorenzo River	12/19/200	5,514	2.54	5.0
5	5.1	Carbonera Creek	12/7/2000	1,887	1.52	3.4
6	6.1	Branciforte Creek	12/7/2000	1,264	1.47	2.0
7	7.1	Bean Creek	12/7/2000	1,034	3.21	5.1
7	7.2	Bean Creek	12/7/2000	730	3.21	2.6
8	8.1	Bean Creek	12/8/2000	1,097	1.65	3.9
8	8.2	Bean Creek	12/8/2000	424	1.65	2.0
9	9.1	Zayante Creek	12/7/2000	2,558	5.22	3.8
10	10.1	Zayante Creek	12/8/2000	2,300	1.53	3.2
11	11.1	Fall Creek	12/8/2000	225	2.87	2.0
11	11.2	Fall Creek	12/8/2000	159	2.87	1.9
12	12.1	Bear Creek	12/19/2000	982	1.99	4.4
12	12.2	Bear Creek	12/19/2000	2,300	1.99	3.6
13	13.1	Boulder Creek	12/19/2000	4,213	3.00	2.5
14	14.1	Kings Creek	12/19/2000	1,397	0.90	2.3

The biggest human impact to streamflow conditions is due to water extraction and diversions. These impacts can be exacerbated by drought when streamflow is naturally low and human demand for water is high, predominately for landscaping. To ensure adequate flow is available for salmonid populations there needs to be a good understanding of existing and historic flow conditions.

To understand past flow conditions a standard hydrologic data analysis technique is used to generate exceedence probability curves using average daily streamflow values. These data are generated for four climatic conditions: drought, dry, average, and wet for each of the monitoring stations discussed in Section 2.3. Given the consistent pattern of wet winters and dry summers that characterizes our Mediterranean climate, these data can also be tools used to predict late summer and fall flow conditions given flow conditions at the end of the wet season. When balancing water diversions with the need to maintain flow for salmonid rearing, these data can be powerful tools for water resource managers.

Exceedence probability values for different climatic conditions also provide a framework for evaluating the impacts of water diversions on salmonid rearing habitat. Research conducted by Smith (1982) suggests a strong relationship exists between habitat depth, escape cover, and the ability for the habitat to support juveniles. A rough model was developed relating habitat depth and escape cover to juvenile production. Streamflow can be a primary factor in dictating habitat depth and therefore has a significant influence on rearing habitat quality. With these assumptions in place, impacts to rearing habitat quality and ultimately fish production can be analyzed using the exceedence probability curves and information about the amount of instantaneous flow that is extracted from a particular reach of stream.

Historic streamflow records can also be analyzed to determine long-term trends in hydrologic conditions. Water extractions and an expanding urban population in the San Lorenzo Valley can have impacts on both winter peak flows and summer baseflows. Winter peak flows have been shown to increase in watersheds where there are more impermeable surfaces from rooftops, roads, and driveways. Winter and summer baseflows may also decline due to reductions in natural surfaces that in the past may have been zones for percolation of surface water to groundwater. This is the case in Scotts Valley where much of the area is underlain by highly permeable Santa Margarita Formation that is the dominant source of groundwater in the region.

Methods

Flow Duration – Exceedence Probability

Flow duration curves were derived for all monitoring reaches described in Table 2.8. Since long-term, average daily flow data were not available for most of the reaches of interest, existing gage data from various gage locations throughout the San Lorenzo River watershed were used. Table 2.14 gives information about the available USGS gages.

Table 2.14. USGS gages in the San Lorenzo River watershed used to derive flow duration data

Gage #	Gage Name	Drainage Area (mi^2)	Years of Record
11160500	San Lorenzo River @ Big Trees	106	1937 – present
11160070	Boulder Creek @ Boulder Creek	11.3	1977 – 1992
11160060	Bear Creek @ Boulder Creek	16.0	1978 – 1992
11160430	Bean Creek near Scotts Valley	8.8	1989 – present
11160300	Zayante Creek @ Zayante	11.1	1958 – 1992
11161300	Carbonera Creek @ Scotts Valley	3.6	1985 – present
11161500	Branciforte Creek @ Santa Cruz	17.3	1941 – 1968

The USGS gage on the San Lorenzo River at Big Trees provided the longest period of record of all the gages in the watershed (1937 to present). Since there was often very little overlap between the gage records, we decided to extend each of the gage records to cover the years from 1958 to 1999. Data available after 1999 was considered provisional at the time this analysis was conducted. Gage records were then extended by regressing the available data for each gage against the record at Big Trees.

To develop a synthetic gage record at the downstream end of each monitoring reach, a gage was selected from the list in Table 2.14 that best represented the local conditions. Criteria used to choose an appropriate gage included similarities in geology, groundwater conditions, topography, and response times. In most cases a gage was selected that was in the same sub-watershed as the monitoring reach. To account for differences in drainage area between the gage location and the monitoring reach a drainage area reduction or expansion was then factored in to produce a synthetic daily streamflow record for each monitoring reach from 1958 to 1999 (Table 2.15).

The synthetic record for each monitoring reach was then used to generate monthly exceedence probability flow values under different climatic conditions, namely wet, average, dry, and drought year conditions. Exceedence probabilities can be defined as the percent chance that a certain flow is exceeded under a specified criterion. For example, in July during a wet year, the flow may exceed 39 cfs, 70% of time but only exceed 42 cfs, 60% of the time.

Table 2.15. Criteria used to develop synthetic flow records at monitoring reaches

Reach #	Location	Drainage Area (mi^2)	Gage Record Used	Drainage Area Ratio
1	San Lorenzo River	112.9	SLR @ Big Trees	1.03
2	San Lorenzo River	109.4	SLR @ Big Trees	1.07
3	San Lorenzo River	55.1	SLR @ Big Trees	0.52
4	San Lorenzo River	20	Bear Creek	1.25
5	Carbonera Creek	7.2	Carbonera Creek	2
6	Branciforte Creek	7.1	Branciforte	0.41
7	Bean Creek	9.8	Bean Creek	1.11
8	Bean Creek	9.2	Bean Creek	1.04
9	Zayante Creek	16.4	Zayante Creek	1.48
10	Zayante Creek	10.9	Zayante Creek	0.98
11	Fall Creek	4.4	Boulder Creek	0.38
12	Bear Creek	14.7	Bear Creek	0.92
13	Boulder Creek	11.4	Boulder Creek	1.01
14	Kings Creek	6.2	Bear Creek	0.39

The initial step required to generate the exceedence probabilities for each month is to separate all the available flow data into wet, average, dry, and drought. The data was sorted by month and then sorted further into percentiles with a wet year being daily flow values greater than the 75th percentile, an average year ranging from the 75th to the 25th percentile, a dry year ranging from the 25th to the 10th percentile and a drought year being values occurring below the 10th percentile. Once sorted by month and flow-type, the data within each class was analyzed to determine the exceedence probability using standard statistical techniques (Dunne and Leopold, 1978).

Results from the flow duration curves were then visually checked against known ranges of flow collected by Santa Cruz County Environmental Health for summer conditions. The results for most monitoring reaches show good correspondence between predicted summer baseflow conditions and measured flows given a general understanding of the seasonal patterns that existed during the measurements (i.e.-dry year versus wet year).

Two reaches that appeared to underestimate summer baseflow conditions were the lower Bean (Monitoring Reach 7) and lower Zayante (Monitoring Reach 9) sites. These sites were extrapolated from the gage records on Bean and Zayante Creek upstream of each of the monitoring reaches. In both instances a known contact between the Santa Margarita and the Monterey Formations occurs between the monitoring reach and the gage site. It is at this contact that water is released from stored groundwater in the Santa Margarita to stream baseflow as springs as seeps. In high flow months, the magnitude of this effect compared to total streamflow is likely to be minimal but in the summer and early fall months the effect could be significant.

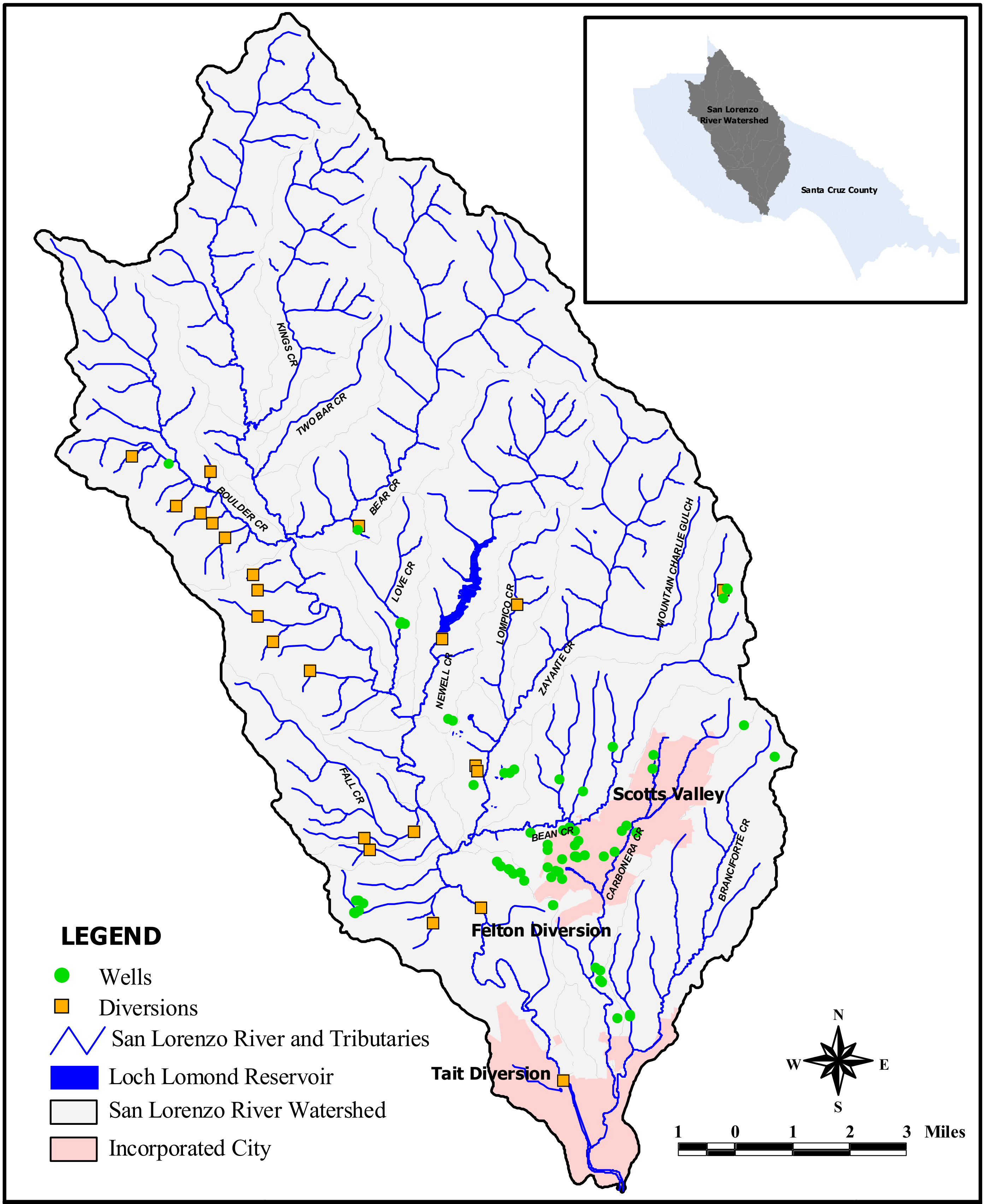
To account for the differences in hydrologic conditions from the gage location and streamflow estimates in Reaches 7 and 9, measured streamflow in the vicinity of the monitoring reach for known dates were compared against the gage records. Some measured streamflow values were discarded from the analysis if they were associated with rainfall events, considered an anomalous event during the dry season, or fell outside the dry season window from May to October. The average ratio between these two values was then used to adjust the exceedence probability values for Reaches 7 and 9 for the months of May to October. Based on this analysis an adjustment ratio of 1.12 was used for Reach 7 (Bean Creek) and an adjustment of 1.84 was used for Reach 9 (Zayante Creek).

Historical Flow Conditions

Historical flows were analyzed using the San Lorenzo River at Big Trees since it consists of the longest period of record of all the existing and past gages in the watershed. The Big Trees gage (USGS gage #11160500) has daily average flow data dating back to 1938. From this data, a monthly mean, minimum, and maximum was determined for each year. To assess long-term trends, an 11-year moving average was computed for the mean, minimum, and maximum values for each month. An 11-year moving average was selected to account for five years on either side of the year of interest. Trend lines were then determined for each month based on the results of the 11-year moving average with equations derived to determine the change in flow conditions over the last 60 years.

Diversion Reductions

Direct water extraction from the San Lorenzo River and its tributaries and groundwater pumping for municipal supplies can have a significant impact on aquatic habitat conditions and salmonid populations, especially during summer and fall low flow months and drought years. Diversions and wells dot the entire San Lorenzo River Watershed (Figure 2.6) with ownership ranging from large diverters such as the City of Santa Cruz, Scotts Valley Water District, and the San Lorenzo Valley Water District to smaller local homeowner utilities such as California American and the Lompico County Water District. Wells are primarily confined to the Scotts Valley area where water is being pumped from the Santa Margarita aquifer. The diversions are primarily on the mainstem or on the western tributaries that drain Ben Lomond Mountain.



Swanson Hydrology and Geomorphology

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Diversion and wells in the San Lorenzo River Watershed. Information regarding the location of wells and diversions was provided by Santa Cruz County staff. The status of existing wells and diversions was not verified independently.

Figure 2.6

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In order to understand the impact that water diversions and well pumping has on fish populations, information needs to be generated describing the quantity of water extractions, by month, for each area of interest. Our approach involved developing monthly instantaneous extraction values for each of the geomorphic monitoring sites (Figure 2.5) by collecting and analyzing diversion data available from the primary water companies extracting water in the basin. This data would then be analyzed from a fisheries perspective to determine the impact water diversion have on salmonid populations, by reach (*see Section 2.5*). Since we were interested in significant point source reductions to baseflow, extraction rates from smaller water purveyors and individuals were not included in the analysis. Though cumulatively, water use by small water purveyors and riparian users may be significant, there is a lack of data to assess and analyze their water use on a location-by-location basis.

Since not all water purveyors collect or report their information in the same way, different assumptions were made for each dataset to arrive at a value that could be combined into a total estimated instantaneous extraction rate. Data was obtained from the City of Santa Cruz, San Lorenzo Valley Water District, California American, and Lompico County Water District. An estimate was also made regarding the impact of Scotts Valley well pumping on flows in Bean Creek based on an analysis conducted by County staff.

In addition to flow extractions, attempts were made to account for any possible increases in flow that might occur in the summer months due to water supply infrastructure and required flow releases. Since the San Lorenzo Valley does not currently have a centralized sewage system, all homes and businesses rely solely on septic systems to treat their waste. By doing so, a portion of the water that is diverted from San Lorenzo River streams or pumped from wells in the Santa Margarita Aquifer, makes its way back to stream channels, providing an additional source of flow for instream aquatic uses. Streamflow is also augmented downstream of Loch Lomond in late summer and fall months due to release requirements developed by CDFG when Loch Lomond Reservoir was constructed.

The following describes the methods of estimating instantaneous extraction rates from each source:

Extractions

City of Santa Cruz – Felton Diversion: We were provided with monthly extraction values in acre-feet from 1980 to 2000. These values were converted to cubic feet per second for each month for each year. The maximum rate for each month for the period of record was then used as the final extraction rate for the Felton Diversion.

San Lorenzo Valley Water District: Final extraction values for each month were provided by Nick Johnson and represent monthly averaged diversion rates for the Districts diversions on Boulder Creek and Clear Creek.

Lompico County Water District: A maximum instantaneous extraction rate was determined from a maximum pumping rate provided by District staff. A maximum pumping rate of 120 gallons per minute was then converted to cubic feet per second (0.25 cfs).

California American: Based on conversations between County staff and California American staff, a maximum instantaneous diversion rate from the Fall Creek diversion was determined to be 1.1 cubic feet per second.

Scotts Valley Well Pumping: Historic flow information collected by County staff on Bean Creek up- and downstream of the contact between the Santa Margarita and Monterey Formations was analyzed to determine the amount of flow reductions that have occurred on Bean Creek. The results suggest a 0.5 cfs reduction.

Additions

Septic System Recharge: The amount of septic system recharge was calculated for SLVWD and California American diversions for the months of July to October, which were assumed to be the months of highest water use where septic recharge could potentially have a significant influence on total streamflow amounts. The assumptions that were used to calculate an estimated recharge rate include the following:

- 85% of water users live in close proximity to receiving streams to allow recharge, and
- The recharge amount equals 20% of water use for the summer months. An original estimate developed by the County put the recharge efficiency at 50%. This value is based on an average for the entire year. During the summer months, low soil moisture conditions likely reduce recharge efficiencies. This is especially true in dry years. No differentiation is made between wet, average, or dry years in our calculations.

Based on these assumptions, a total estimated recharge rate, in cfs was calculated. Since recharged water is not discharged at a single point in the watershed, the recharge value was partitioned across the watershed based on a qualitative understanding of population distribution in the San Lorenzo River Watershed.

Flow Releases for Loch Lomond: To account for possible flow augmentations in Newell Creek and the lower and middle mainstem of the San Lorenzo River, due to required releases from Loch Lomond Reservoir, flow records from Newell Creek prior to construction of Loch Lomond were analyzed. Unfortunately, only two years of data was available for this analysis (1958-1959). The results suggest that the 1.0 cfs releases from Loch Lomond are augmenting August to November baseflows in Newell Creek by a total of 0.3 cfs.

Extraction and flow addition information was then compiled by reach location (Figure 2.5) to determine the cumulative impact at each geomorphic reach site.

Results and Discussion

Exceedence Probability Results

The results from the exceedence probability analysis are shown in Appendix D. An example of the results for Reach 9 on Zayante Creek is shown in Table 2.16. Each monitoring station has results for the 95th, 90th, 80th, 70th, 60th, and 50th exceedence probability value for wet, average, dry, and drought conditions for each month. Though the data does not generate conclusions by themselves, it is valuable information for resource managers by providing a predictive tool.

Following the cessation of winter rains streamflow can be measured at monitoring site locations and compared with the exceedence probability table for that particular reach. The flow year could then be categorized into a percent exceedence for a given climatic condition (e.g. – wet, average, dry, or drought). Predictions could then be made about expected flow conditions during the dryer summer and fall months and decisions could be made regarding water use practices or potential conservation measures. For example, using Monitoring Reach 9 on Zayante Creek, a flow measurement of 2.7 cfs made in March would correspond to an 80% exceedence probability in a dry year. Assuming no significant rainfall occurs following the measurement, streamflow in October, a critical month for salmonid juveniles, is expected to be 0.6 cfs.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	26.3	2.6	1.4	0.8		February	95	45.6	4.9	1.9	0.9
	90	30.5	2.9	1.4	0.8			90	51.2	5.5	2.0	0.9
	80	38.9	3.4	1.5	0.9			80	62.6	6.7	2.2	1.0
	70	47.3	3.9	1.5	1.0			70	74.0	8.6	2.5	1.1
	60	55.7	4.6	1.5	1.0			60	91.9	10.7	2.6	1.1
	50	64.0	5.3	1.6	1.1			50	112.6	12.8	2.8	1.2
March	95	35.8	6.2	2.2	0.9		April	95	21.3	3.3	1.8	0.6
	90	39.1	6.9	2.4	1.0			90	23.3	3.7	1.9	0.7
	80	45.8	8.0	2.7	1.1			80	27.4	4.3	2.0	0.8
	70	52.4	9.0	2.9	1.3			70	31.5	5.0	2.1	1.0
	60	59.0	10.3	3.2	1.4			60	35.6	5.8	2.2	1.1
	50	68.9	12.2	3.6	1.5			50	39.7	7.0	2.3	1.2
May	95	17.0	3.8	2.4	0.9		June	95	8.6	2.4	1.5	0.3
	90	18.2	4.1	2.5	1.1			90	8.8	2.5	1.5	0.4
	80	20.8	4.6	2.7	1.3			80	9.1	2.8	1.6	0.5
	70	23.3	5.2	2.8	1.5			70	9.8	3.0	1.7	0.6
	60	25.8	5.9	2.9	1.7			60	10.6	3.5	1.8	0.8
	50	28.3	3.7	3.0	1.9			50	11.2	4.1	1.9	0.9
July	95	5.0	1.3	0.6	0.1		August	95	3.1	0.9	0.4	0.0
	90	5.1	1.4	0.7	0.1			90	3.2	0.9	0.4	0.0
	80	5.4	1.6	0.8	0.2			80	3.5	1.0	0.4	0.1
	70	5.8	1.7	0.8	0.3			70	3.6	1.1	0.5	0.1
	60	6.4	1.9	0.8	0.3			60	3.8	1.4	0.6	0.2
	50	6.8	2.2	0.9	0.3			50	4.0	1.5	0.6	0.2
September	95	2.9	0.9	0.4	0.0		October	95	3.7	1.0	0.6	0.1
	90	3.2	0.9	0.4	0.0			90	4.8	1.1	0.6	0.2
	80	3.8	1.0	0.5	0.1			80	6.9	1.2	0.6	0.3
	70	4.5	1.0	0.5	0.1			70	9.1	1.4	0.7	0.3
	60	5.1	1.2	0.5	0.2			60	11.2	1.6	0.8	0.3
	50	5.7	1.4	0.6	0.2			50	13.3	1.7	0.8	0.4
November	95	3.6	1.1	0.7	0.4		December	95	8.8	1.6	1.1	0.5
	90	4.0	1.1	0.7	0.4			90	10.1	1.7	1.1	0.6
	80	4.8	1.2	0.7	0.4			80	12.7	1.8	1.2	0.8
	70	5.5	1.3	0.7	0.4			70	15.2	2.1	1.2	0.8
	60	6.3	1.4	0.8	0.5			60	17.8	2.7	1.3	0.8
	50	7.3	1.6	0.8	0.5			50	20.4	3.1	1.3	0.9

Table 2-16: Zayante Monitoring Station #9 flow frequency (in cfs) for wet, average, dry and drought conditions.

Changes in Historic Flow Conditions

Historic daily flow data from the San Lorenzo River at Big Trees provides a record of daily values dating back to 1937. Significant changes in the watershed have occurred since 1937 including regrowth of tree stands cut in the early 1900's, urban expansion, development of permanent roads, and increased water use. These factors can all contribute to changes in the overall water balance for the San Lorenzo River. Urban expansion and increases in impermeable area have been well documented to cause higher peak flow values since water will flow off these surfaces much faster and reduce infiltration rates (Thom et. al., 2001; Booth and Henshaw, 2001). Though an increase in impermeable surfaces may not increase the frequency or magnitude of moderate to large storms due to already saturated soil conditions during these events, early season, late season, and low to moderate storms do see a significant increase in flows in the urbanized portions of the watershed. Vigorously growing, dense second growth forest stands can also reduce runoff due to high evapotranspirative demand and more interception from trees.

Historic changes in flow conditions at Big Trees can also be a reflection of climatic conditions that influence the duration and intensity of mesoscale storm systems, define the cycle of wet years and dry years, and ultimately influence groundwater storage conditions. Unfortunately, climate is the least well-understood variable in the myriad of factors that influence streamflow within a particular basin. Due to the complicated web of positive and negative feedbacks that control climatic conditions, and ultimately rainfall, there is still very little agreement on the magnitude and impact that changing climatic patterns are having on watershed scale conditions.

Based on an analysis of trends in flow conditions for each month at the Big Trees gage from 1937 to 1997, the results suggest that during most months there has been a significant reduction in flows over the last 60 years (Table 2.17). Potential factors for changes in flow conditions can be observed in the months of October (Figure 2.7) and December (Figure 2.8). October was chosen because it is typically one of the months of lowest streamflow. December was chosen because it typically is the month where soil saturation occurs and flows begin to increase.

Table 2.17. Changes in average monthly flow conditions from 1937 to 1997 at Big Trees (USGS Gage #11160500). Water Year 1955 was removed from the December analysis since it was determined to be an extreme outlier (1955 Flood).

Month	**Mean (based on trend line)**			**Min (based on trend line)**			**Max (based on trend line)**		
	1937	*1997*	*% Change*	*1937*	*1997*	*% Change*	*1937*	*1997*	*% Change*
Jan	316	361	14.1	84	51.3	-38.7	2333	2122	-9.1
Feb	436	407	-6.7	139	105	-24.6	2423	1656	-31.7
Mar	854	839	-1.7	139	101	-27.2	1556	1407	-9.6
Apr	238	131	-44.5	108	73	-31.8	989	309	-68.8
May	82	71	-13.4	57.7	44.7	-22.5	127	166	-31
Jun	47.4	39.3	-17.2	37.5	29.1	-22.5	61.4	57	-7.3
Jul	30.9	25.4	-17.7	25.1	21.3	-15.2	37.9	32.3	-14.7
Aug	22.8	19.3	-15.4	19.9	16.1	-18.9	26.8	23.6	-12
Sep	20.4	16.6	-18.8	18	14.1	-21.3	24.8	25.2	1.6
Oct	23.7	19.6	-17.2	19	12.9	-32.1	56.2	71	25.5
Nov	59.2	53.8	-9.1	22.4	15.8	-29.5	352	276	-21.6
Dec	169.2	107.9	-36.2	35.7	28.7	-19.6	1142	614	-46.2

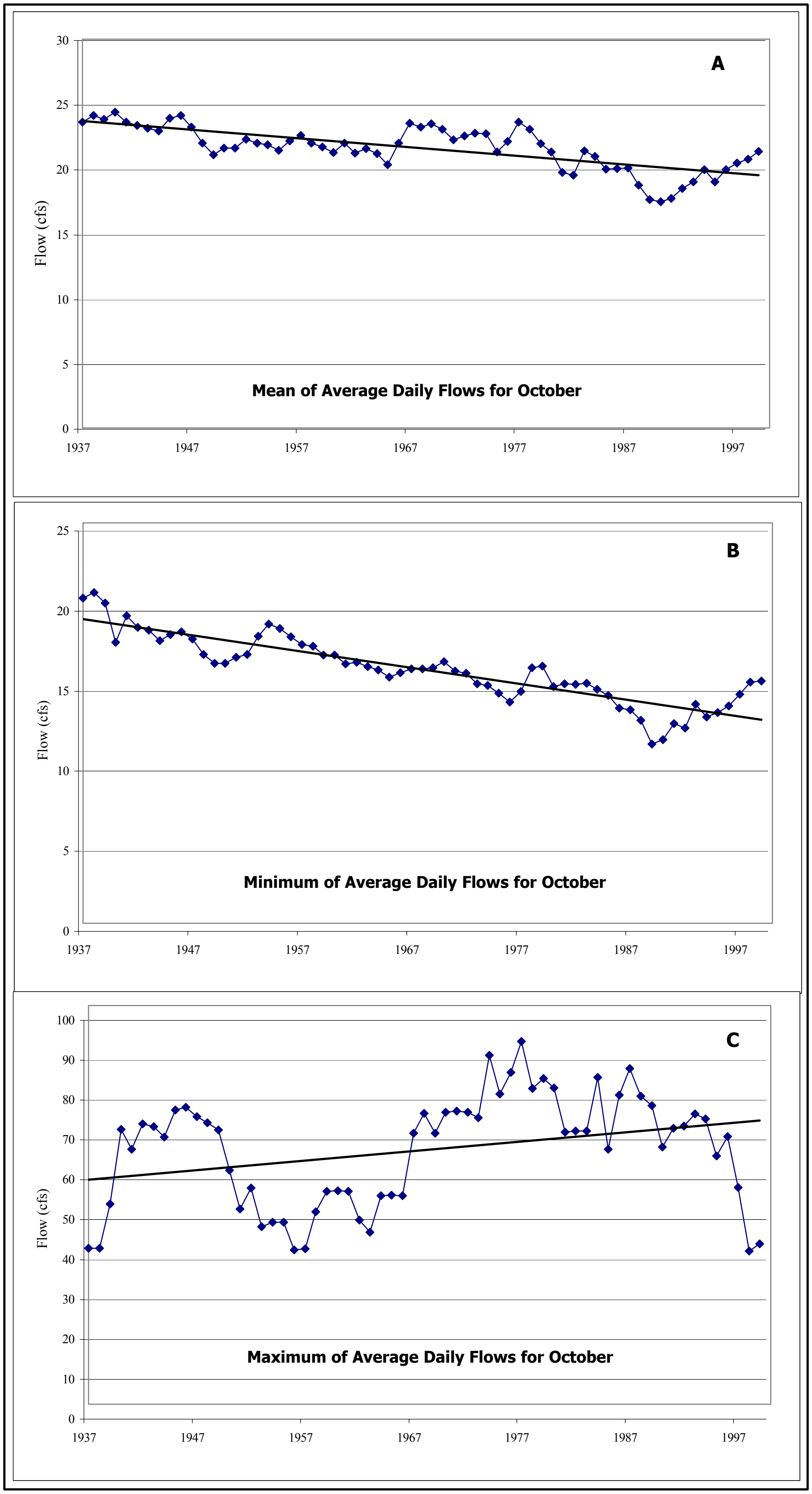


Figure 2.7: San Lorenzo River at Big Trees (ID #: 11160500) - 11 year Moving Average for October with trend line for the last 60 years. A) Mean of Average Daily Flows, B) Minimum of Average Daily Flows, C) Maximum of Average Daily Flows.

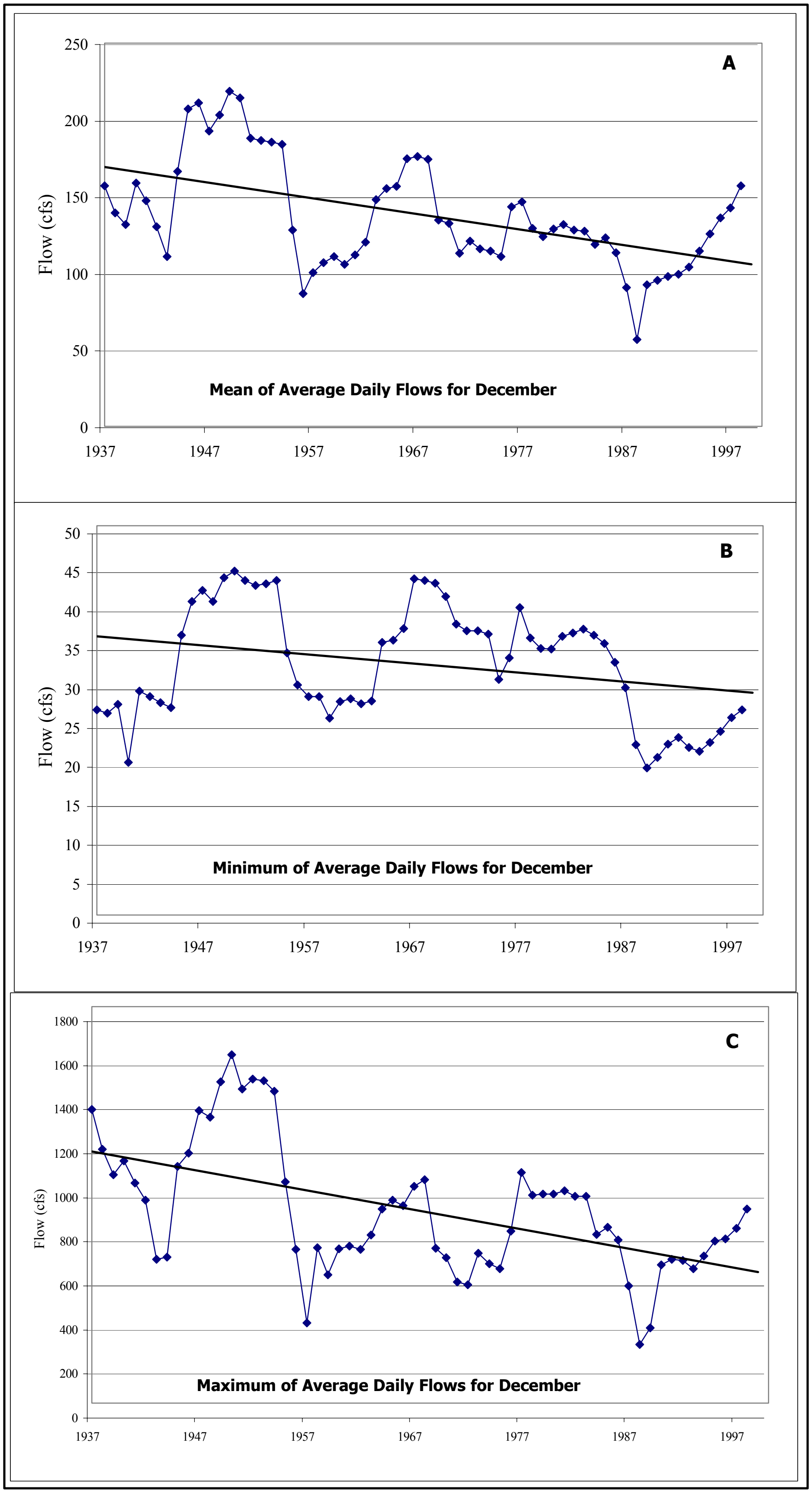


Figure 2.8: San Lorenzo River at Big Trees (ID #: 11160500) - 11 year Moving Average for December with trend line for the last 60 years. The 1955 Water Year was removed from the analysis due to extremely high flows that acted as an outlier. A) Mean of Average Daily Flows, B) Minimum of Average Daily Flows, C) Maximum of Average Daily Flows.

Mean and minimum streamflow trends for October show a 17.2% and 32.1% decrease between 1937 and 1997. On the other hand, the trend in maximum streamflow for the month of October increases 25.5%. The increase in maximum streamflow in October can most likely only be explained by climatic conditions that have resulted in a slight shift in the wet season that bring more storms early in the year with a reduction in late winter storms. This is supported by a significant drop in maximum streamflow in April and May (68.8% and 31% respectively). The reduction of mean and minimum baseflow conditions in October is likely due to water extraction from both surface diversions and well pumping in addition to a possible reduction in late season rainfall (e.g. – April and May results) that would carry through the summer into fall.

The magnitude of the results from the Big Trees trend analysis should be tempered by a change in the location of the Big Trees Gage that occurred in 1972 and the construction of Loch Lomond Reservoir in 1960. In 1972, the Big Trees gage was located at the head of the gorge, just downstream, from Eagle Creek, with a drainage area of 111 square miles. Moving the gage upstream, to its present location, reduced the drainage area by 5%, but may have reduced the baseflow contribution by as much as 10%, given that the area lost contributes relatively high baseflow compared to much of the rest of the watershed. The construction of Loch Lomond Reservoir in 1960 isolated 8.3 square miles of watershed on Newell Creek, accounting for 7.5% of the drainage area contributing to the Big Trees gage until 1973, and 7.8% afterwards.

The impact of surface diversions, reservoir construction, and well pumping becomes clearer after reviewing the December trends. Mean and maximum streamflow falls 36.2% and 46.2%, respectively. The magnitude of these reductions, particularly for the mean value, is significantly higher than all other months except for April. A viable explanation for the observed flow reductions is that groundwater pumping has reduced groundwater storage to a level where the response time between winter rains and release of water to stream channels has increased. Historically, rains in October and November would percolate into groundwater reservoirs allowing rains in December through March to contribute directly to runoff. Capture of runoff from Newell Creek behind Loch Lomond during the early to middle part of the winter would also account for an approximate 7-9% reduction of December maximum flows over the period of record (based on drainage area upstream of the dam).

Though these results point to significant reductions in streamflow over the last 60 years further analysis should be conducted to determine the primary mechanisms that are causing observed reductions. Furthermore, additional flow gages along with subsets of the Big Trees record should be analyzed to determine decade-scale trends in streamflow reductions.

Diversion Reductions

The extraction results and their impact on each geomorphic survey reach show a significant impact on both summer and winter baseflows in several areas (Table 2.18), whereas Reaches 4, 5, 6, 10, 11, 12, and 14 show no impact. The Middle and Lower mainstem of the San Lorenzo experiences the biggest impact from upstream diversions since most of the tributaries, excluding Branciforte and Carbonera, flow into them. Reaches 1 and 2 (in the Gorge, and below Zayante Creek, respectively) show significant reductions in winter baseflow due to the diversion operation at Felton. During dry or drought years this could significantly impact salmonids migrating through the Gorge.

The other two areas where baseflows during the summer months may have a significant impact on rearing salmonids is in Boulder Creek and Bean Creek. Groundwater pumping in Scotts Valley and diversions in many of the headwater tributaries to Boulder Creek may have an impact.

The following section (Section 2.5) discusses these impacts in more detail.

REACH ID	MONTH											
	January	February	March	April	May	June	July	August	September	October	November	December
1 Rincon	12.23	1.96	11.43	13.86	4.68	3.10	2.10	1.62	1.51	1.64	2.78	8.23
2 H.Cowell	12.23	1.96	11.43	13.86	4.68	3.10	2.10	1.62	1.51	1.64	2.78	8.23
3 M. River	1.16	1.23	1.39	1.59	1.45	1.16	0.65	0.47	0.36	0.34	0.72	1.70
4 U. River	No significant water extractions.											
5 Carbonera												
6 Branciforte												
7 L. Bean	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
8 U. Bean	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
9 L. Zayante	0.25	0.25	0.25	0.25	0.25	0.25	0.15	0.15	0.15	0.15	0.25	0.25
10 U. Zayante	No significant water extractions.											
11 Fall												
12 Bear												
13 Boulder	0.89	0.98	1.17	1.29	1.70	0.79	0.47	0.33	0.26	0.26	0.50	0.81
14 Kings	No significant water extraction.											

Table 2.18: Estimated average daily maximum flow extractions (in cfs) at Fish Enhancement Strategy monitoring reaches. Estimates were derived from historical production numbers provided by the San Lorenzo Valley Water District (courtesy Nick Johnson) and the City of Santa Cruz. A total of 0.5 cfs flow reduction was assumed due to well pumping in Scott's Valley (John Ricker, pers. comm.). These numbers also include an assumed maximum diversion rate of 1.1 cfs from the Fall Creek diversion based on conversations between County staff and California American and a maximum diversion rate of 0.25 cfs from a diversion on Lompico Creek (Lompico County Water District). These numbers do not include production numbers from other smaller water purveyors or private diverters. Estimates of return flow from septic systems and flow enhancements due to required releases from Loch Lomond were accounted for in the months of July to November, resulting in lower extraction amounts for the appropriate reaches.

SECTION 2.5 – FLOW REDUCTION IMPACTS TO SALMONIDS

Introduction

It has been widely noted that many physical microhabitat conditions change for stream fishes as streamflow increases and decreases (Alley, 1994-2002). These microhabitat features include habitat width, water depth, water velocity, surface turbulence (affects the amount of cover), rate of insect drift as food for drift-feeding salmonids, foraging opportunities and, to some degree, water temperature and oxygen concentration. Many other factors besides streamflow also affect microhabitat quality. Scour objects (woody material, large boulders, bedrock outcrops) affect pool depth and escape cover. Other geomorphic features that influence microhabitat include steepness of the streambank, degree of channel entrenchment, undercut streambanks, amount of fine sediment deposition, substrate size composition, substrate embeddedness, stream gradient, frequency and length of shallow fastwater habitat versus slower deepwater habitat and the hydraulic features of transitional breaks between habitat types. Still other factors are riparian tree composition (species and size), proximity of riparian trees to the streambank (affecting frequency of undercut streambanks) and tree canopy (affecting visual clarity, food productivity and water temperature). All of these microhabitat features impact each phase of fish life history differently. Streamflow and the physical features affect spawning habitat and rearing habitat in different ways.

In this chapter, linear regression relationships were determined for annual dry season streamflow (late spring, summer and fall) versus annual measures of juvenile steelhead density by size class at sampling sites. A linear rather than nonlinear relationship made the most biological sense because at sites other than the San Lorenzo Gorge, streamflow provided for rearing habitat were far less than the predicted optimal for habitat area, based on previous IFIM modeling (Alley, 1993; Santa Cruz County, 1978). The lower limbs of the weighted usable rearing area curves derived with increasing streamflows are typically linear. At mainstem San Lorenzo River sites, two streamflow statistics were compared to the average density of young-of-the-year (YOY) steelhead that grew into smolt-size fish the first year. These were the annual average of mean monthly streamflow for May through September at the Big Trees Gage and the annual minimum baseflow at the fish sampling sites. At tributary sites (where YOY's seldom grew to smolt size the first year), annual densities of YOY steelhead were compared to annual minimum baseflow. In addition, at the Bean Creek site the annual average of mean monthly streamflow for May through September at the Mt. Hermon Road Gage was compared to YOY density.

After a regression analysis was completed, the percent loss in juvenile steelhead production due to water diversion and well pumping was estimated by comparing differences between fish production predicted under existing flows and production under unimpaired flows. Regression analysis was restricted to sites where streamflow estimates were available and to years when non-streamflow related microhabitat features had not changed substantially due to sedimentation and channel widening and to years when previous high winter stormflow had not washed juveniles out of the sampling sites. Estimates of passage flows required for steelhead through the Gorge were based on previous surveys and observations of critical passage problems in the Gorge made by D.W. ALLEY & Associates, limited instream flow incremental methodology (IFIM) analysis by D.W. ALLEY & Associates and adult trapping data collected under the supervision of the Monterey Bay Native Anadromous Fish Hatchery at the Felton Diversion Dam on the San Lorenzo River.

Methods

Adult Passage

Estimates of streamflows necessary for steelhead and coho salmon passage in the San Lorenzo River Gorge and Rincon area are based on IFIM work completed by D.W.ALLEY & Associates on one representative high gradient riffle in the Gorge in 1992 (Alley, 1993) and more recent visual estimates made by Donald Alley at critical passage locations in 2002. Additional data included streamflow estimates at the Big Trees Gage on the first day that adult steelhead were trapped at the Felton Diversion Dam in 1991, a drought year. Further work is needed to better evaluate the streamflow necessary to allow fish passage at difficult locations.

Predictions of maximum spawning weighted usable area as a function of streamflow in various locations came from instream flow incremental methodology (IFIM) work performed by Santa Cruz County prior to 1978 during the development of the original San Lorenzo River Watershed Management Plan (Santa Cruz County, 1979) and by D.W. ALLEY & Associates in 1992 (Alley, 1993) during a water feasibility study funded by the City of Santa Cruz.

Juvenile Rearing

Predictions of maximum rearing weighted usable area as a function of streamflow in various locations came from IFIM work performed by Santa Cruz County prior to 1978 and by D.W. ALLEY & Associates in 1992 (Alley, 1993) during a water feasibility study funded by the City of Santa Cruz.

Streamflow data came from several sources. USGS gage data came from the Big Trees Gage on the San Lorenzo River just downstream of the Zayante Creek confluence and from the Bean Creek Gage just upstream of the Mt. Hermon Road overpass. Summer and fall streamflow measurements collected by Santa Cruz County personnel were used from lower Boulder Creek, on the San Lorenzo River in Ben Lomond, on Bean Creek below Lockhart Gulch and on Zayante Creek near its mouth. D.W. ALLEY & Associates made additional fall streamflow measurements or visual estimates at annual fish sampling sites (Alley, 1994-2001).

Estimated flow extractions at various locations were derived from historical production numbers provided by the San Lorenzo Valley Water District (SLVWD) via Nick Johnson to D.W. ALLEY & Associates and by the City of Santa Cruz to County staff and Swanson Hydrology and Geomorphology. Allowances for recycling of domestic water through septic systems in calculating net extraction rates was determined by Swanson Hydrology and Geomorphology. The estimated flow reduction of 0.5 cfs on Bean Creek due to well pumping was an estimate made by Santa Cruz County personnel. The maximum diversion rate of 0.25 cfs on Lompico Creek was based on information provided by the Lompico County Water District to Swanson Hydrology and Geomorphology. The assumed maximum diversion of 1.1 cfs from the Fall Creek diversion was based on information provided by the California American water agency to County staff.

Data on steelhead densities at representative fish sampling sites came from work performed by D.W. ALLEY & Associates during annual steelhead and habitat monitoring projects at sites funded by the City of Santa Cruz, the San Lorenzo Valley Water District and Santa Cruz County (1994-2000) and the original sites used in the Santa Cruz County funded study in 1981 (Smith, 1982). Six annually sampled, representative mainstem sites and 4 tributary sites were used. Juvenile densities were determined by standard capture depletion methods using electro fishing. An assumption was that growth rate at sampling sites was similar to growth rate elsewhere in the reach that was sampled. A source of error in fish density estimates was variable efficiency in electrofishing under different annual stream conditions. Electrofishing efficiency may diminish somewhat with increased streamflow.

A linear relationship between juvenile fish densities and streamflow rather than non-linear one made most biological sense because at sites other than in the San Lorenzo Gorge, the streamflows provided for rearing habitat were far less than the predicted optimal for habitat area, based on previous IFIM modeling (Alley 1993; Santa Cruz County 1978). The lower limbs of the weighted usable rearing area curves derived with increasing streamflow are typically linear (Bovee 1977; 1982).

Regression analysis between juvenile steelhead densities and streamflow was applied to only those age/size classes that appeared to correlate to streamflow statistics. Age/size class densities having no linear relationship to streamflow were total YOY density at mainstem sites, total density of yearling-sized steelhead at mainstem sites and yearling density at tributary sites. This means that factors other than streamflow overshadowed streamflow effects for these age/size classes in certain portions of the watershed.

For 4 middle River sites, the annual average density of yearling-sized YOY's (=> 75 mm SL) was plotted against the annual minimum daily flow at the Big Trees Gage and against the annual average of the mean monthly flows at the gage for the 5-month dry period from May through September. The same plots were developed at two lower River sites. Additionally, at each middle River site, the streamflow during sampling, which was approximately the annual minimum, was plotted against the annual density of these larger YOY's.

Regression analysis was restricted to 1981 and 1994-97 in the middle River and to 1994-97 in the lower River to evaluate effects of streamflow on juvenile growth rate. At the two lower River sites, 1981 data were not used because there were considerable geomorphic changes between 1981 and 1994.

Mainstem data from 1998 onward were not used because El Nino storms in 1998 brought considerable sediment into the mainstem with substantially degraded habitat in the middle River. Substantial streambank erosion occurred in the Henry Cowell reach, with considerable channel and riparian changes. In addition, juvenile mortality was undoubtedly high in the mainstem in winter of 1998 and survival in the ocean was also difficult the following spring and summer with a shortage of food leading to poor adult returns. Juvenile densities have been down in the middle and lower River since El Niño, apparently due to factors other than summer streamflow, making comparisons to previous years difficult.

In tributaries, very few YOY's reached smolt size and were < 75 mm SL. At tributary sites, the annual density of YOY steelhead was plotted against streamflow. Regression analysis was performed for the three tributary sites where streamflow data were available. For the lower Boulder and lower Zayante Creek sites, annual YOY density was plotted against minimum annual streamflow estimated at or near the time of fall sampling. At the Bean Creek site below Lockhart Gulch, YOY density was plotted against two streamflow statistics. Those were: 1) annual averaged mean monthly flow (May –September) at the Bean Creek gage and 2) annual minimum streamflow below Lockhart Gulch.

The loss in fish density due to the effects of water extraction at each fish sampling site was estimated by comparing the sample density to estimated density with unimpaired flows from each linear regression relationship. The slope of the regression line was multiplied by the estimated extraction rate to obtain the estimated loss for all diversions at the fish-sampling site. For the diversion rates from Lompico and Fall Creeks, the maximum diversion rate was used. For extraction rates in Bean Creek, an estimate of 0.5 cfs was obtained from County estimates. For diversions in the Boulder Creek sub-watershed and Clear Creek sub-watershed by the SLVWD, the average monthly extraction rates were used with a 0.25 cfs addition due to recycling through septic systems to obtain an average fish loss in the middle River. Actually, the SLVWD diverts more water during wetter years than during drier years. To estimate losses during September of a dry year (1994) and a wet year (1995, 1996 or 1998) the actual average monthly diversion rate from SLVWD diversions, as provided by Nick Johnson, were used along with the 0.25 cfs addition from septic recycling. The total expected density under unimpaired flows was calculated by adding the measured fish density in a particular year to the predicted loss in fish density estimated from the regression relationship. The loss was then converted to a percent of total density expected under unimpaired flow conditions that this loss would constitute. The percentage of density lost was determined for a drier year and a wetter year.

Here is an example of the aforementioned process of estimating fish loss due to extraction and computation of the percent loss compared to unimpaired flow. The example is for the tributary, Boulder Creek. The loss is measured in YOY's/ 100 ft. The linear regression equation for annual minimum streamflow versus YOY density is $Y = 58.17x - 11.59$ where "x" is streamflow and "Y" is the YOY density. The measured extraction rate for September 1994 was 0.3 cfs, with an augmentation of 0.15 cfs, resulting in a net extraction rate of 0.15 cfs. Therefore, the expected loss due to diversion was 58.17 times 0.15, equaling 8.7 YOY's/ 100 ft. To estimate the percent loss due to extraction, we add 8.7 to the density of YOY's determined by sampling from 1994, which was 22.2 YOY's/ 100 ft. The estimated density under unimpaired flows was 22.2 + 8.7 = 30.9 YOY's/ 100 ft. The percent loss in YOY's would be 8.7/ 30.9 = 28% (Table 2.23).

For the middle River, a percent loss in fish density was determined for 4 individual sites and for the combination of four sites. The loss in fish density was determined from the regression using Big Trees Gage data, average fish densities for the four sites and the effect of extraction rates at the gage. Percent losses at each site and for the combined sites were calculated as specified above.

Results and Discussion

Impacts to Passage for Adult Salmonids and Spawning Habitat

When water extraction (diversions and well pumping) causes streamflow through the San Lorenzo River Gorge to diminish below approximately 100 cfs during December through May, passage for some fish during spawning migration is likely to be adversely affected until stormflows of more than 100 cfs develop. When water extraction causes streamflows to diminish below 50-70 cfs, fish passage is likely to be significantly delayed.

Survey work in the San Lorenzo River gorge through Henry Cowell State Park identified approximately 12 natural passage impediments that exist that may restrict salmonid passage, consisting of high gradient riffles or boulder falls (Alley, 1993). The study concluded that 35 cfs is probably an adequate streamflow to allow adult salmonid passage through the Gorge, except at 2 locations: a wide riffle in the Rincon area (Site #1) and a falls created by a boulder field just above Four Rock (Site #2A). Flow for passage at the first barrier was estimated at approximately 100+ cfs, and for the latter was probably 50 cfs.

In 1991 during a drought, adult steelhead did not reach the Felton Diversion Dam until the mean daily flow reached 100 cfs. Although the boulder cluster above Four Rock in the San Lorenzo River Gorge was presumably limiting passage in 1991, it was observed to have become favorably rearranged in 2002. However, it may remain difficult to pass at streamflows less than 50 cfs. Visual observations of a critically wide riffle in the Rincon area of the lower San Lorenzo Gorge indicated that adequate passage flows for steelhead may not be reached at flows less than 70 cfs (Alley personal observation).

Water diversion during a drought year, in combination with naturally low baseflow, may prevent adult salmonid access to the upper watershed above the Gorge or at least severely limit it. Mean daily streamflow was less than 50 cfs at the Big Trees Gage for most of the winter from winter of 1986-87 through winter of 1990-91 (5 years), except for one to three minor storm events each winter.

Reduced streamflows in April and May indicated by the trend line (Table 2.17) suggest reduced passage flows for later spawning steelhead in April and May, which may be partially attributed to water diversion and well pumping.

Limited IFIM results (Alley, 1993; S.C. County, 1979) indicated that maximum spawning weighted usable area (WUA) in the lower River above the Gorge and in the Gorge occurred in the 70-100 cfs range. These results imply that water diversions and well pumping may adversely affect spawning conditions during the months of November and December when mean monthly streamflow is estimated at 53.8 and 107.9 cfs, respectively, based on the trend line for average monthly streamflow conditions (Table 2.17). During drought years, water extraction may have especially adverse effects upon salmonid spawning conditions in the lower River when winter baseflow may be much less than 70 cfs.

Although the dam on Newell Creek is a complete barrier to steelhead migration, there would be little benefit in transporting adults above and providing smolt passage down past the dam. There is less than 2 miles of stream habitat for salmonids, which is of low quality due to relatively shallow pools, low baseflow and limited escape cover (Alley unpublished). Juvenile growth may be expected to be slow. The cost of assuring passage of adults and smolts past the dam would be considerable and more wisely spent on other restoration projects or re-routing of releases from the reservoir into other drainages with water retrieval further downstream.

IFIM Analysis of Rearing Habitat in the Lower and Middle River

IFIM (Alley, 1993; Santa Cruz County, 1979) work indicated that considerable benefit in the production of yearling-sized juveniles might be gained from maximizing summer streamflow. If sufficient flow exists, a high proportion of YOY's grow to yearling (smolt size) after just one year in fresh water. This response can dramatically increase the production of smolt-sized juveniles in the lower and middle River, more so than can be achieved in most tributaries even with improved habitat.

IFIM results in the lower and middle River upstream of the Gorge (Santa Cruz County, 1979) indicate that summer streamflow for juvenile steelhead rearing is well below optimal in most years. IFIM modeling by Alley (1993) showed that the maximum WUA for juvenile rearing occurred at 30 cfs at 3 middle River sites: in Brookdale (downstream of Clear Creek), between Felton and Ben Lomond (downstream of Newell Creek) and in Felton (downstream of Fall Creek). IFIM modeling by Santa Cruz County (1979) showed that the maximum WUA for rearing was 20 cfs downstream of the Boulder Creek confluence and 75 cfs in the lower River, upstream of the Gorge. In the San Lorenzo River Gorge, IFIM results (Alley 1993) indicated that summer streamflow was closer to optimal in many years, with the maximum WUA area for rearing occurring at 20 cfs. However, a limited number of IFIM transects were modeled in the past, and a more in-depth IFIM analysis with more transects may refine these estimates.

Average monthly flows at the Big Trees gage indicates that streamflow falls below 30 cfs from July through October (Table 2.17). Thus, rearing conditions at the Henry Cowell site are sub-optimal during these months based on the IFIM results. Subtracting the flow input from Zayante Creek, the streamflow upstream of the Zayante confluence in the middle River is sub-optimal during the same months and also in portions of June and November, as well. The downward trend in average monthly flows from 1937-1997 indicates that water extraction is worsening rearing conditions (Table 2.17; Figure 2.7).

Regression Analysis of Rearing Success in the Lower and Middle River

In 1981 and 1994-97, much faster growth rates of YOY steelhead occurred in the mainstem River in wetter years as summer baseflow increased (Tables 2.19-2.22). This relationship was determined by plotting densities of YOY's reaching yearling (smolt) size in the first growing season at traditional sampling sites as a function of several measures of streamflow (averaged mean daily flow for each month during May-September at the Big Trees Gage; minimum daily flow at the Big Trees Gage in September; baseflow measured or estimated at sampling sites during sampling). Juvenile densities were determined by standard capture depletion methods using electrofishing. The largest impacts of streamflow on juvenile steelhead growth in the mainstem River were seen in the middle River (between the Zayante Creek and Boulder Creek confluences) where there was generally a higher proportion of yearling-sized YOY's (capable of smolting the following spring) as annual summer streamflow increased, as well as higher densities of these fish during wetter years compared to drier years (Table 2.22). Therefore, the annual density of yearling-sized YOY's was plotted against measures of streamflow in regression analysis. Annual densities of YOY's at sampling sites in tributaries also increased substantially with increasing baseflow.

Table 2.19. Percent of YOY steelhead reaching smolt size (=>75 mm SL), juvenile steelhead densities (fish/ 100 ft) for all fish => 75 mm SL and density for all juveniles at the *San Lorenzo River Gorge* site in 1994-97, with streamflow statistics at the Big Trees Gage.

Year	% YOY's of Smolt size	YOY's => 75 mm SL/100 ft	Total Juvenile Density (fish/100 ft)	Mean Monthly Flow at Big Trees (May-Sep in cfs)	Big Trees Gage Minimum mean daily flow (cfs)
1994	46.0	47.9	136.5	17	9
1995	63.2	52.8	78.7	74	18
1996	69.1	74.4	110.5	56	19
1997	36.9	31	83.9	28	15

Table 2.20. Percent of YOY steelhead reaching smolt size, juvenile steelhead densities (fish/ 100 ft) for fish => 75 mm SL and density for all juveniles combined at the *upper Henry Cowell Park* site in 1994-97, with streamflow statistics at the Big Trees Gage.

Year	% YOY's of Smolt size	YOY's =>75 mm SL/100 ft	Total Juvenile Density (fish/100 ft)	Mean Monthly Flow at Big Trees (May-Sep)	Big Trees Gage Minimum mean daily flow (cfs)
1994	33.8	15.6	56.7	17	9
1995	65.1	28.7	45.2	74	18
1996	71.9	43.3	65.9	56	19
1997	19.6	15.9	86.9	28	15

Table 2.21. Average percent of captured YOY steelhead at the ***4 middle San Lorenzo River*** sites in 1981 and 1994-97 reaching smolt size (=>75 mm SL) by fall sampling; average density of YOY's =>75 mm SL for the 4 sites and available streamflow statistics at the Big Trees Gage and the 4 fish sampling sites.

Year	% YOY's of Smolt size	Average YOY's => 75 mm SL/100 ft	Mean Monthly Flow at Big Trees (May-Sep in cfs)	Big Trees Gage Minimum mean daily flow (cfs)	Fall Streamflow (cfs) at 4 Sample Sites			
					Below Fall Creek	Ben Lomond	Brookdale	Boulder Creek
1981	14.6	4.5	17	9	4.9 [v]	2.1 [r1]	1.5 [r1]	0.9 [r1]
1994	26.9	6.9	17	9	5.1 [m]	2.5 [m]	1.8 [m]	1.1 [m]
1995	29.5	27.4	74	18	14.6 [m]	5.8 [m]	4.6 [m]	4.2 [m]
1996	21.2	21.1	56	19	12.9 [c]	5.1 [r2]	4.0 [r2]	3.7 [r2]
1997	11.8	12.9	28	15	5.5 [v]	3.5 [v]	3.0 [v]	2.2 [v]

v- indicates streamflow was visually estimated by measuring depths and surface velocity of floating objects.

r1- indicates streamflow was calculated by multiplying the ratio of minimum daily flows at the Big Trees Gage between 1981 and 1994 by the measured flow in 1994 at each site.

m- indicates streamflow was measured with a flow meter.

c- indicates streamflow was calculated by subtracting measured streamflow in Zayante Creek from measured streamflow below the Zayante Creek confluence.

r2- indicates streamflow was calculated by multiplying ratios of measured flow between sites in 1995 by first the calculated flow at Fall Creek and then successively upstream to the other sites.

Table 2.22. Linear regression equations generated between streamflow and YOY steelhead densities at mainstem San Lorenzo River and tributary sites for years 1981, and 1994-1997.

Location		Variables	Regression Equation[1]	R-Squared Statistic[2]	F-Statistic P-Value[3]
Lower River	Gorge	Mean monthly flow @ Big Trees; YOY's => 75 mm SL/ 100ft	Y = 0.36x + 35.59	0.28	0.47
		Annual minimum daily flow @ Big Trees; YOY's =>75 mm SL/ 100 ft	Y = 2.02x + 20.50	0.26	0.49
	Henry Cowell	Mean monthly flow @ Big Trees; YOY's => 75 mm SL/ 100 ft	Y = 0.36x + 10.11	0.51	0.29
		Annual minimum daily flow @ Big Trees; YOY's =>75 mm SL/ 100 ft	Y = 2.30x – 9.23	0.43	0.21
Middle River	4-site composite	Mean monthly flow @ Big Trees; Average YOY's => 75 mm SL/ 100 ft	Y = 0.38x – 0.13	0.99	0.00
		Annual minimum daily flow @ Big Trees; Average YOY's => 75 mm SL/ 100 ft	Y = 1.86x – 11.46	0.86	0.02
	Below Fall Creek	Annual minimum streamflow; YOY's => 75 mm SL/ 100 ft	Y = 0.95x + 0.54	0.85	0.03
	Ben Lomond	Annual minimum streamflow; YOY's => 75 mm SL/ 100 ft	Y = 13.48x – 26.99	0.89	0.02
	Brookdale	Annual minimum streamflow; YOY's => 75 mm SL/ 100 ft	Y = 8.45x – 7.99	0.87	0.02
	Below Boulder Creek	Annual minimum streamflow; YOY's => 75 mm SL/ 100 ft	Y = 1.29x + 5.20	0.22	0.42
Zayante Creek	Below Bean Creek	Annual minimum streamflow; YOY Density/ 100 ft	Y = 11.51x – 0.16	0.58	0.08
Bean Creek	Below Lockhart Gulch	Mean Monthly flow @ Mt. Hermon YOY Density/ 100 ft	Y = 14.43x + 3.15	0.59	0.04
		Annual minimum streamflow; YOY Density/ 100 ft	Y = 56.84x + 8.25	0.38	0.14
Lower Boulder	Above Hwy 9	Annual minimum streamflow; YOY Density/ 100 ft	Y = 58.17x – 11.59	0.77	0.02

[1] The independent variable "x" is a measure of streamflow. The dependent variable "y" is the juvenile fish density.

[2] Percent of the variation in fish density explained by the linear model.

[3] Probability that an error would be made in rejecting the null hypothesis that the slope of the regression is zero.

Regression Analysis of Rearing Habitat for the Lower River

Growth rate of YOY's at the San Lorenzo Gorge site was the most poorly correlated of all of the analyzed sites with minimum baseflow or averaged mean monthly streamflow (May- September) in linear regression analysis (Tables 2.19 and 2.22; Appendix Figures E-1 and E-2). The R-squared statistic was only 0.28 for the averaged mean monthly flow versus density of yearling-sized YOY's regression and only 0.26 for minimum daily flow versus density of yearling-sized YOY's. The relatively low correlation was apparently present because the steep gradient in the Gorge provided relatively abundant fastwater habitat in most years over a wide range of streamflows.

At the Henry Cowell site, the density of yearling-sized juveniles was better correlated, with mean monthly streamflow (R-squared = 0.51) and minimum daily flow (R-squared = 0.43) (Tables 2.20, and 2.22; Appendix Figures F-3 and F-4.) Analysis of the impact of water extractions above this site suggested potential reductions in densities of smolt-sized fish between 7% (wetter year) and 12% (drier year) but these are only approximate, given the somewhat low R-squared coefficient.

Regression Analysis of Rearing Success for the 4 Combined Middle River Sites

The highest correlations come from linear regression analysis for average densities of YOY's reaching smolt size at the 4 low-gradient, middle River sites versus the averaged mean monthly flow (May-September) (R-squared = 0.99) and the annual minimum daily flow (R-squared = 0.86) at the Big Trees Gage (Tables 2.21, 2.22 and 2.23; Appendix Figures F-5 and F-6). The higher correlation implies that growth and survival of YOY juveniles is more affected by the hydraulic environment created over a period of months than the minimum baseflow at the end of the dry season.

Using the middle River's 4-site composite regression equation of minimum daily flow at the Big Trees Gage versus average density of YOY's => 75 mm SL, an estimated average of 1.51 cfs. lost in September from estimated average extraction rates with a slope of 1.86, lead to a predicted 9% reduction in YOY's => 75 mm SL in a wet year (1995) (Table 2.23). The regression equation used was Y = 1.86x – 11.46 (Table 2.22). In the drier year 1994, the estimated extraction rate would be 1.35 cfs leading to a 27% reduction in the estimated total density of larger YOY's (Table 2.23).

In 1994 the estimated reduction of larger juveniles due to water extraction would be 17% of the average total density of yearling-sized juveniles expected without extraction (Table 2.23). For the wetter 1995, the reduction would be 6%. Estimated losses of 6% (wetter year) and 17% (drier year) in the middle River indicate a significant reduction in smolt production caused by water extraction.

Regression Analysis of Rearing Habitat for Individual Middle River Sites

Reductions in yearling-sized YOY densities from water extraction were estimated at each of the 4 middle River sites, in addition to estimating reductions of larger YOY densities averaged over the entire middle River. Estimated reductions were based on regression analysis between minimum measured baseflow and fish densities. Table 2.22 and Appendix Figures F-7 through F-10 indicate regression relationships and graphical representations for individual sites. Correlation coefficients between baseflow and density of YOY's reaching smolt size were generally good (R-squared values of at least 0.85), with the exception of the site below Boulder Creek (R-squared value of 0.22) where growth rates were less than at other sites. Flow extractions from Fall Creek, the Boulder Creek sub-watershed and Clear Creek appeared to significantly impact the growth rate of YOY's and the overall density of smolt sized juveniles produced in the middle River, particularly in drier years. Appendix F describes results at individual sites in more detail.

Estimated reductions in juveniles => 75 mm SL from water extraction in the drier year 1994 at 4 middle River sites were the following: 1) 12% below Fall Creek confluence, 2) 11% in Ben Lomond, 3) 15% below Clear Creek confluence in Brookdale and 4) 2% below Boulder Creek confluence (Table 2.23). These reductions were calculated using the estimated fish densities at fish sampling sites (Table 2.24). In a wetter year 1995 at the same 4 sites, the estimated losses were 5%, 5%, 8% and 1%, respectively. Therefore, flow extractions appeared to significantly impact growth rate of YOY's and overall density of yearling-sized juveniles at individual sites in the middle River. The largest impact was seen at the middle two sites of the middle River, where the potential for production of these larger juveniles is highest. The loss was least at the Boulder Creek site presumably because much fewer YOY's reach smolt size at that site, where there is less of the deep, fastwater habitat necessary to produce large YOY's found at other sites.

Table 2.23. Estimated instantaneous flow extractions in September and associated estimates of reduced density for yearling-sized YOY's at mainstem River sites and reduced total YOY density at tributary sites where linear regression relationships were developed between: 1) annual minimum streamflow at mainstem sites versus YOY steelhead => 75 mm SL for mainstem sites, 2) annual minimum daily flow at the Big Trees Gage versus average density of YOY steelhead => 75 mm SL for the Middle River 4-site composite and 3) annual minimum streamflow at tributary sites versus density of YOY steelhead at tributary sites. Instantaneous flow extractions were determined by using the maximum diversion rates from Fall Creek and Lompico Creek, 0.5 cfs extraction rate from Bean Creek and for San Lorenzo Valley Water District diversions, both average September diversion rates and measured diversion rates in 1994 and 1998 provided by Nick Johnson. Water recycling through septic systems was factored in.

Site		Annual Minimum Flow cfs. Wet/Dry Year Wet Year ('95) Extraction (%) Dry Year ('94) Extraction (%)	Correlation Coefficient (R2) of Linear regression of flow to fish density*	Estimated % Reduction of Age/Size Category due to Water Extraction and Estimated Density with Unimpaired flows (fish/ 100 ft)*			
				YOY's => 75 mm SL		All Juveniles => 75 mm SL	
				1994 dry	1995 wet	1994 dry	1995 wet
Middle River	4-Site Composite	18 / 9 1.51(_9_%) 1.35 (8%	0.86 (YOY=>75mm to annual min. Flow at Big Trees)	27% (9.4)	9% (30.2)	17% (14.4)	6% (44.3)
	Below Fall Creek	14.6 / 5.1 0.9 (6%) 0.8 (16%	0.85 (YOY=>75mm to annual min. Flow at Big Trees)	13% (6.2)	8% (11.8)	12% (6.8)	5% (19.7)
	Ben Lomond	5.8 / 2.5 0.36(6%) 0.2 (8%)	0.89 (YOY=>75mm to annual min. Flow at Big Trees)	22% (12.2)	7% (65.8)	11% (25.4)	5% (90.6)
	Brookdale	4.6 / /1.8 0.36 (8%); 0.2 (11%))	0.87 (YOY=>75mm to annual min. Flow at Big Trees)	36% (4.7)	10% (29.4)	15% (11.7)	8% (40.0)
	Below Boulder Creek	4.2 / 1.1 0.26 (6%) 0.15 (14%)	0.42 (YOY=>75mm to annual min. Flow at Big Trees)	3% (10.0)	3% (11.8)	2% (17.8)	1% (23.0)
Estimated Flow: Wet (1998) Dry (1994) Average Extraction (% reduction)				**1994 (dry) YOY's**	**1998 (wet) YOY's**		
Lower Boulder	Above Hwy 9	2.2 / 0.6 0.26 (12-43%)	0.77 (Total YOY to Minimum Measured flow)	28% (30.9)	24% (186.3)		
Bean Creek	Below Lockhart Gulch	6.7 / 2.1 0.5 (7 – 24%)	0.59 (Total YOY to Mean summer flow@ Mt. Hermon)	67% (42.3)	20% (132.7)		
Zayante Creek	Below Bean Creek	8.8 / 3.8 0.65 (9-17%)	0.58 (Total YOY to Minimum Measured flow)	19% (38.8)	9% (87.5)		

* Regressions were developed from density estimates at historical sampling sites within reaches, and estimated reductions in fish densities may not be directly extrapolated to entire reaches. However, the significant correlation coefficients (>= 0.7) indicate that there is a meaningful direct linear relationship between flow and fish density at those sites. Based on available data, the relationship is less direct in other sites downstream of the Zayante Creek confluence with lower correlation coefficients.

Table 2.24. Fall density of all YOY steelhead and yearling-sized (=>75 mm SL) YOY steelhead at middle San Lorenzo River sampling sites in 1981 and 1994-97 (from Smith 1982 and Alley 1995-98).

Year	Below Fall Creek (Site #1) YOY's/ YOY's=>75 mm SL (fish/ 100 ft)	Ben Lomond (Site #2) YOY's/ YOY's=>75 mm SL (fish/ 100 ft)	Brookdale (Site #3) YOY's/ YOY's=>75 mm SL (fish/ 100 ft)	Below Boulder Creek (Site #4) YOY's/ YOY's=>75 mm SL (fish/ 100 ft)	Estimated Streamflow (cfs) (Sites 1-4)
1981	17.0/ 4.9	27.9/ 1.7	78.4/ 10.3	17.3/ 1.8	4.9/ 2.1/ 1.5/ .9
1994	53.3/ 5.4	21.6/ 9.5	25.2/ 3.0	23.6/ 9.7	5.1/ 2.5/ 1.8/ 1.1
1995	41.7/ 10.9	139.7/ 60.9	112.9/ 26.4	46.7/ 11.53	14.6/ 5.8/ 4.6/ 4.2
1996	64.2/ 15.3	106.6/ 29.9	142.7/ 32.1	69.4/ 7.1	12.9/ 5.1/ 4.0/ 3.7
1997	42.0/ 5.9	143.5/ 19.2	152.0/ 15.0	119.9/ 11.5	5.5/ 3.5/ 3.0/ 2.2

Regression Analysis of Rearing Habitat at Tributary Sites

Regression analysis in tributaries focused on streamflow versus YOY densities, since nearly all YOY's were <= 75 mm SL. Results indicate that annual YOY densities increase substantially in wetter years with higher summer baseflow. Yearling densities did not correlate with summer streamflow in these small tributary sites. Densities of larger, smolt-sized juveniles were most dependent on primarily escape cover and the habitat depth in pools. Escape cover is dependent more on the amount of woody debris, unembedded boulders, overhanging vegetation and undercut banks than streamflow. Pool depth during the summer is less dependent on streamflow and more dependent on the presence of scour objects, such as bedrock outcrops, large woody debris and large boulders, and the amount of sedimentation that occurred over the previous winter. The model used by Smith (1984) for small steelhead streams is a reasonable predictor of yearling-sized juvenile steelhead densities, using an escape cover index and average habitat depth as variables. Pool depth and escape cover provide both summer habitat suitable for yearlings and overwintering refuges necessary for winter survival and yearling retention.

Another factor that affects fall densities of larger juveniles (and early emerging YOY's) is water clarity during the late winter and early spring when overwintering juveniles can feed heavily if low turbidity exists. A spring without many storms provides great clarity to allow the visually feeding juveniles to grow rapidly as occurred in 1997. Wet winters are at the other extreme. With stormy winters and springs, the high intensity of winter stormflows may flush yearlings and early emerging YOY's out of the system. This apparently occurred during the 1997-98 El Niño winter, leaving few yearlings in the system and reducing YOY densities in some locations. High mortality over the winter of 1997-98 probably translated into fewer adults returning in 1999-2000, with depressed juvenile production in 2000.

YOY juveniles use the remaining rearing habitat after the yearlings have utilized the best habitat. In wet years with higher streamflow, water depth in tributaries is slightly greater. Overhead cover from surface turbulence, particularly in riffles, heads of pools and in step-runs, is also greater with higher baseflow. YOY's will utilize habitat with less cover and shallower depth than yearlings. In years with higher baseflow in tributaries, YOY's can take advantage of increased depth with more surface turbulence sufficiently to increase YOY density while the yearlings continue to use the better escape cover. In addition, YOY densities may be more dependent on competition for food than yearling densities. More food is available in wetter years, with more spring and summer streamflow of adequate clarity once the storms end. Differences in tributary YOY production are obvious between dry versus wet years. YOY production in 1997 was high despite the relatively low summer streamflow in tributaries. This indicated that if high, early spawning success occurs and/or especially good water clarity for feeding exists during the spring growth period, these factors may overshadow the effects of low summer baseflow on YOY densities.

Lower Boulder Creek Site

YOY densities in lower Boulder Creek tracked positively (R-squared = 0.77) with minimum summer streamflows, excluding 1997 and 2000 data (Table 2.22 and Appendix E; Figure E-11). YOY densities in 1997 were especially high relative to minimum summer baseflow, presumably because the unusually heavy, early winter storms and absence of significant rain after January provided for exceptional spawning success and high water clarity in spring for feeding when baseflow was still high. Therefore, 1997 data were considered atypical and not included in the analysis. YOY densities in 2000 were especially low relative to minimum summer baseflow, presumably because of the low adult returns from the 1998 El Niño year and were also excluded from the analysis. Data in Table 2.25 are the basis for a linear regression between the minimum summer baseflow and YOY density at the sampling site on lower Boulder Creek in 1981, 1994-96 and 1998-99. Because diversion points are in the headwaters of tributaries to Boulder Creek, the maximum diversion rate is less in drier years, and the resulting reduction in juvenile steelhead production due to diversion would be less. In the drier year 1994, the measured September diversion rate was 0.3 cfs, with a net extraction rate of 0.15 cfs with septic recycling factored in, leading to a predicted 28% reduction in the estimated total YOY density under unimpaired flow (Table 2.23). The estimated flow reduction was 17%, from 0.9 to 0.75 cfs. In the wetter year 1998, the measured September diversion rate was 0.92 cfs, with a net extraction rate of 0.77 cfs, leading to an estimated 24% reduction in the estimated total YOY density under unimpaired flow, after a flow reduction of 25% from 3.1 cfs to 2.3 cfs.

Table 2.25. Fall density of YOY steelhead in *lower Boulder Creek near Highway 9* in 1981 and 1994-98, with minimum measured streamflow in summer/fall. (Average net extraction rate in September was 0.26 cfs. Net extraction rate was 0.15 cfs in September 1994 and 0.77 cfs in September 1998).

Year	YOY's / 100 ft	Yearlings / 100 ft	Minimum Measured Flow (cfs)
1981	28.9	19.6	0.35*
1994	22.2	20.3	0.6
1995	117.3	25.0	2.0
1996	52.1	17.7	1.6
1997	119.2	22.8	1.1
1998	141.5	21.9	2.2
1999	50.7	17.8	1.5

* visually estimated

Despite the limited fish data and approximate streamflow estimates, flow extractions in the Boulder Creek sub-watershed appeared to significantly reduce YOY densities in Boulder Creek (28% in 1994 and 24% in 1998). This reduced production would also likely reduce the number of YOY's that might enter the mainstem as yearlings.

Bean Creek Site below Lockhart Gulch

A positive correlation existed between streamflow and numbers of YOY steelhead in middle Bean Creek. The two measures of streamflow available that correlated positively with YOY densities below Lockhart Gulch include the annual averaged mean monthly flow for May through September at the gage located near the Mt. Hermon Road Overpass (R-squared = 0.59) (Tables 2.22 and 2.26; Appendix E; Figure E-12) and the minimum measured streamflow below the Lockhart Gulch confluence (R-squared = 0.38) (Table 2.22 and Appendix E; Figure E-13). Streamflow is substantially higher at the gage than at the fish-sampling site upstream, but plotting averaged mean monthly flow gives an indication of a composite of the streamflow through the summer and its correlation to YOY density. For Bean Creek, the minimum baseflow at the end of the dry season correlated poorly with streamflow in early summer, especially for 1998. Although the minimum summer baseflow in 1998 was low compared to 1995, streamflow over most of the summer was considerably higher than in 1995. Although regression analysis between minimum measured streamflow and YOY densities indicated that YOY density increased generally with increased baseflow, the R-squared statistic was low (0.38). The scatter in the minimum streamflow versus

YOY density regression relationship resulted from the especially low YOY density in 1994 and the high YOY density in 1998 relative to the minimum measured streamflow.

Table 2.26. Fall site density of YOY steelhead in ***Bean Creek below Lockhart Gulch*** in 1994-98, with average mean monthly streamflow for May- September by year at the downstream Gage at the Mt. Hermon Road overpass and minimum measured streamflow in summer/fall below Lockhart Gulch. (Estimated extraction rate was 0.50 cfs).

Year	YOY's / 100 ft	Yearlings / 100 ft	Mean Monthly flow (cfs) for May-Sep @ Mt Hermon Overpass Gage	Minimum Measured Flow (cfs) below Lockhart Gulch
1981	55.2	9.2	Prior to gage	0.7 (visual estimate)
1994	13.9	10.3	2.1	0.73
1995	87.3	9.9	4.7	1.53
1996	41.8	9.1	4.6	0.91
1997	60.7	12.3	2.5	0.71
1998	104.3	11.3	6.7	1.08
1999	59.0	33.3	2.8	0.59
2000	41.3	7.0	3.4	0.67

The considerable scatter about the regression line made any predictions on reduced YOY density with water extraction very approximate. With the estimated maximum extraction rate of 0.5 cfs (Table 2.17) and the slope of the regression line being 56.84, the estimated reduction in YOY density from water extraction was 28.4 YOY fish/ 100 ft (Table 2.23). Though the R-squared was low, the resulting predicted reduction in YOY's indicated potentially significant impacts to YOY density resulting from water extraction. In the drier year 1994, this reduction would have been 67% of the total YOY density under unimpaired flows (Table 2.23), after a 40% reduction in minimum baseflow (1.2 cfs to 0.7 cfs). In the wet year 1998, the reduction would make up 20% of the total YOY density anticipated under unimpaired flows, after a 32% reduction in minimum baseflow (1.6 cfs to 1.1 cfs). Placement of a gage just below the Lockhart Gulch confluence would allow measurement of mean monthly flows and an annual minimum daily flow for the sampling site, which would likely increase the R-squared for a streamflow versus YOY density regression. Despite the great scatter in the regression line, the predicted 20% (wet year) and 67% (dry year) reductions in YOY densities indicated that water extraction has a significant affect upon juvenile habitat.

Lower Zayante Creek Site

Water diversion from Lompico Creek estimated at 0.25 cfs (Table 2.17) would adversely affect juvenile steelhead rearing habitat in Zayante Creek downstream of the Lompico Creek confluence and would have additive impact to the Zayante Creek reach downstream of the Bean Creek confluence along with water extraction in Scotts Valley and Mt Hermon estimated at 0.5 cfs. An estimated 0.1 cfs was recycled through septic systems, resulting in a net extraction rate of 0.65 cfs. Using the only available long-term streamflow measurements from Santa Cruz County near the mouth of Zayante Creek and fish sampling data in Zayante Creek, a positive correlation was determined between the minimum measured streamflow and YOY densities below the Bean Creek confluence (R-squared = 0.58) (Tables 2.22, 2.23 and 2.27; Appendix Figure E-14). With a net extraction rate of 0.6 cfs and a regression slope of 11.51, the predicted reduction in YOY density was 7.5 fish/ 100 ft. In the drier year 1994, this would constitute 19% of the total estimated YOY density, with a 17% reduction in the minimum baseflow (3.8 cfs to 3.15 cfs). In the wet year 1998, the loss would constitute 9%, with a 9% reduction in minimum baseflow (8.8 cfs to 8.15 cfs). The predicted 9% (wet year) and 17% (dry year) reductions in YOY density are significant impacts from water extraction affecting lower Zayante Creek.

Table 2.27. Fall density of YOY steelhead in ***lower Zayante Creek below Bean Creek*** in 1981, 1994-96 and 1998-99, with minimum measured streamflow in summer/fall. (Estimated extraction rate was 0.75 cfs.

Year	YOY's / 100 ft	Yearlings / 100 ft	Minimum Measured Flow (cfs)
1981	35.5	5.4	4.0 (visually estimated)
1994	31.3	6.6	3.1
1995	50.6	16.9	5.3
1996	67.8	6.8	5.3
1997	No data	No data	4.6
1998	80.0	3.0	8.1
1999	96.4	7.6	5.7

IFIM Analysis in Tributary-Sized Channels and Management Implications

Previous IFIM work performed in similarly sized channels indicated that reduced summer streamflow caused by water extraction will likely reduce juvenile densities in tributaries such as Bean, Boulder and Zayante creeks. This work indicated that maximum weighted usable area (WUA) for rearing occurred within a range of streamflows of 6 to 10+ cfs at various sites. At a site 2,300 feet upstream of the Teilh Road Bridge in the upper San Lorenzo River, the maximum juvenile rearing WUA occurred at 6 cfs (Alley 1993). Further upstream in the San Lorenzo River at Waterman Gap, the maximum juvenile rearing WUA occurred at 7.5 cfs (Santa Cruz County 1977-78). In upper Zayante Creek near Mt. Charlie Gulch, the maximum rearing WUA occurred at 7.5 cfs (Santa Cruz County 1977-78). In lower Kings Creek the maximum rearing WUA was 10+ cfs (Alley, 1993). The past IFIM work based WUA upon water depth, water velocity and substrate size. These environmental factors more closely correspond to rearing conditions for YOY's in these small streams. Escape cover was not incorporated into the IFIM model, though it is a primary factor in determining densities of yearling-sized juveniles. Therefore, based on these limited IFIM results, it is reasonable to assume that additional IFIM modeling in Bean, Boulder and lower Zayante creeks would indicate that once summer baseflow declined into the range of 6-7.5 cfs, juvenile steelhead rearing habitat for YOY's would become reduced, but habitat for yearlings would involve more complex relationships. Streamflow falls below 6 cfs in Bean and Boulder creeks every summer and in lower Zayante Creek in average to drier years. Impacts from water extraction may be reduced if extraction locations are placed as far downstream as possible.

Water diversion from Bean Creek near its confluence with Zayante Creek would substantially reduce the negative impact of water extraction compared to present water extraction locations in Scotts Valley. Jerry Smith surveyed Bean Creek in January 1981, noting that streamflow was approximately 1 cfs in the vicinity of Lockhart Gulch, approximately 1.75 cfs at the Mt. Hermon Road overpass and approximately 3.2 cfs at the Zayante Creek confluence (Smith, 1981). Water extraction in the heavily shaded reach near the mouth of Bean Creek, with its much poorer substrate and lower juvenile densities than upstream of the Mt. Hermon Road overpass, would have much less impact than extraction in the Scotts Valley area. However, diversion at the mouth of Zayante Creek would be even more environmentally advantageous to allow maximum surface flow through lower Zayante Creek, as well.

SECTION 2.6 – GAPS IN THE RIPARIAN CORRIDOR

Introduction

A riparian corridor is sometimes defined as the strip of land on either side of a stream or watercourse dominated by vegetation that is dependent upon year-round surface or shallow groundwater. A more ecologically functional definition includes all streamside vegetation that affects stream conditions (e.g. provides stream shading, is a source of nutrients from leaf drop, retards bank or slope erosion and surface runoff). Characteristic woody species found in riparian corridors in the Santa Cruz Mountains include, but are not limited to, various types of willow (*Salix* sp.), red alder (*Alnus rubra*), white alder (*Alnus rhombifolia*), bigleaf maple (*Acer macrophyllum*), box elder (*Acer negundo*), black cottonwood (*Populus* *trichocarpa*), California bay laurel (*Umbellularia californica*), coast live oak (*Quercus agrifolia*), Douglas fir (*Pseudotsuga menziesii*), redwood (*Sequoia sempervirens*), tanbark oak (*Lithocarpus densiflorus*) and western sycamore (*Platanus racemosa*) . Redwood and various shrubs and herbaceous vegetation form multiple canopy layers that support a rich diversity of wildlife species that rely on adjacent water supplies.

Depending on the configuration of the valley where the riparian corridor occurs, riparian corridor width can range from a narrow strip along the bottom of a canyon (10's of feet wide), to wide swaths of dense vegetation where the canyon opens up into a wide valley floor (100's of feet wide). The function of riparian corridors also differs by location. In the case of a narrow canyon, the roots of riparian vegetation stabilize stream banks, provide scour objects that improve fish habitat, reduce direct sunlight and keep water temperatures cool, and provide wood to the channel that act as grade control and escape cover elements. In addition to stabilizing stream banks and proving for improved habitat conditions, riparian corridors on wide valley floors reduce water velocities during flooding events and filter out fine sediment, resulting in improved water quality.

In the San Lorenzo River watershed, riparian corridors have been significantly impacted from a variety of land uses including road development, rural residential development, and timber harvest practices. The most significant impact has been a reduction of the riparian width in many areas. Narrowing of riparian corridors reduces the filter efficiency of the system and can result in bank instability, ultimately resulting in an increased risk to private property and public infrastructure. Roads are often built along the floors of valleys throughout the San Lorenzo River watershed where streams have been straightened to accommodate the roadbed. The resulting loss in natural channel morphology and meander patterns reduces fine sediment deposition on the floodplain and limits recruitment of riparian vegetation for habitat and channel forming functions. Over the long term, as existing, single-aged stands of riparian trees senesce and die, younger trees may not be available to take their place.

There is a lack of data describing the historic and present condition of riparian corridors in the San Lorenzo River watershed. Much of the riparian vegetation inventory work completed to date is associated with fish habitat surveys where information about canopy density and species composition data is collected. Though this is valuable information when assessing the direct impact of riparian canopy cover on aquatic habitat conditions in the reach of interest, it does not provide a larger picture of the health or extent of riparian corridors across the entire watershed.

Unfortunately, the task of providing detailed information regarding the extent, health, and species composition of riparian corridors throughout the watershed is an extremely large task. Our approach aimed to identify significant gaps in riparian canopies across the watershed using high-resolution digital aerial photography. This comprehensive survey provides a baseline of information to assess future conditions and provides the necessary data to determine where riparian restoration actions would prove the most valuable.

Methods

Approximately 280 miles of primary stream channel (i.e. - USGS blue lines) exist in the San Lorenzo River watershed. The approach we used to assess riparian conditions was to use high-resolution digital aerial photography already available at the County. This data consists of 2-meter resolution color aerial photographs flown in June 2000 by AirPhotoUSA. Stream channels included in the County GIS database, which are essentially USGS 1:24,000 blue lines, were used to identify potential riparian corridors.

With the stream channels overlaying the digital photography, we searched for possible gaps in the riparian canopy by identifying bare soil areas or locations where the channel, water surface, or bars could be seen directly in the digital image. Since most of the stream channels could not be located directly on the aerial photography due to dense vegetation cover, direct observations of the channel or channel features was a good indicator of a riparian gap. Each gap was mapped in order to identify total gap length along each stream.

The process of identifying gaps is not as accurate on the mainstem of the San Lorenzo River since direct viewing of the water surface or channel features does not necessarily imply a complete gap in the riparian canopy. Due to the greater width of the channel in those areas, the pixel resolution allows easier identification of channel features on the digital image. Regardless, direct viewing of channel features on the aerial photo would suggest more direct sunlight and heating of the water. To maintain consistency, all areas where channel features were identified were mapped as gaps in the riparian canopy.

Once all riparian gaps were mapped, the lengths were totaled by sub-watershed. Sub-watersheds, as opposed to stream channels, were used to account for the smaller tributary channels to the San Lorenzo River mainstem that fall between larger sub-watersheds. The mainstem was divided into sub-watersheds representing the lower, middle, and upper River using the same breaks as shown in Figure 1.1. The mainstem sub-watershed, therefore, include the smaller tributary drainages.

Results and Discussion

The results from the riparian gap analysis are summarized in Table 2.28. Overall, the results suggest that the riparian canopy along the San Lorenzo River is fairly intact with over 95% of stream channels in the watershed having some form of shading. At the sub-watershed level there appears to be some significant pieces of the river where gaps in the riparian canopy are prevalent. This includes the lower and middle River mainstem and Love Creek and to a lesser degree Carbonera and Branciforte Creeks.

Though the results on the lower and middle River are skewed by the size of the channel, which makes it much easier to see apparent gaps in the canopy, the middle River and stretches along upper Henry Cowell Park are experiencing high impacts from rural residential development and bank erosion that are reducing the already narrow riparian width. The data appears to suggest a general trend of increasing riparian gaps with increasing human impacts from rural residential development and road building.

Although the data does not provide a complete picture of the health of the riparian corridors along the San Lorenzo River and tributaries, it does show trends that will allow more specific focus on problem reaches and sub-watersheds. What is needed now is a general understanding of the health of the riparian corridor in terms of riparian width, species diversity, presence of exotic species, and the ratio of hardwoods versus conifer species within the riparian canopy.

Table 2.28. Identified gaps in riparian canopy on the San Lorenzo River, by sub-watershed, based on 2-m resolution color digital aerial photographs.

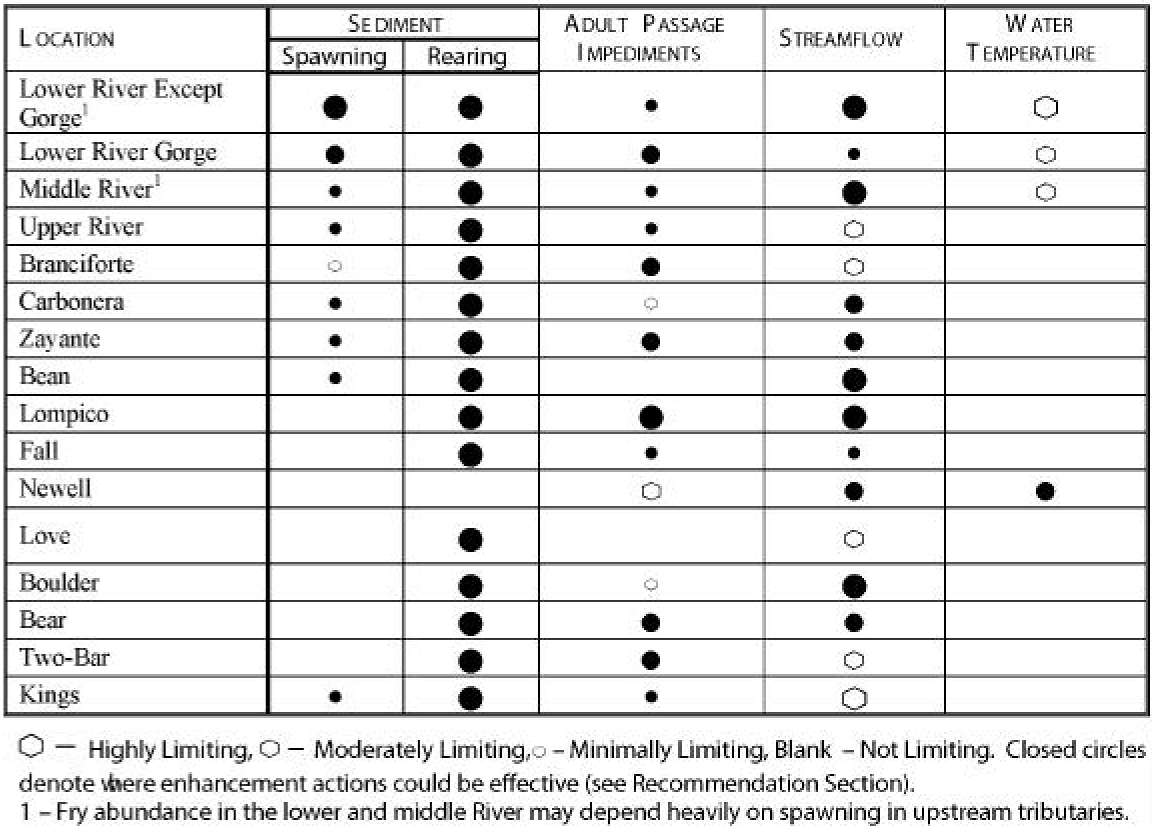
Sub-watershed	Total Length (mi)	Length w/ Gaps (mi)	Percent Gap
Bean	20.0	0.82	4.1
Bear	32.1	0.64	2.0
Boulder	26.4	0.47	1.8
Branciforte	19.6	1.00	5.1
Carbonera	13.9	0.77	5.5
Fall	12.0	0.16	1.3
Kings	18.1	0.27	1.5
Lompico	6.2	0.14	2.2
Love	6.3	0.54	8.6
Lower River	23.4	2.57	11.0
Lower Zayante	4.5	0.17	3.8
Middle River	22.8	4.66	20.5
Newell	21.1	0.41	1.7
Two Bar	4.0	0.10	2.6
Upper River	27.4	0.57	2.1
Upper Zayante	21.0	0.32	1.5
Grand Total	**281.6**	**13.60**	**4.8**

CHAPTER 3 - LIMITING FACTORS

For an anadromous (ocean and freshwater living) salmonid to survive to adulthood and then successfully reproduce, a variety of habitat requirements must be satisfied. Interruptions in any phase of the salmonid life cycle can devastate the entire population. When a salmonid fry emerges from an egg, the long process of rearing, migration to the ocean, growing large and returning to spawn has begun. If poor quality habitat, high predation, starvation, or barriers to migration exist, the salmonid life cycle will be cut short. Each risk to the salmonid life cycle can be a limiting factor for the entire population (Figure 1.2). This chapter summarizes the key limiting factors to salmonid production on the San Lorenzo River based on available data and discussions presented in the previous chapters.

Table 3.1 summarizes the limiting factors by reach or tributary of the San Lorenzo River. The table was developed through review of existing habitat and population data and group discussions with the project team and County staff members to reach a consensus on the primary and secondary limiting factors. Factors were considered limiting regardless of their likelihood for improvement or remediation. For example, in many cases streamflow is limiting fish production even if low flows are the natural condition. This is analogous to nitrogen or phosphorus limitations in phytoplankton populations. More nitrogen can be added until phosphorus becomes limiting. Limiting factors that can be addressed through management measures and restoration plans are denoted by a closed circle in Table 3.1. In most cases, those factors are limiting due to anthropogenic influence or disturbance.

Table 3.1. Assessment of Limiting Factors for the San Lorenzo River.



LOCATION	SEDIMENT		ADULT PASSAGE IMPEDIMENTS	STREAMFLOW	WATER TEMPERATURE
	Spawning	Rearing			
Lower River Except Gorge[1]	⬤	⬤	•	⬤	◯
Lower River Gorge	●	⬤	●	•	○
Middle River[1]	•	⬤	•	⬤	○
Upper River	•	⬤	•	○	
Branciforte	◦	⬤	●	○	
Carbonera	•	⬤	◦	●	
Zayante	•	⬤	●	●	
Bean	•	⬤		⬤	
Lompico		⬤	⬤	⬤	
Fall		⬤	•	•	
Newell			○	●	●
Love		⬤		○	
Boulder		⬤	◦	⬤	
Bear		⬤	●	●	
Two-Bar		⬤	●	○	
Kings	•	⬤	•	◯	

◯ – Highly Limiting, ○ – Moderately Limiting, ◦ – Minimally Limiting, Blank – Not Limiting. Closed circles denote where enhancement actions could be effective (see Recommendation Section).

1 – Fry abundance in the lower and middle River may depend heavily on spawning in upstream tributaries.

Chapter 4 discusses specific management recommendations that, if implemented, will improve conditions for salmonids on the San Lorenzo River by addressing the identified factors limiting their numbers.

SECTION 3.1 - HABITAT PARAMETERS

Spawning Habitat Quality and Success of Emergence

Based on qualitative observations, the quality of spawning habitat varies greatly throughout the San Lorenzo River. Generally, spawning gravel quality is high enough to allow returning fish to saturate the available habitat with fry due to the high reproductive capacity of adult salmonids and the ability of YOY's produced in the tributaries to move down into the mainstem to saturate rearing habitat where survival from egg to swim-up fry may be less. Though this is the general rule and spawning may not be the primary limiting factor in most reaches of the watershed, spawning conditions are sub-optimal. For example, the density of juveniles found in the lower and middle River is probably very dependent on recruitment from the upstream tributaries. Most tributaries have less than optimal spawning conditions, but juvenile production is more limited by restricted rearing conditions resulting from low summer streamflow, shallow pool conditions and the absence of good escape cover rather than spawning success.

The primary causes of poor quality spawning habitat or limited success of emerging fry are:

- Excessive fine sediment in spawning gravels that limit use of impaired areas by adult fish or cause egg or alevin mortality after spawning has occurred.
- Mobile bed conditions that result in loss of redds after spawning has already occurred.

In the Lower and Middle River, poor spawning conditions exist due to the input of high fine sediment loads from tributary streams such as Boulder, Bear, Kings, Zayante, and Bean Creeks. Fine sediment from these tributaries is deposited in the lower gradient reaches, increasing the fraction of fine sediment at the terminus of pools where spawning gravels are typically found. High fine sediment deposition in the Lower and Middle River forces spawning adults to use areas dominated by sand that become mobile during late winter and early spring high flow events.

The apparent relationship between late winter and early spring high flow events, a mobile streambed and loss of salmonid redds is evidenced in high YOY numbers sampled in the lower and middle River in Water Year 1997. In that year, moderately high winter flows occurred early in the year with very little rain falling after January. High late winter and early spring baseflows provided adequate rearing habitat without potentially bed-scouring flows that could result in the loss of salmonid redds. However, rearing habitat was better that year which added to the higher than usual juvenile densities in these reaches.

Poor spawning habitat quality and low spawning success as limiting factors to juvenile numbers in the lower and middle River are likely offset by recruitment of YOY fish from productive tributaries such as Boulder, Bear, Fall and Zayante creeks. Excess spawning compared to rearing habitat in larger tributaries may force YOY or yearling fish to seek available habitat in the mainstem River that is not already saturated by juveniles. It is this dynamic that makes it difficult to determine the most limiting factor on juvenile production in the lower and middle River in some years.

The impact of high fine sediment loads in Carbonera is a streambed that is extremely mobile during high flow events resulting in loss of existing spawning redds. In Kings Creek excessive fine sediment may significantly reduce fry emergence in some sections of the creek. However, low summer streamflow, sedimented pool habitat and limited escape cover are more limiting in these tributaries.

In the case of tributaries, the variability of gradient and structural elements such as bedrock outcrops and large woody material may allow for good quality spawning habitat to exist in localized patches even if high fine sediment loads are present. Hydraulic variability created by these flow separators or constrictors allows fine sediment to be sorted and removed from certain locations, leaving higher quality gravel beds in their place that can be sought out by adult fish. In the case of tributaries where hydraulic variability does exist, the question remains whether enough of these small patches are available to be found by the small number of fish that seek them.

Potential improvements to spawning habitat quality should be approached from the perspective of limiting inputs of excessive fine sediment into the system and implementing policies that limit removal of large woody material from the stream channel. In both cases, the recovery of the system may be fairly slow depending on the pace of erosion control efforts in the upper watershed and the availability of large woody material for recruitment. Improvements to spawning habitat quality will be seen much more rapidly in tributaries than in the mainstem due to the high residence time of sediment and higher storage potential in lower reaches. This fact may make it likely that the tributaries remain a source of YOY fish to the mainstem for years and possibly decades.

Rearing Habitat Quality

The quality of rearing habitat in the San Lorenzo River and tributaries affects the growth and survival of salmonids from the time they emerge from the gravels as fry to the time they leave for the ocean as smolts. Rearing salmonid juveniles can take up to two years depending upon the species and growth rates. The primary variables that determine the quality of rearing habitat for salmonids are food availability, fast water feeding areas, escape cover from predators, adequate water depth, water clarity, and water temperature.

The quality of rearing habitat in the mainstem San Lorenzo River and tributaries is directly linked to streamflow (see Section 3.3) and the presence of excessive fine sediment loads. Table 3.2 summarizes the primary factors impacting each of the rearing habitat quality variables.

Table 3.2. Factors affecting rearing habitat quality on the San Lorenzo River

Rearing Habitat Quality Variable	Primary Limiting Factor
Food availability	Primary - Excessive fine sediment, Secondary – Streamflow
Fast water feeding areas	Primary – Streamflow, Secondary- Shortage of large woody material
Escape cover	Primary – Excessive fine sediment without sufficient large woody material for scour, Secondary – Streamflow
Adequate water depth	Primary – Excessive fine sediment without sufficient large woody material for scour, Secondary – Streamflow
Water clarity	Primary – Excessive fine sediment
Water temperature	Primary – Absence of closed riparian canopy, Secondary- Streamflow

In the lower and middle River, excessive fine sediment loads have resulted in pool filling, high embeddedness in riffles and runs (Table 3.3) and a general loss of total habitat area. Rearing conditions in these reaches remain adequate to support a high proportion of the watershed's fast growing juveniles that are large enough to smolt within one year during high streamflow years in the middle River and in all years in the lower River. Faster growth of juvenile fish in the lower and middle River can be attributed partly to the wider river, allowing primary productivity to increase as the result of higher solar input. Higher primary productivity results in higher production of macroinvertebrates that salmonid juveniles feed upon. Higher water velocity resulting from higher streamflow increases the insect drift rate for juvenile salmonids, allowing for them to feed throughout the summer. Warmer water temperature allows faster digestive rates to process food faster. However, the warmer water increases the metabolic rate of juveniles and their food demand. Therefore, they are restricted to primarily fastwater habitat (riffles and runs) and cannot utilize much of the slow water pool and glide habitat, which constitutes between 30 and 60% of the stream length in lower River reaches and between 50 and 75% in middle River reaches. If pool substrate was less dominated by fine sediment and cobble and boulder substrate was exposed, they may be able to provide better rearing habitat for juveniles.

Table 3.3. Average Substrate Embeddedness by Habitat Type in Mainstem Sampling Sites of the Middle San Lorenzo River, 1996-2000. (From Alley 2000; Figures 30a and 32a).

Site/Reach	Fastwater Habitat [1]					Pool Habitat [2]				
	1996	1997	1998	1999	2000	1996	1997	1998	1999	2000
6	38	35	35	45	50	30	40	40	100	75
7	30	43	38	43	40	35	45	50	50	50
8	25	38	35	43	45	35	35	30	60	45
9	50	43	40	48	43	100	100	35	65	45

1 - Fastwater habitat included riffles and runs. Embeddedness was estimated for cobbles larger than 100 mm (4 inches) prior to 1999 and cobbles larger than 150 mm (6 inches) from 1999 onward. This likely had very little effect on embeddedness estimates. A management goal should be to reduce embeddedness in fastwater habitat to 25% or less.

2 - Embeddedness in pool habitat had little relation to habitat quality in the middle River because the pools were mostly sandy substrate and few juveniles inhabited them in this reach except in 1998. It is unclear at this time whether pools dominated by coarser substrate would provide better habitat for rearing juveniles. The high metabolic demand for food by steelhead in the warm lower and middle River necessitate their use of fastwater habitat not found in pools, except in very wet years. A rating of 100% indicated that there were no cobbles large enough to be rated.

Even though high sediment loads reduce available habitat and can impact food production, this is offset by the overall size of the river and the increased production of primary producers. Fish in the lower and middle River may be playing a delicate balance between increased metabolic rates from higher water temperatures against more food availability. Therefore, the limiting factors in the lower and middle River may be the habitat quality of the fast water feeding areas and the proximity of escape cover to these locations.

In the upper River and tributaries to the San Lorenzo River conditions are quite different. Thick riparian canopies, narrow streams, and deep canyons produce a cool climate where water temperatures are cool and primary production is low. Suitable substrate in higher gradient riffles is not limiting, although macroinvertebrate production is low due to cool temperatures and low primary productivity. Conversely, due to cool temperatures, salmonid food requirements are lower, often counterbalancing the low availability of food. The result is slow growing fish in the tributaries.

The dominant factor limiting juvenile production in the upper River and most tributaries is the presence of excessive fine sediment without enough large woody material to act as scour objects, thus reducing habitat depth and available escape cover. Sands and fines now dominate streambeds in some tributary streams that may have once been dominated by less embedded cobble and boulders. Limited rearing habitat greatly reduces the productive capacity of tributary streams. The shortage of instream objects such as large woody material reduces the complexity of escape cover that is required for healthy rearing habitat.

Improvements to rearing habitat quality in tributaries to the San Lorenzo River can be accomplished by reducing inputs of excessive fine sediment and discouraging the removal of large woody material. Narrow, higher gradient reaches of tributaries would see fairly rapid improvements in habitat depth and escape cover quality on the order of 5-10 years following comprehensive measures to reduce sediment loads and protect natural recruitment of large woody material. Reaches through wider valleys with lower gradients may take longer to recover since they are natural sediment deposition areas and have large amounts of stored sediment available.

Water Temperature Requirements of Steelhead

The relationship between water temperature and metabolic rate (measured as oxygen consumption) is basic to fish physiology and important in understanding fish distribution and ecology. Fish being ectotherms (cold-blooded), their body temperatures increase along with metabolic rate as water temperature increases. At higher temperatures, steelhead oxygen requirements and food demands increase, and steelhead are forced into fastwater habitat or other sources of abundant food. References that indicate that oxygen consumption by fishes increases with water temperature include Fry (1947), Beamish (1964) and Beamish (1970). Many fisheries textbooks refer to this relationship. An example is The Chemical Biology of Fishes by Malcolm Love (1970). The positive relationship between water temperature and metabolic rate in fishes leads to higher oxygen requirements as water temperature increases (Nikolsky, 1963).

In the San Lorenzo River, water temperature is primarily a food issue. In the mainstem, warm water is not directly lethal, though higher temperatures increase food demands and restrict steelhead to faster habitats for feeding, especially above 21ºC (70ºC) (Smith and Li, 1983). The lethal level for steelhead would probably be above 26-28ºC (79-82ºF) for several hours during the day. But this is rarely, if ever, reached. Even so, warmer temperatures could result in slow growth or starvation in steelhead if food supply becomes very limited. As part of annual steelhead monitoring on the San Lorenzo River in 1997-2001, Alley (2001) measured water temperatures of 21ºC+ in August and September in the lower and middle River from Paradise Park to Brookdale in a number of reaches, except during the cool and high-flow summer of 1998. Cool water from tributaries aided in reducing mainstem temperatures. These mainstem reaches often provide habitat for large yearling steelhead and fast-growing young-of-the-year fish. The high growth rate in the lower mainstem and in the middle River during high baseflow years often leads to relative high densities of smolt-sized juveniles.

A water quality goal should be to maintain water temperature at 21ºC or cooler in the San Lorenzo mainstem. Cooler temperatures may not be possible in the lower River (downstream of the Zayante Creek confluence) and in portions of the middle River (downstream of the Boulder Creek confluence) due to the wide stream channel and lack of riparian canopy closure, even where the riparian corridor is intact. Therefore, maintaining fastwater feeding habitat by protecting maximum streamflow in the mainstem is especially important. Where the river passes through canyons and is narrow, cooler water may be obtained through adequate protection of the riparian corridor and maintenance of adequate summer baseflow. Water temperature in tributaries remains well below 21ºC throughout the summer and is not a water quality issue for steelhead as long as the riparian corridor is protected.

Fortunately, steelhead in the San Lorenzo River do not face competition or predation from more warm water adapted, introduced species, such as the pike minnow (*Ptychocheilus grandis*) (formerly known as the squawfish). Though pikeminnow is absent from the San Lorenzo River, in other drainages where pikeminnow is present, steelhead abundance in warmer habitats has been significantly reduced, especially in pools.

There are many central coast examples of steelhead surviving and growing well at water temperatures above 21ºC. Many of these come from coastal lagoons and lower reaches of unshaded drainages, but only where food is abundant. When food is abundant, growth is actually better at warmer temperatures because digestive rate is increased, allowing fish to consume more food and grow more quickly.

Supporting evidence for steelhead tolerance of higher water temperatures may be found in Appendix B.

Water Temperature Considerations -Coho Salmon in the San Lorenzo River

Because of the existing spawning challenges for coho and typical summer water temperatures found in the mainstem below the Boulder Creek confluence, no acceptable water temperature goal can realistically be attained for coho. It is highly unlikely that coho salmon can successfully spawn in the mainstem below the Boulder Creek confluence in most years. With their early spawning period and the sandy conditions, their redds are extremely vulnerable to scour and sedimentation from later winter and spring storms. In drier years when scour is less likely, passage through the gorge may be very difficult and much of the watershed may be inaccessible to most adult coho. However, if there was successful spawning in these mainstem reaches or if juveniles produced by spawning in tributaries moved down into these reaches, juvenile coho would easily starve because they cannot utilize productive fastwater habitat as steelhead do. Although the lethal temperature limit for coho is similar to steelhead, they would likely starve at temperatures above 18-20ºC (65-68ºF) in the lower and middle mainstem. Coho can potentially tolerate temperatures nearly as high as steelhead, but usually are found at much cooler temperatures. In Washington, stocked coho were found to do well in streams where temperatures exceeded 24.5ºC for more than 100 hours and reached 29.5ºC (Bisson et al. 1988). However, those were very productive sites, and other species (including steelhead) were scarce. The warm lagoon at Waddell Creek failed to support coho in 1996, even though it was productive, and coho were present immediately upstream of the lagoon. Apparently coho could not compete with steelhead in this warm, large pool situation. However, in smaller and/or cooler pools, coho tended to successfully exclude young-of-the-year steelhead (Smith, unpublished). Even if water temperatures below 18ºC could be attained in some portions of the middle mainstem, few coho would likely survive in the long pools where food is in short supply.

Oxygen Requirements for Steelhead and Coho Salmon

Steelhead can likely survive oxygen levels in the cooler, early morning as low as 2 mg/l. However, the water quality goal for the San Lorenzo River should be to maintain oxygen levels above 5 mg/l because activity is likely restricted at lower oxygen levels. This goal is easily met in flowing stream habitat throughout the watershed because riffles recharge oxygen, but may not be in the lagoon under conditions in which saltwater has been trapped by sandbar closure without sufficient lagoon inflow. Artificial sandbar breaching after the initial sandbar formation has been shown to cause both temperature and dissolved oxygen problems in the lagoon (Smith, 1990). Even without breaching, dissolved oxygen levels in the lagoon may continue to be problematic as a result of biological activity supported by the high nutrient load into the lagoon (Beck, 2003).

Local field data are lacking for establishing the minimum oxygen requirements for coho salmon juveniles. However, it is likely that warm water temperature associated with starvation would become limiting to coho in the San Lorenzo River system long before low oxygen levels would become a factor. It is probable that oxygen levels in flowing stream and riverine habitat would be ample for coho salmon, as is the case for steelhead. Saline lagoon conditions may reduce oxygen levels in deeper portions of the water column below the tolerance for coho, as with steelhead. The 5 mg/l oxygen goal for steelhead in the San Lorenzo system would also be adequate for coho salmon.

Supporting evidence for steelhead tolerance of low oxygen concentrations may be found in Appendix B.

Potential Impacts from Summer Flashboard Dams

Summer flashboard dams are common within the San Lorenzo River watershed and have come under increasing pressure from NOAA Fisheries and CDFG staff due to their potential impacts on adult and juvenile steelhead in the San Lorenzo River. The potential impacts of flashboard dams include:

- *Adult Passage:* Even though flashboard dams are not in place during the winter salmonid migration period, the infrastructure associated with flashboard dams, including abutments and aprons, often limits adult passage under certain flow conditions. Flow conditions limiting passage may include high velocities during peak winter flows or shallow depths over concrete aprons during drought years. These impacts could be mitigated through retrofitting of existing structures.
- *Free Movement of Juveniles:* While the flashboards are in place during the summer, the elevation drop at the dam structure impedes upstream movement of juveniles. There is currently no evidence of juvenile movement upstream though this question is certainly up for debate. Shapovalov and Taft (1954) in a multi-year study with a very effective trap in Waddell Creek detected very limited upstream juvenile steelhead movements in the winter only, and that was near the lagoon/estuary.
- *Loss of Fastwater Riffle Habitat:* During installation of the flashboards and filling of the impoundment, fastwater habitat, such as riffles, will be lost during the summer months, with a resulting loss of critical steelhead rearing habitat. In some situations, the loss of productive fastwater habitat may be offset by an increase in total habitat area found in the impoundment. The benefits/detriments of a conversion from fastwater to slack water habitat greatly depend on the conditions present at each site. The slack water habitat provided by flashboard dams is likely to be unsuitable for steelhead and coho salmon in the middle and lower San Lorenzo River, unless food production within the seasonal pond is high. Abundant algae production with resulting high invertebrate production (similar to the productive habitat potentially found in lagoons at the mouths of streams) may make some flashboard ponds into adequate fish habitat. In cool tributaries, small flashboard ponds often provide good summer habitat even if food production is low. The added water depth provides adequate escape cover for over-summering juveniles in these settings.
- *Increased Water Temperatures:* Since flashboard dam locations are often highly modified to provide recreational opportunities for local residents, riparian vegetation is often removed from the banks to provide more space and reduce the risk of injury. The result is often an open canopy with significantly increased exposure to the sun and increases in water temperature downstream, compared to upstream of the impoundment. The magnitude of the temperature change will depend greatly on the location and configuration of the impoundment (direction of valley, height and angle of canyon walls, associated vegetation on hillslopes, etc), and potentially, where in the water column the water is released. The impact of any temperature change will also depend on the range of temperatures measured and how close those are to recommended threshold values.
- *Modified Streamflow Regime:* Flashboard impoundments have a potential impact on the existing streamflow regime during filling of the impoundment, under full impoundment conditions, and while flashboards are being removed. During filling, flow into the impoundment exceeds what is being released, resulting in the potential for stranding of juvenile fish. The reverse can occur during removal of flashboards with the potential for causing fluctuations in streamflow downstream of impoundments. In the past, spikes of 80 cfs have been detected at the Big Trees gage in Felton during draining of the Ben Lomond flashboard dam. This may displace fish from their summer rearing locations or strand fish at the margins, both potentially causing take of steelhead. NOAA Fisheries and CDFG staff are in the process of developing fill and release schedules for flashboard dams. Current requirements dictate that during filling, wetted width should not decrease more than 20%. Release requirements dictate

that water depth in the impoundment be decreased no more than 1 inch per hour. Flow reduction may also occur during the summer months when the impoundment is in place. At a flashboard dam located on the Little Sur River, a 20% reduction of streamflow from upstream to downstream has been measured (Dvorsky, unpublished data).

Additional studies should be conducted to better understand the impacts or benefits that flashboard dams have on adult and juvenile salmonids in a variety of river systems. It may turn out that each flashboard dam location is unique and therefore must be evaluated individually. Current research being conducted at the Ben Lomond Dam on the San Lorenzo River and the Pico Blanco Dam on the Little Sur River may provide a pair of dams that can be used to compare and contrast potential impacts based on the apparent differences in the physical conditions and land use impacts present in each watershed. As more information becomes available, land managers will be better equipped to evaluate potential impacts.

SECTION 3.2 - PASSAGE IMPEDIMENTS

A discussion of passage impediments is necessary in order to understand the current upstream limits of anadromous fish habitat and to determine potential habitat that would be available to spawning adults if they were removed or modified to allow fish passage. Passage impediments include man-made features such as flashboard dams, diversions, culverts, low-water crossings and reduced streamflow conditions that limit migration past critical riffles. They also include natural features such as bedrock shelves, waterfalls, and high-gradient riffles. Passage impediments can also range from complete barriers that limit upstream migration under all flow conditions (e.g. a 20-foot high waterfall) as well as partial barriers that may only limit migration under certain flow conditions.

Adult Passage

Potential passage impediments in the San Lorenzo River have the greatest impact on adult salmonids migrating to spawning grounds because they are moving upstream long distances to spawn. Access to upstream spawning habitat may be especially limiting when streamflow is insufficient to provide adequate water depth to allow them to jump over waterfalls or swim through steep or shallow riffles. Passage impediments that limit adult migration in the lower reaches of the mainstem River and tributaries are especially limiting because they may impede access to much of the potential spawning and rearing habitat in drier winters.

Since passage over many potential barriers, such as high gradient riffles and perched culverts, is flow dependent, and coho salmon migrate upstream and spawn in late fall and early winter, they are much more vulnerable to passage impediments than steelhead. Coho are also weaker jumpers than equally sizes steelhead. Though winter storms may begin in November and December, soil conditions do not often reach saturation until January when additional rainfall results in increased flows in streams and rivers of the San Lorenzo Valley. If winter storms are delayed or drought conditions exist, flows may be inadequate to allow coho salmon migration over certain passage impediments. If drought conditions persist steelhead may also be impacted by low flow conditions that limit migration over certain passage impediments.

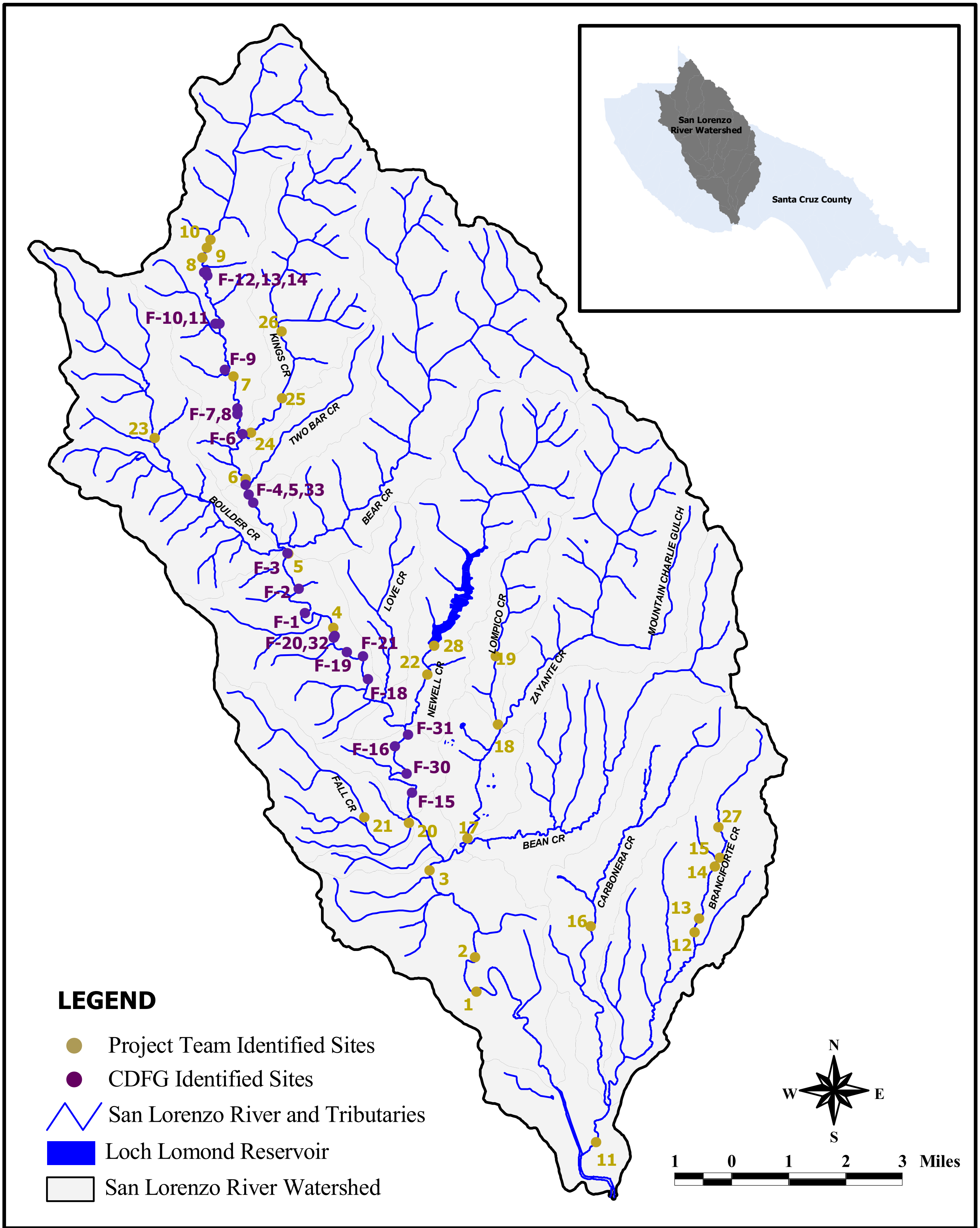
Table 3.4 and Figure 3.1 describe the type and location of known passage impediments occurring on the San Lorenzo River and its primary tributaries. Other barriers do exist on minor tributaries near their confluence with the mainstem San Lorenzo River that have not been adequately identified and therefore have not been described. There may also be additional passage impediments at other locations that limit migration during low-flow conditions. Where data is available, information regarding the degree that each location impedes passage and under what flow conditions it is passable is noted (Table 3.4).

Table 3.4. Description and locations of fish passage impediments on the San Lorenzo River. This list includes only identified passage impediments and is not meant to represent all possible impediments.

ID	Location	Description	Degree of Passage Impediment
1	San Lorenzo River	Wide critical riffle in upper Rincon	Passable at ~ 70 cfs[1]
2A	San Lorenzo River	Boulder falls above Four Rock	Passable at ~ 50-70 cfs[1]
3	San Lorenzo River	Felton Diversion Dam	Difficulty passing at certain intermediate-flow conditions
4	San Lorenzo River	Bedrock outcrop below Brookdale	Low flow barrier
5	San Lorenzo River	Erwin Way flashboard dam apron and base	Low flow barrier
6A	San Lorenzo River	Fern Road flashboard dam apron and base	Low flow barrier
6B	San Lorenzo River	Camp Campbell flashboard dam apron and base	Low flow barrier
7	San Lorenzo River	Bedrock channel above Teilh Road	Passable at ~16.5 cfs
8	San Lorenzo River	Log jam below Waterman Gap	Low flow barrier
9	San Lorenzo River	Riprap boulder jam below Highway 9 repair downstream of Waterman Gap	Low flow barrier
10	San Lorenzo River	Highway 9 bridge apron	Low flow barrier
11	Branciforte Creek	Branciforte flood control channel	Low flow barrier. Passage depends upon maintenance schedule
12	Branciforte Creek	Concrete flashboard dam abutment	
13	Branciforte Creek	15’ high Denil ladder over 10’ high dam	Needs maintenance to allow passage
14	Branciforte Creek	Flashboard dam abutment with inadequate pool/weir ladder	Needs maintenance to allow passage
15	Branciforte Creek	Rock and concrete wall at Happy Valley Estates	Low flow barrier
16	Carbonera Creek	Moose Lodge Falls	Impassable at all flows
17	Zayante Creek	Flashboard dam abutment	Low flow barrier
18	Lompico Creek	Concrete wall and bedrock chute above fish ladder	Only passable at higher flows
19	Lompico Creek	Concrete floor in creek with approach apron	Low flow barrier
20	Fall Creek	Concrete weir fish ladder	Continuous maintenance required
21	Fall Creek	Boulder falls	Impassable at all flows
22	Newell Creek	Bedrock falls	Passable at ~ 200-300 cfs
23	Boulder Creek	Bedrock chute	Impassable at all flows
24	Kings Creek	Flashboard dam apron	Low flow barrier
25	Kings Creek	5 bedrock chutes and shelves	Low flow barriers
26	Kings Creek	Bedrock/boulder falls – 2 steps	Impassable at all flows
27	Branciforte Creek	Flashboard dam just downstream of Vine Hill Road	Low flow barrier
NA*	Love Creek	Denil ladder	Needs maintenance to allow passage
NA*	Branciforte Creek	Concrete structure below flashboard dam	Low flow barrier
28	Newell Creek	Loch Lomond dam	Complete passage barrier

* - Precise location currently unavailable.

1 – More detailed work will be completed during the implementation phase to refine the passage flow requirements at these two sites in the Gorge.



Swanson Hydrology and Geomorphology ***D.W. Alley & Associates*** ***Jerry Smith, PhD***	Figure 3.1: Location of identified fish passage impediments on the San Lorenzo River and it's major tributaries. For descriptions of each gold site refer to Table 3.4. Purple sites are those identified by CDFG and CAB on the mainstem in a survey conducted in Summer 2001 (Table 3.5). There may be overlap between locations.	***Figure 3.1*** ***April 2002***

With partial funding by CDFG, the Community Action Board (CAB) completed a comprehensive assessment of human-caused passage impediments in the mainstem of the San Lorenzo River upstream of Highway 1 in the summer of 2001. This information is presented in Table 3.5 and shown on Figure 3.1. Some of these impediments may overlap with those identified by D.W. Alley and Associates and County staff. Of the 24 sites identified, 21 consisted of current or abandoned flashboard dams. Numerous flashboard dams also occur on tributaries to the San Lorenzo River but were not mapped as part of this project. Even though many of the dams are no longer in use, the abutments or concrete sills can prove to be impediments to passage for adults under a range of flow conditions during low water years.

Passage impediments on the lower and middle mainstem of the San Lorenzo River are potential limiting factors for the entire River since they can restrict access to important spawning habitat in the tributaries. Good quality spawning habitat may be limiting in the lower and middle River, so access to higher quality tributary spawning habitat is important to steelhead abundance in both the mainstem and the tributaries.

Survey work in the San Lorenzo River gorge through Henry Cowell State Park identified approximately 12 natural passage impediments that may restrict salmonid passage, consisting of high gradient riffles or boulder falls (Alley, 1993). The study concluded that 35 cfs was probably an adequate streamflow to allow adult salmonid passage through the Gorge using the criteria of 0.6 feet minimum depth across 5 contiguous feet of channel width, except at 2 locations: a falls created by a boulder field just above Four Rock (Site #2A) and a lesser boulder falls that has since become rearranged and is no longer a barrier. After the El Nino storms of 1998, a critically wide riffle developed in the Rincon area that was a significant passage impediment and was still present in 2002.

In 1991 during a drought, adult steelhead did not reach the Felton Diversion Dam until the mean daily flow reached 100 cfs. Although the boulder cluster above Four Rock in the San Lorenzo River Gorge was presumably limiting passage in 1991, it was observed to have become favorably rearranged in 2002. However, it may remain difficult to pass at streamflows less than 50 cfs. Visual observations of the Rincon area in 2001indicated that adequate passage flows for steelhead may not be reached at flows less than 70 cfs. (Alley personal observation). Water diversion during a drought year, in combination with naturally low baseflow, may prevent adult salmonid access to the upper watershed above the Gorge or at least severely limit it. Mean daily streamflow was less than 50 cfs at the Big Trees Gage for most of the winter from winter of 1986-87 through winter of 1990-91 (5 years), except for one to three minor storm events each winter.

In the middle River, the Felton Diversion Dam (Site #3) may have caused passage difficulties at certain streamflows. Difficulty in locating the fish ladder when streamflow is spilling over the inflatable dam may be a problem at certain intermediate flows when fish cannot jump over the dam. A Memorandum of Agreement was signed by the Department of Fish and Game and the City of Santa Cruz in 1996 to alter the operation of the dam to improve fish passage (Entrix, 1997). Under the new operating procedures, when the dam is deflated and the flow is less than 40 cfs, air bladders are used to focus water in the center of the dam. When the dam is inflated and flows are greater than 300 cfs, a slide gate is opened 8 inches to allow for fish passage. When streamflow is greater than 300 cfs for more than 5 days in a row and the dam is inflated, the dam is partially deflated to 4 feet and the slide gate is closed overnight. The dam may then be re-inflated the next morning as needed. Due to the lack of a consistent steelhead trapping or monitoring program at the dam, the effectiveness of these measures is unclear.

To improve migration conditions for salmonids more detailed studies need to be conducted to assess the barriers identified in this report. The solution at each of the individual sites will depend on the type of barrier, its configuration, and streamflow conditions at different times of the year. Remediation of existing barriers should begin with sites lower down in the watershed since they restrict access to more adequate spawning and rearing habitat.

MAP ID	CAB ID	Description	Concern	Priority
1	1	active large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	highest
2	2	legacy large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	high
3	3	active large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	highest
4	4	active large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	high
5	5	active large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	highest
6	6	active large concrete flashboard dam	debris and geomorph and moderate flow concerns	highest
7	7	grouted bed associated with bank revetement	geomorph and low flow concern	high
8	8	active large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	highest
9	9	grouted bed associated with bank revetement	geomorph and low flow concern	highest
10	10	active large concrete flashboard dam	debris and geomorph and low-moderate flow	highest
11	11	legacy large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	high
12	12	legacy large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	high
13	13	legacy large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	high
14	14	active large concrete flashboard dam	debris and geomorph and low-moderate flow concerns	high
15	15	small grouted rock dam	low flow concern	low
16	16	legacy concrete flashboard dam	minor debris and geomorph and low flow concerns	low
18	18	legacy concrete flashboard dam	debris and geomorph and low flow concerns	moderate
19	19	legacy concrete flashboard dam	debris and geomorph and low flow concerns	high
20	20	active small grouted rock flashboard dam	minor debris and geomorph and low flow concerns	low
21	21N	natural bedrock slide	moderate flow concern	high
30	n/a	legacy concrete flashboard dam	debris and geomorph and low flow concerns	high
31	n/a	legacy concrete flashboard dam	minor debris and geomorph and low flow concerns	low
32	n/a	legacy concrete flashboard dam	debris and geomorph and low flow concerns	low
33	5N	legacy small concrete flashboard dam	debris and geomorph and low flow concerns	low

Table 3.5: Passage impediments identified in the summer of 2001 on the mainstem of the San Lorenzo River from walking surveys by CDFG and CAB. It represents all man-made, channel spanning structures with potentially adverse effects on fish passage and other important watershed processes on the mainstem from Highway 1 upstream. It does not include the two City of Santa Cruz diversion facilities at Tait and Felton. Restoration priority was suggested based on field estimates with consideration of feasibility of fixing the site and potential fisheries benefit, without doing hydraulic calculations

Smolt Out-Migration

Smolt out-migration of both coho and steelhead occurs primarily from March through May, based on smolt trapping in the lower San Lorenzo River at Tait Street in 1987-89. The primary limiting factor on movement of smolts from their rearing habitat to the ocean would be excessive dewatering of the stream channel resulting in very shallow riffles or dry sections, which would create physical barriers to migration. From March through May, complete dewatering of the channel or early closure of the lagoon mouth could occur during a year, or period of years, under drought conditions.

Streamflow records for the USGS gage on the San Lorenzo River at Santa Cruz (Gage ID# 11161000) report mean daily flow measurements from 1988 to present do not suggest that dewatering has occurred on the Lower River during periods of smolt out-migration. However, this gage is located near the Tait Street diversion and could not detect the dry channel that developed in summer of 1988 between there and Highway 1, presumably caused by a cone of depression created by well pumping (J. Smith and D. Alley, personal observations). During the severe drought of 1975-77, flow may have been even less during those months. Flows dropped below 0.5 cfs in July and August during the drought years from 1987 to 1992.

With an increased human population using limited water resources and the presence of a City of Santa Cruz diversion at Tait Street on the lower River near Highway 1, smolt out-migration and open access to the ocean may become more of a limiting factor when the area experiences the next severe drought period.

SECTION 3.3 - STREAMFLOW

Streamflow as a limiting factor has been discussed in the context of other limiting factors such as rearing habitat for juveniles and passage barriers for adults. It is the primary element that defines total available habitat for salmonids with other limiting factors affecting the quality of the habitat and the ability to reach available habitat.

In a climate where rain is seasonal, streamflow is often a scarce resource for human systems where there are demands for municipal, agricultural, and industrial uses as well as fire protection and recreation. All of these human demands for water compete with the need to maintain streamflow for biological systems. Human water demand also peaks during summer and early fall when streams are experiencing their lowest flows of the year. Due to the low streamflow during the summer months in most streams, streamflow is likely to be a limiting factor for fish production even in the absence of human use of this valuable resource. When water extractions are added, streamflow as a limiting factor becomes even more severe.

In the San Lorenzo River, the disparity in timing that exists between the seasonal availability of water and the demand for its use has resulted in a complicated system of water storage systems, groundwater pumping, winter and summer diversion systems and cross-basin transport of water. Multiple agencies distribute water to residents in the San Lorenzo Valley and other local communities. The largest agencies are the City of Santa Cruz Water Department, California American (formerly California American), the San Lorenzo Valley Water District, and the Scotts Valley Water District, with the former two agencies primarily obtaining water from surface water resources and the latter extracting it from groundwater wells.

To understand the impact that water extraction has on fish populations, the timing, magnitude, and location of the facility are important. The timing of water extraction is important in determining which salmonid life stage is being impacted. The magnitude is important in terms of the quantity of water that is being extracted and what remains for bypass. The location is important in understanding the cumulative effect of multiple diversions on downstream habitat conditions and population numbers.

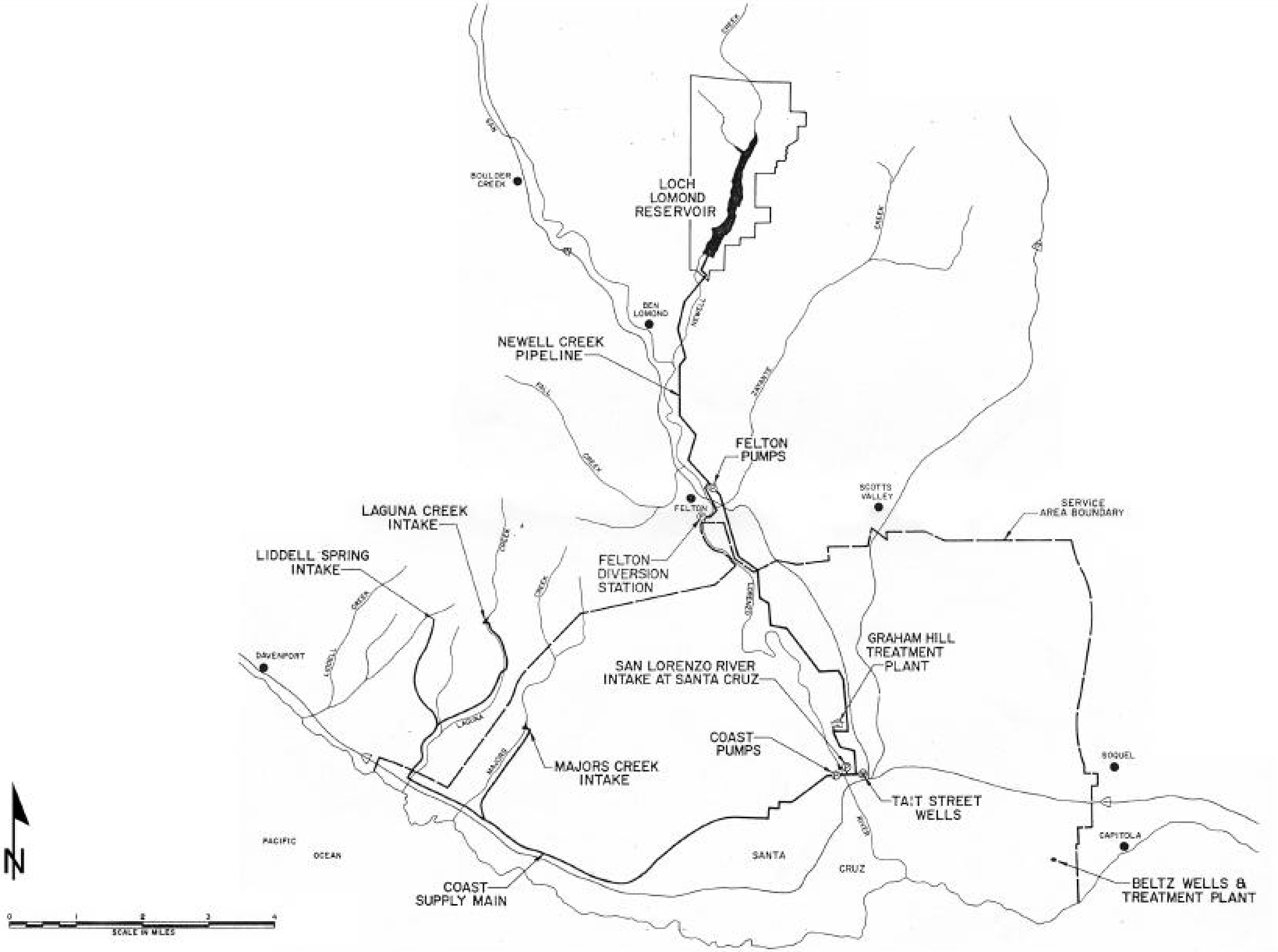
The primary water diverter on the lower mainstem of the River is the City of Santa Cruz. The City of Santa Cruz Water Department has three primary facilities that divert and store water. The systems include Loch Lomond Reservoir on Newell Creek, the Felton Diversion Dam a half mile downstream of the Zayante Creek confluence, and the Tait Street Diversion near Santa Cruz (Figure 3.2), which include streamside wells that can be used in the place of the diversion. The use of these facilities varies greatly depending upon the water season, turbidity, availability, and demand. Additionally, the City diverts water from several locations on the north coast of Santa Cruz County and pipes the water to their treatment facilities within the San Lorenzo basin.

The Tait Street Diversion is the primary source of water for the City, particularly during the summer. Flow reductions at Tait Street can be significant, especially during summer low-flow months. Although the City is not required to bypass flow, it currently adjusts pumping rates to maintain a minimum flow downstream. Operationally, pumping capacity at the diversion site reduces the likelihood of the City completely dewatering the lower River since these high-capacity pumps can only operate in the on or off position. Pumping of flows below the capacity of an individual pump can damage the system. Future upgrades of the Tait Street infrastructure will give the City more control of their pumping operation through variable speed pumps. As a part of its water right for surface diversion, the City can also use its wells near the Tait Street Diversion to divert water. During past drought years when the well pumps were in operation, a cone of depression apparently developed that dewatered the river downstream before it reached the lagoon, as occurred in the mid 1970's and in 1988. Impacts related to the Tait Street Diversion are addressed further in the Lower San Lorenzo River and Lagoon Management Plan recently developed with funding from the City of Santa Cruz and the California Coastal Conservancy.

Loch Lomond reservoir is the only significant impoundment facility within the City's water supply system. This reservoir captures approximately 8.3 square miles of runoff in the Newell Creek Watershed and stores a maximum of 8,990 acre feet of water. The reservoir acts as an emergency water supply during drought periods, though the City may also tap this water supply when other sources, such as the north coast pipeline and the Tait Street Diversion are highly turbid and would require significant treatment. When water is being used from Loch Lomond it is pumped directly from the reservoir to the Graham Hill treatment facility. Loch Lomond provides some augmentation of baseflow during low flow periods with a year round minimum release requirement of 1.0 cfs. During wetter months, peak flows and higher baseflows are captured by the dam until the reservoir is full and spilling. Spilling usually occurs by midwinter in normal to wet years, but may not occur at all during dry years.

Storage within Loch Lomond Reservoir is augmented by mainstem San Lorenzo River diversions at Felton. The Felton Diversion consists of an inflatable dam with pumps that transport water from the San Lorenzo River up to Loch Lomond through a pipeline. The water right at Felton only allows water to be stored and not directly used. The City can begin diverting at Felton on September 1st. Between September 1st and October 1st a bypass of 10 cfs is required. From October 1st to October 31st the minimum bypass requirement is increased to 25 cfs, and then remains at 20 cfs from November 1st to May 31st. Due to operational considerations the City does not typically begin diversion until flows exceed 25 cfs. A maximum of 3,000 acre-feet can be diverted seasonally to Loch Lomond Reservoir between September 1st and May 31st.

Due to the limited storage capacity of Loch Lomond, the reservoir will often spill in an average to wet year. This limits the usefulness of diverting water from Felton to supplement storage during average to wet years. Usually a significant amount of water is diverted only in average to dry years when water resources are scarce for both humans and aquatic organisms. This situation warrants close inspection to determine if storage could be further augmented to reduce the reliance on summer flows (*see Management Recommendations – Chapter 4*).



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Map of the water supply system serving the City of Santa Cruz, California.

Figure 3.2

Water diversions also occur on tributaries to the San Lorenzo River. A significant diversion on Fall Creek, operated by the California American Water Company, provides water for municipal use to the Felton area. Additionally, significant diversions occur from tributaries of Boulder Creek and Clear Creek by the San Lorenzo Valley Water District and Lompico Creek by the Lompico County Water District. Each of these diversions collectively has an impact not only on local tributary stream conditions but has a cumulative impact on the middle and lower mainstem of the San Lorenzo River. There are also many individual private diversions in the watershed. At least 130 were counted in an assessment of statements of water use submitted to the State and past stream surveys of all major stream reaches (Ricker, 1979). Recent spot checks suggest that the number has not increased significantly. The potential impact of these is expected to be relatively small, given the small size of the properties and limited amount of irrigation where water is used. Assuming a maximum diversion rate of 5-15 gallons per minute (0.01-0.03 cfs.) and assuming that 10% might be operating simultaneously at any point in time, the cumulative extraction would be 0.13-0.4 cfs. (Ricker, 1979). This could present some impact, particularly on smaller streams during dry years.

Another significant source of flow reduction that is much more difficult to monitor and quantify is the use of groundwater through well pumping. Groundwater basins support springs and seeps that are a significant source of summer baseflow for the San Lorenzo River and its tributaries, especially in Bean, Zayante, and Carbonera Creeks. Much of the pumping of significant groundwater resources occurs in the Zayante and Bean Creek watersheds by the Scotts Valley Water District and the San Lorenzo Valley Water District. These groundwater basins are formed in the highly permeable, porous Santa Margarita sandstone formation and underlying Lompico formation. It is estimated that overdraft of the Scotts Valley groundwater basins has reduced summer baseflows to the creeks draining the area underlain by the Santa Margarita. These reductions significantly impact rearing conditions for juvenile steelhead by reducing baseflow during the critical summer months.

Restoration of adequate summer baseflow to streams that drain these potentially overdrafted groundwater basins would involve cooperation between the major water purveyors including the City of Santa Cruz, Scotts Valley Water District, and the San Lorenzo Valley Water District. Cooperation between these agencies may allow a system of conjunctive water use where winter high flows during above normal rainfall years could be used to replenish groundwater resources. During below normal rainfall years this water could be used by each agency for municipal uses and reduce direct removal of water from the San Lorenzo River (*see Management Recommendations – Chapter 4*).

SECTION 3.4 – SYNTHESIS OF LIMITING FACTORS

The three major factors limiting steelhead production on the San Lorenzo River are shortage of high quality rearing habitat, low quality spawning habitat in the lower and middle River, and barriers to migration. Rearing habitat quality and migration impediments are highly influenced by winter stormflow and summer baseflow conditions and the amount of fine sediment embedding pool and riffle habitat. Which factors limit steelhead populations the most depends on where you are in the watershed. Instream flow may be expected to diminish in the future, thus increasing the limiting affects of reduced streamflow on steelhead population size and restoration of coho salmon. Unless additional or alternative water supplies are exploited along with greater use of treated effluent and per capita reduction in water use, human water demand may be expected to increase with associated loss of streamflow and increased difficulty for adult salmonids to negotiate passage impediments. The impacts will be most severe during drought.

Coho salmon are more vulnerable than steelhead to sediment impacts and have more difficulty in negotiating passage problems because they spawn earlier in the winter. Coho salmon are more vulnerable to streamflow effects on rearing and food availability because they cannot inhabit fastwater areas with more food that steelhead exploit. Coho are more negatively impacted by warmer water temperature than steelhead because they inhabit slower water areas where food is less available. We suspect that the last two drought periods, 1976-77 and 1987-1992, were devastating to coho salmon and virtually eliminated them from the San Lorenzo River.

The San Lorenzo River Gorge is a formidable passage problem for the coho in years when winter rains are delayed or few in number. Water diversion during a drought year, in combination with naturally low baseflow, may prevent adult salmonid access to the upper watershed above the Gorge or at least severely limit it.

In the lower San Lorenzo River there is fastwater rearing habitat that allows juvenile fish to grow quickly, but most of the pool habitat (except for the heads of pools) is unusable due to high food requirements brought on by warm water conditions. In the middle River, steelhead growth and abundance in any given year is limited by the amount of streamflow and degree to which sedimentation has reduced water depth, escape cover, and insect production in fastwater riffle and run habitat. In both the lower and middle River, available spawning habitat and the degree of spawning success can also limit steelhead abundance. However, this may be offset by recruitment of juveniles from tributaries. In the tributaries, there appears to be adequate spawning habitat for juvenile production. The limiting factor in tributaries is the lack of high quality rearing and overwintering habitat due to the lack of deep pools and woody material that provides important escape cover and scour, all of which are related to increased sediment loads that have impaired available habitat. The tributaries appear to provide an important role in saturating the available mainstem habitat with juveniles.

Coho salmon appear to be limited by access to available spawning habitat, poor redd survival, and the lack of rearing areas in the form of large, deep, complex pools in the cooler tributaries. Unfortunately very little data exists to verify this claim. Since coho salmon spawn in the late fall and early winter, they are particularly sensitive to reduced baseflow conditions due to drought and water diversions. This can be especially true when considering the streamflow reductions from water diversions (Table 2.17) in late fall and early winter prior to significant stormflow. Streamflow conditions may often limit coho access past the Gorge to important tributary reaches where spawning and rearing habitat exists. Even when spawning is successful, a lack of deep pools with adequate escape cover limits juvenile survival through the low flow months.

The primary question that remains regarding limiting factors to salmonids in the San Lorenzo River, is which limiting factors have the most impact, and, ultimately what factors should enhancement efforts focus on. It is evident from data and discussions presented in the preceding sections, that the primary limiting factors throughout the watershed are related to available streamflow and excessive delivery of fine sediment to stream channels from poor land use practices in the watershed. . Since production of smolt-sized juveniles in reaches of the middle River appears to be the most sensitive to sediment and streamflow, we have attempted to assess the degree to which each of these factors are limiting. Table 3.6 presents the results of this analysis.

To evaluate the impacts of sedimentation on fish numbers, data from 1995 and 1999 in reaches 6 through 9 of the middle River were used. These years were used because they represent years where summer baseflow was similar (Figure 2.1), allowing for a comparison of the impacts of sedimentation while holding streamflow constant. Though the data was not analyzed statistically, there is a clear inverse relationship between juvenile steelhead numbers of all size classes and embeddedness. The results suggest that higher embeddedness values, presumably due to increased delivery of fine sediment from upland sources (Swanson and Dvorsky, 2001), coincided with a decrease in steelhead juvenile numbers, on the order of a 35-40% reduction in the middle River. Though there may have been additional factors such as number of returning adults, spawning success, overwinter survival of juveniles and annual differences in summer baseflow, it appears that sedimentation, with a resulting increase in embeddedness, has a significant impact on juvenile numbers.

Table 3.6. Estimated reduction in fish numbers in the middle reaches of the mainstem San Lorenzo River due to sedimentation (A) and streamflow (B). To assess sedimentation effects, fish population and embeddedness data was compared between 1995 and 1999 since summer baseflow conditions were similar in those years. To assess reductions in fish numbers due to streamflow, the results of the analysis presented in Section 2.5 was used.

A - Sedimentation Data and Results

Year	Reach	Size Class 1	Size Class 2&3	All Juveniles	Riffle Embeddedness	Pool Embeddedness
1995	6	8,042	22,606	30,648	38	35
	7	14,484	30,117	44,601	30	35
	8	20,322	32,676	52,998	30	40
	9	24,423	35,695	60,118	45	95
1999	6	7,397	17,107	24,504	45	100
	7	8,029	18,416	26,445	43	50
	8	10,007	19,268	29,275	43	60
	9	11,856	20,183	32,039	48	65
Percent Change from 1995 to 1999	6	-8.0	-24.3	-20.0	18.4	185.7
	7	-44.6	-38.9	-40.7	43.3	42.9
	8	-50.8	-41.0	-44.8	43.3	50.0
	9	-51.5	-43.5	-46.7	6.7	-31.6
Average % Change		-38.7	-36.9	-38.1	27.9	61.7

B - Streamflow Data and Results

		Estimated Dry Year % Reduction due to Flow Extractions			Estimated Wet year % Reduction due to Flow Extractions	
	Reach	YOY's => 75mm	All Juveniles => 75mm		YOY's => 75mm	All Juveniles => 75mm
	6	13%	12%		8%	5%
	7	22%	11%		7%	5%
	8	36%	10%		10%	8%
	9	3%	2%		3%	1%
	Combined	27%	8%		9%	6%

Streamflow impacts on steelhead juvenile numbers in the middle reaches of the San Lorenzo River are also reported in Table 3.6, based on data developed and analyzed in Section 2.5 of this report. After combining the results for all four reaches of the middle River, the results show anywhere from a 6% to 27% reduction in fish numbers due to streamflow reductions from extractions, depending on the flow year and size classes analyzed.

Generally, the results from this analysis suggest that sedimentation due to excessive erosion of fine sediment from the watershed, may be having more of an impact on juvenile production in the middle River than reductions in streamflow (except possibly in drought years)), though both are clearly important factors when considering management recommendations to improve conditions for salmonids in the middle mainstem of the San Lorenzo River. The analysis presented in Table 3.6 should be considered a rough preliminary analysis that should direct resource managers to consider erosion control measures to reduce sedimentation in the near-term with an eye at long-term maintenance and/or enhancement of streamflow to improve juvenile rearing habitat.

In order to protect and enhance salmonid production in the lower and middle River, the focus should be on streamflow maintenance enhancement, reducing fine sediment production, and improving passage conditions. Since spawning and rearing habitat in the mainstem has been degraded by the input of excessive fine sediment, a long-term goal would be to reduce fine sediment input in the watershed through erosion control efforts and sediment detention basins at important non-fish-bearing locations identified in the watershed. Passage impediments should be identified and remedied at locations where a considerable amount of high quality spawning and rearing habitat exists upstream.

Rearing habitat quality in most tributaries is limited by the shortage of deep pools with adequate escape cover. Considerable improvements could be made if large woody material were left alone in stream channels to scour deeper pools and provide more cover for juvenile salmonids. Changes need to be made to current policies and public perception that result in the cutting up and removal of woody material from the San Lorenzo River watershed. Allowing the natural recruitment and retention of in-channel large woody material is the most cost effective approach to increasing the woody material quantity. However, when streambank projects are undertaken to stop erosion, placement of in-channel woody material is beneficial at those locations.

The quality and quantity of salmonid rearing and spawning habitat could be substantially improved through maintenance and increases in streamflow. Streamflow also affects the location and size of passage impediments to migrating salmonids. Due to the water needs of an increasing human population in Santa Cruz County, solutions to water supply problems that will not seriously impact salmonids are not easy. Solutions to water shortage in the San Lorenzo River must encompass the entire watershed and include a comprehensive approach to address methods of water storage, well extraction, surface diversion, conjunctive use and groundwater replenishment. Any future water management approach must be tailored to have a positive (or least negative) effect on fishery resources.

Unless appropriate protective measures are taken, erosion, sedimentation and habitat degradation are expected to increase in association with increased road building in suburban areas, increased impermeable surfaces, higher stormflow from increased runoff and less percolation, logging without adequate protection of the riparian corridor and lack of maintenance of erosion control measures during re-entry periods, increased clearing of forested areas for development, increased use of unpaved road surfaces, continued clearing of streamside vegetation by streamside residents and continued removal or cutting of instream large woody material.

Increased development and demand for water supply from surface and groundwater within the San Lorenzo River watershed will result in further declines in streamflow and fish habitat, unless measures are implemented to mitigate those impacts through 1) timing of winter diversions to minimize impact on adult passage during dry winters, 2) increased basin groundwater storage, 3) reduced summer stream extractions, 4) reduced overall demand for extraction through water conservation, desalination and/or water reuse and 5) locating and timing of stream extractions to minimize impacts on spawning and rearing fish habitat.

In order to protect and enhance salmonid production in the lower and middle River, the focus should be on streamflow maintenance and enhancement, reducing fine sediment production, and improving passage conditions. Since spawning and rearing habitat in the mainstem has been degraded by the input of excessive fine sediment, a long-term goal would be to reduce fine sediment input in the watershed through erosion control efforts and sediment detention basins at important non-fish-bearing locations identified in the watershed. Passage impediments should be identified and remedied at locations where a considerable amount of high quality spawning and rearing habitat exists upstream.

SECTION 3.5 - RESTORATION GOALS

1. To reduce or remove limiting factors affecting juvenile steelhead.
2. To restore coho salmon habitat.
3. To establish and protect refugia where habitat conditions are particularly suitable for steelhead and/or coho.
4. To develop and promote implementation of management measures and projects that will promote the following objectives:
    a. Maximize baseflow and prevent stream reaches from drying out.
    b. Maintain water temperatures at levels suitable for steelhead and coho.
    c. Restore and maintain riparian vegetation for proper floodplain/riparian function and stream cooling.
    d. Minimize sand content in spawning gravels and minimize sediment embeddedness in rearing areas.
    e. Restore and maintain adequate levels of large woody material in the channel to sort sediment and provide habitat structure.
    f. Reduce impediments to adult fish migration, particularly those caused by culverts, dams, and other structures.

CHAPTER 4 - MANAGEMENT RECOMMENDATIONS

The management recommendations described in this chapter were developed with the goal of improving conditions for salmonids on the San Lorenzo River. They are based on review of the limiting factors to salmonid success identified in Chapter 3. Published reports and reports currently being prepared by Santa Cruz County Environmental Health and Planning Departments, the Regional Water Quality Control Board and the City of Santa Cruz were reviewed to maintain consistency between efforts designed to improve salmonid conditions in the San Lorenzo River. Those reports include the following:

- Zayante Area Sediment Source Study (Swanson Hydrology & Geomorphology, 2001)
- Draft San Lorenzo River Sediment Total Maximum Daily Load (Central Coast RWQCB, 2001)
- An Assessment of Streambed Conditions and Erosion Control Efforts in the San Lorenzo River Watershed, Santa Cruz County, California (Hecht and Kittleson, 1998)
- Draft San Lorenzo River Watershed Plan Update – Erosion and Sediment Chapter, 2001
- Draft County of Santa Cruz Implementation Plan for FishNet 4C Goals for County Policies, Planning and Management Practices, 2001
- Draft Lower San Lorenzo River and Lagoon Management Plan

The management recommendations put forth in this chapter are meant to be general, programmatic and watershed-wide. The recommendations should be reviewed and discussed in terms of how each may change or influence current policies, ordinances or programs within the County of Santa Cruz or other stakeholder agencies such as the Department of Fish and Game and National Marine Fisheries Service. More specific recommendations that identify potential habitat enhancement, erosion control, or water projects are discussed in the Project Plan, which is bound separately.

SECTION 4.1 - SEDIMENT RECOMMENDATIONS

Recommendation S-1: Focus initial sediment reduction efforts on tributaries that have high habitat value and/or impact the Middle and Lower River. Though excessive amounts of erosion and sediment delivery to the mainstem San Lorenzo River originate from the Santa Margarita Sandstone Formation in Zayante and Bean Creeks, the key reach identified in the limiting factors assessment is the Middle River, which is upstream of the Zayante confluence. Though the Lower River downstream of Zayante Creek is an important reach for steelhead production, even with substantial effort at erosion control in Bean Creek, sediment input from the sandy areas will likely remain high and the Lower River will continue to have a high sand content. Sediment reduction efforts should focus on tributaries such as Kings, Two-Bar, Boulder and Bear Creeks that deliver sediment directly to the Middle River and on Zayante and Branciforte Creeks, which have high habitat value. Sediment reduction in these tributaries will have a cumulative benefit to the Middle River, which is potentially a very productive reach of the River. A secondary focus would be to reduce sediment production from areas draining the highly erodible Santa Margarita Sandstone formation. Santa Cruz County and the City of Scotts Valley should coordinate and standardize erosion control efforts including implementation of standardized BMP's and strengthening of existing erosion control ordinances.

Recommendation S-2: Identify and repair bank failures or landslide toes that are a significant source of chronic fine sediment loads to the River. Repairs should be completed using bioengineering techniques and material, where appropriate. Habitat enhancement should be incorporated into the engineering design, where feasible. When using riprap, rocks placed at the toe of the bank should be large enough to provide cover and scour objects.

Recommendation S-3: Locations for long-term sediment spoil sites should be identified and developed. A significant amount of sediment is removed from inside ditches, and road surfaces during the winter months due to general erosion and removal of landslides. Much of this sediment is deposited temporarily in road turnouts or on the outside edge of the road surface, only to be eroded further in subsequent storm events. Establishing a site where removed sediment could be effectively disposed of would remove a significant source of fine sediment to adjacent stream channels. Potential sites could include old quarries or provide cap material for landfills. Alternatives to pursue this recommendation are currently being pursued by the Santa Cruz County Public Works Department.

Recommendation S-4: Locations for sediment catchment basins should be identified and developed, where appropriate. Though a limited number of areas may be suitable for sediment catchment basins, where feasible, they should be used to retain and remove potentially chronic fine sediment sources that significantly impacts primary stream channels. Sites should be located on smaller tributaries or first order streams that are non-fish bearing. To make sediment catchment basins successful, each site must have a maintenance plan along with a reliable source of funding to periodically remove the retained sediment.

Recommendation S-5: Increase the width of no-impact riparian buffers where appropriate to protect aquatic habitat from excessive sedimentation. There is a growing body of evidence that buffers that limit all land use activities from the riparian corridor protects aquatic ecosystems from potential disruption and degradation. No cut buffer zones were recommended for Federal lands in the Pacific Northwest (Femat, 1993). The National Marine Fisheries Service (Spence et. al., 1996) made similar recommendations for the design of Habitat Conservation Plans on non-federal lands in the same region. Under the Northwest Forest Plan, prescribed buffer widths for fish-bearing streams are a minimum of two tree heights' width, and the ManTech report concluded that buffers equal to or greater than one tree height's horizontal width were necessary, depending on which riparian functions were to be maintained. The Nevada Ecosystem Project recommended a minimum of a one-tree-height buffer (Kondolf et. al., 1996). All of these recommendations state that management activities such as logging, road building, clearing, and construction are to be avoided within riparian zones unless those activities are compatible with restoration and preservation of riparian and aquatic function. Consider amending general plan polices, riparian corridor protection ordinance, forest practice rules, and general waste discharge requirements to require wider buffers as appropriate, taking into account factors such as vegetation, slope, soil, geology, and surrounding land uses.

Recommendation S-6: Develop a County road database and emergency road repair fund. A database documenting the existing public road system in the County should be developed within a GIS framework. Once developed, periodic road assessments should be completed to document road, culvert, and ditch conditions, required repairs, estimated repair costs, and project priorities. This information could then be used to plan repair projects as funds become available as well as provide a documented system to apply for road maintenance funds through state and federal agencies. Grant funding should be pursued for existing road and culvert problems identified in the database. Repairs should be prioritized which will provide the greatest benefits for fish passage and sediment reduction. An emergency road repair fund should also be developed to supplement money available from FEMA for road repairs. FEMA often only supplies funding to replace an existing road, if damaged, even if the road is continually damaged due to a poor location or design. A supplemental fund could provide the necessary moneys to design a long-term fix to a recurrent problem. This proposed fund should also allow for focused staff resources to educate and train County employees on recent improvements in public road maintenance practices.

Recommendation S-7: Implement a sediment reduction program for private roads. Since many private roads are often substandard and numerous, a sediment reduction effort coordinated by the Santa Cruz County Resource Conservation District, could be an important element in reducing erosion from private lands. A sediment reduction program for private roads should be designed as a cooperative effort between local governments and private landowners, reducing the need for enforcement actions. A comprehensive program should include cost sharing for private road improvement, development of a private road database that would include treatment priorities and strategies, an education program, and improved enforcement.

Recommendation S-8: Reduce erosion from timber harvest roads. The Zayante Area Sediment Study and San Lorenzo River Sediment TMDL both identify timber harvest roads as a major contributor of fine-grained sediment to stream channels. A series of recommendations have been outlined in the Zayante Area Sediment Study to reduce sediment from these sources. These recommendations are important in terms of protecting salmonid habitat and include the following measures:

- Surfacing of year-round access roads that are being used for timber harvest activities,
- Up to five years of maintenance and monitoring of unsurfaced roads and skid trails. This would include seeding with appropriate grass mixes, slash packing, or mulching, development of rolling dips, and installation and maintenance of barriers to reduce trespassing,
- Identify and fix problems associated with legacy roads during the initial THP process, and
- An engineering geologist should certify grading on inner gorge slopes.

SECTION 4.2 - LARGE WOODY MATERIAL RECOMMENDATIONS

Recommendation WD-1: Large woody material should be retained, not removed, in all streams. Woody material is often removed from stream channels or cut into smaller pieces through both public and private effort because of the potential flood control, erosion, and property damage issues. Since wood is an important feature in developing good salmonid rearing and spawning habitat, attempts should be made to retain wood that is recruited to the channel unless there is an impending threat to life and property. In limited cases, large woody material jams can result in fish passage barriers. In these cases, the debris jam should be modified to allow passage but should not be removed. In order to develop a policy for woody material management, a workshop should be held to discuss the scientific, technical, and in-the-field factors that should be considered. Participants should include technical experts, maintenance staff, and policy makers involved in issues on the San Lorenzo River.

Recommendation WD-2: Implement an outreach program to educate agencies and private landowners about the benefits of large woody material. An education program needs to be established that describes the habitat needs of fish and how woody material plays an important role in their life cycle. In addition, misconceptions about the danger of large woody material in the channel need to be dispelled. The outreach program could include mailers to streamside residents, public workshops and other volunteer efforts on local creeks to get residents involved in protecting aquatic and stream resources. The existing *County Stream Care Guide* may be updated and distributed or recirculated in its present form.

Recommendation WD-3: When bridges require replacement, use free-span designs with increased flow capacity to allow for passage of large woody material. The removal or cutting of woody material from streams is often described as a means to maintain unimpeded flow through bridges. During high flow events, narrow and undersized bridges, especially those with center columns, cause log jams to form behind them. The reduced flow capacity through the bridge can result in flooding, bridge loss, severe bank erosion and potential loss of life and property. Since not all of the woody material could be removed from the system, the best way to reduce the risk is to replace existing, undersize bridges with free-span bridges that have adequate freeboard above the 100-year water surface elevation to allow passage of large roughness objects such as woody material. A cost-share program could be developed to provide public funding to private individuals or road associations to encourage upgrades to private bridges or culverts.

Recommendation WD-4: Incorporate large woody material into stream bank protection projects, where appropriate. Habitat improvements and scour elements, such as large woody material, should be incorporated into stream bank protection projects to mitigate potential impacts to salmonid habitat, as appropriate, taking into account hydrology and geomorphology at the project location. This recommendation can be cross-referenced to Recommendation S-1.

Recommendation WD-5: Encourage mixed stands of conifer and deciduous riparian forest. Much of the riparian forest occurring along streams of the San Lorenzo Watershed consist of deciduous trees such as alder, willow, sycamore, and big-leaf maple. Though these species of trees are important for nutrient cycling, shade, bank stability and sources of woody material, they often lack the size and integrity necessary to act as long-term roughness elements. Large conifer stands, such as redwood and Douglas fir adjacent to stream channels, act as founder logs that provide long-term storage of sediment and scour objects for pool development. These founder logs stabilize the grade of the stream and reduce downcutting and bank erosion over the long-term. Developing a mixed stand of deciduous and coniferous trees will be difficult to accomplish throughout the entire watershed but could be encouraged in small pieces. For example, replanting of riparian vegetation after streambank stabilization work is often dominated by willow species because they grow quickly, are easy to grow, and act as good soil stabilizers. Conversely, conifers grow slowly and are difficult to include in revegetation projects. The result is a disproportionate amount of willows. To meet the goal of encouraging mixed stands of riparian vegetation, all future streambank stabilization projects should include conifer species (primarily redwood) as a significant element in the revegetation work.

SECTION 4.3 - PASSAGE IMPEDIMENT RECOMMENDATIONS

Recommendation PI-1: Replace problematic culverts in Class I stream with bridges or appropriate cost effective designs. Poorly designed or improperly functioning culverts are the primary source of barriers to salmonids. They are problematic because they often cause downcutting on the downstream side of the culvert, result in high velocities through the culvert and have shallow water during low flow. In addition to their impact on fish passage, culverts often fail catastrophically if they are clogged by debris, result in excessive erosion adjacent and downstream. Existing culverts within the critical range of salmonids should be inventoried and assessed to determine their condition and the cost-effectiveness of their replacement. Identified culverts should be replaced with either a free-span bridge structure or an oversized culvert that is over-excavated into the bed of the channel to allow for natural channel substrate to develop through the culvert. Buried culverts require a good understanding of the local gradient conditions to avoid excessive sedimentation and culvert clogging.

Recommendation PI-2: Modify or remove flashboard dams that create passage problems for adult fish. In the past, the presence of flashboard dams on the mainstem of the San Lorenzo and other major tributaries has limited the availability of spawning and rearing habitat to adult migrating steelhead and coho. Recently, operations at many flashboard dam facilities have been modified to account for the timing of salmonid migration. Though this is a step in the right direction, the infrastructure at each site, consisting of concrete aprons and abutments, needs to be assessed and modified to improve conditions for salmonid migration. Specific recommendations with regards to flashboard dams are as follows:

- Flashboard dams that could create problems for adult or juvenile fish movement should not be installed before June 15th.
- Bypass flows should be maintained during filling of the pools to prevent dewatering downstream.
- Removal of flashboard dams in the fall should be gradual enough to prevent stranding, displacement, or injury to fish.
- Evaluate and mitigate on a case-by-case basis other impacts of flashboard dams.

Recommendation PI-3: Inventory, maintain, and/or modify existing fish ladders to allow passage under most flow conditions. Fish ladders that allow passage over barriers currently exist on several tributaries to the San Lorenzo River, including Fall, Zayante, Lompico, Branciforte and Love Creeks. These existing fish ladders need to be inventoried and assessed for adequacy of passage, modified if necessary, and continually maintained to assure that they are allowing fish passage under most flow conditions. The timing of maintenance checks would vary depending on the severity of the flows during the winter season.

Recommendation PI-4: Consider modifying natural passage impediments in the mainstem of the San Lorenzo River. In some cases, natural conditions may exist that limit passage to salmonids including natural bedrock shelves, boulder fields or wide, high-gradient riffles. Several of these potential passage impediments occur in the Lower River Gorge, potentially limiting or delaying salmonid access to a large majority of potential spawning and rearing habitat in drier winters. Allowing minor modifications to these natural impediments to provide passage under most flow conditions could mitigate for winter flow reduction impacts. Implementation of this recommendation must include close cooperation with natural resource agencies such as CDFG and NOAA Fisheries.

Recommendation PI-5: Support the City of Santa Cruz to provide adult and smolt passage through the Lower San Lorenzo River and the flood control channel on Branciforte Creek according to recommendations in the Lower San Lorenzo River and Lagoon Management Plan. City of Santa Cruz should continue to work with federal and state agencies to pursue long-term solutions for providing steelhead passage through the flood control channel on Branciforte Creek.

SECTION 4.4 - STREAMFLOW RECOMMENDATIONS

Recommendation SF-1: Continue to prohibit new or increased summer diversions. Water resources in the San Lorenzo watershed during the summer months are already scarce. This recommendation would encourage the prohibition of additional summer water diversions at existing diversion sites and new sites to maintain summer flows at a level adequate to sustain existing and future salmonid populations.

Recommendation SF-2: Conduct water supply pumping overnight to the extent feasible, particularly for upstream diversions. Streamflow is often the highest during the nighttime hours as evaporation and transpiration are reduced. This is also the period of time when fish are relatively inactive and are usually not feeding. During the low-flow summer months, water that is being stored off-channel for use during peak demand periods should be diverted primarily between the hours of 9pm and 5am to the extent that this is feasible. Municipal water suppliers should assess their operations during low-flow summer months based on this recommendation.

Recommendation SF-3: Develop critical flow levels for stream reaches impacted by water diversions. Minimum flow requirements should be developed for reaches impacted by water diversions. Critical flow values would include minimum bypass flow requirements for upstream adult migration during winter months and rearing habitat conditions in the summer and fall months.

Recommendation SF-4: Use developed exceedence probability curves to predict late summer flow conditions. Exceedence probability curves were developed for several locations in the San Lorenzo watershed based on historic flow data for wet, average, dry, and drought conditions. This information, specifically the data developed for the Big Trees gage at Felton (USGS Gage #11160500), can be used to determine the range of flows that could be expected in the low-flow summer and fall months. If predicted flows are below a level considered critical to maintain viable rearing habitat for salmonids, measures to reduce water consumption can be initiated by municipal water suppliers in the San Lorenzo Watershed through conservation programs.

Recommendation SF-5: Study the feasibility of reconfiguring the water supply system in the San Lorenzo River Watershed to increase summer flow. The focus of any future expansion of municipal water supplies extracted from the San Lorenzo River should be on storage of excess high winter flows, maintenance or enhancement of summer flow, and extraction of water at a low point in the water system (e.g. – Tait Street diversion). A potential scenario to achieve this goal may be to increase the storage capacity of Loch Lomond Reservoir by raising the dam. Water rights could then be consolidated throughout the watershed by transferring the water right to Loch Lomond, which could potentially store more winter flow through the use of the Felton Diversion. The stored water would then be released into adjacent tributaries to Loch Lomond (e.g. Bear or Lompico Creeks) and collected at Tait for distribution. Though this plan would be costly in the short-term, in the long-term it would provide a more reliable source of water through increased winter storage and provide benefits to fish and other aquatic organisms. An additional strategy would be to take advantage of high winter flows in wet years to actively or passively recharge existing groundwater basins that have been drawn down (i.e. – Santa Margarita aquifer). Recharged water could then be utilized during low flow and drought periods to limit impacts to streamflow. Conjunctive use of wells under critically low streamflow conditions instead of direct stream diversion in the San Lorenzo Valley should be evaluated. Options for wastewater reclamation should also be fully evaluated and utilized, where feasible. The feasibility of this and other alternatives should be studied carefully under all long-range water supply planning scenarios.

Recommendation SF-6: Operations at the Felton Diversion should be scheduled to minimize impact on migrating salmonids. Steelhead and coho salmon predominately migrate at night. Operation of the Felton Diversion pumps during low flow years should be timed to allow an adequate bypass flow to pass through the Lower River Gorge during the nighttime hours to increase the likelihood of fish migration over documented passage impediments in the Rincon and Four Rock areas (see Tables 3.4 and 3.5). These passage impediments require upwards of 50-70 cfs for salmonids to get past. Current bypass requirements are only 20-25 cfs, which does not appear to be adequate to get past all downstream barriers. Additionally, it is not known how much flow is needed to maintain the Rivermouth in an open condition during very dry years to allow spring time smolt outmigration. We recommend the following schedule be integrated into existing diversion operation at Felton:

- Between January 1 and April 1 of each year, the Felton Diversion will allow a 70 cfs minimum bypass for three consecutive nights between the hours of 9pm and 9am.
- The minimum bypass of 70 cfs for three consecutive nights should occur at least monthly within the January 1 to April 1 timeframe.
- If natural flows do not exceed 70 cfs, the natural flow would be bypassed, without requiring the City to reduce the pool volume behind the diversion dam.
- Pursue measures to modify barriers to reduce the amount of flow need for migration through the Lower River Gorge.
- From April 1 to June 1 each year, allow sufficient bypass at Felton and Tait Street to maintain hydraulic continuity to the estuary and an open sandbar to the ocean.

Recommendation SF-7: Maximize the storage capabilities of Loch Lomond by protecting the existing pool volume through a land management program to reduce sediment input and through potential adjustments in the pumping and storage operations. The storage volume in Loch Lomond should be protected to minimize the future need for large surface water storage projects on the San Lorenzo River. Protection of the storage volume can be accomplished through proper watershed management in the Newell Creek drainage to minimize sediment input to Newell Creek upstream of Loch Lomond. This action will require coordination between the City of Santa Cruz, who owns Loch Lomond and the surrounding land, and private landowners in the headwaters of Newell Creek. The City is currently developing a watershed management plan for their land in the Newell Creek watershed to protect source water quality and reduce sedimentation in Loch Lomond. Initial recommendations in the plan include cessation of logging, putting non-essential roads to bed, limiting high impact land uses in the watershed, and acquiring properties or conservation easements upstream of the City's property to protect the water supply and improve water quality. If logging on City lands is to continue, it should be done in a restrictive manner to avoid additional erosion and sedimentation. No cut/ no entry buffers along all watercourses are essential. Additionally, more flexible provisions for reservoir storage, use and pumping from Felton Diversion Dam should be considered to maximize the potential for storage and use of excess winter flows. This could include modifying the water right to allow more direct diversion of water from Loch Lomond to make more storage available. The feasibility of raising the level of Loch Lomond to allow for more storage of winter flow during moderate and wet years should also be evaluated.

Recommendation SF-8: In conjunction with other measures to maintain and enhance water supply, seek to increase upstream baseflows and manage operations at the Tait Street Diversion to maintain a minimum bypass into the Lower River and Lagoon. The existing water right at the Tait Street Diversion, which is operated by the City of Santa Cruz, allows a diversion of up to 12.2 cfs with no minimum bypass. Maintaining a minimum bypass flow in the Lower River is critical to out-migration of steelhead and coho salmon smolts, movement of young steelhead into the lagoon, and maintenance of a freshwater lagoon for juvenile rearing. The recently published Lower San Lorenzo River and Lagoon Management Plan (LSLRLMP) provides recommendations for bypass flows and other measures to provide fast-water feeding habitat in the Lower River and quick filling of the lagoon in the event of a breach and subsequent closure during critical rearing periods. From April 1 to June 1 each year, a sufficient bypass should be provided to maintain hydraulic continuity to the estuary and maintain an open sandbar to the ocean. Protection of bypass flows could be done in conjunction with modifying City water rights for increased diversion of excess spring and winter flows at Loch Lomond and/or Tait Street. Measures to increase upstream baseflows will also facilitate an adequate bypass below Tait Street while maintaining City supply.

Recommendation SF-9: Provide for a healthy lagoon that will support large numbers of rearing steelhead through implementation of the Lower San Lorenzo and Lagoon Management Plan. Due to the high food production potential of coastal lagoons, they can act as high quality rearing habitat for juvenile steelhead, allowing them to grow quickly to larger smolt sizes that increase survival rates in the ocean. Coastal lagoons have also been severely degraded through encroachment, water diversions, degradation of water quality, and periodic human-caused breaching of the sand bar that develops annually at the mouth (see LSLRLMP and the companion report, Biogeochemical Function of the San Lorenzo River Lagoon (Beck, 2003) for more information). The City should continue to pursue a strategy for maintaining a freshwater lagoon at water levels that are optimal for fishery habitat without creating other adverse impacts and for implementation of the LSLRMP to improve the biological integrity of the lagoon to support rearing steelhead.

SECTION 4.5 – MONITORING AND GENERAL RESEARCH RECOMMENDATIONS

Recommendation GR-1: Continue monitoring habitat and population conditions in the San Lorenzo River and tributaries on an annual basis. In order to assess improvements or declines in population numbers and habitat conditions and to further resolve primary limiting factors on salmonid production we recommend continued monitoring. Monitoring should include standard habitat assessment and juvenile population censusing based on protocols outlined in the California Salmonid Stream Habitat Restoration Manual (Flosi, et. al., 1998) and developed by the National Marine Fisheries Service and experienced researchers in the region. Add random sampling if funding is made available to provide measure of statistical confidence of population estimates.

Recommendation GR-2: Conduct biannual spawning habitat surveys in the Middle River. Spawning habitat quality was identified as a limiting factor in the Middle reaches of the San Lorenzo River and sediment control efforts in the upper tributaries may potentially improve spawning conditions there. Since very little quantitative information exists on the extent to which spawning habitat quality impacts fry production, biannual surveys to quantify available spawning habitat is an important component of an overall monitoring plan for reaches of the San Lorenzo River where the sand component may potentially be reduced.

Recommendation GR-3: Improve the adult fish counting facility at the Felton Diversion Dam and consider implementing other fish assessment programs. To make this a more effective program, the efficiency and/or infrastructure used to count spawning steelhead adults would need to be improved. An automatic counting device similar to the one used at San Clemente Dam on the Carmel River could be installed. This device would reduce the stress on fish of the present trapping process and the labor involved in working the present trap. Periodic trapping could continue to obtain other data such as the ratio of wild to hatchery origin adults and size distribution. Other measures would be needed to identify fish species, however, if coho were reintroduced. Consider other assessment efforts, including scale analysis, mark and recapture methods to assess in basin movement, and monitoring for downstream smolt migrants if feasible methods can be developed and funding is made available for this very challenging pursuit.

Recommendation GR-4: Monitor large woody material density and recruitment potential. The effectiveness of recommendations to increase the size and abundance of woody material in and available to the channel to create habitat and provide sediment storage capacity should be monitored. Monitoring should occur on a three-year cycle using appropriate methods described in the *California Salmonid Stream Habitat Restoration Manual* (Flosi, et. al., 1998) or other relevant monitoring protocols.

Recommendation GR-5: Monitor pool volume at key reaches in the watershed using V* or other appropriate measures. Due to the lower velocities present in pools when sediment deposition is occurring, measuring pool volume through time or similarly, the total pool volume that is lost due to accumulation of fine-grained sediment is an excellent measure of changes in sediment conditions in the reach. This parameter should be measured on an annual basis. This method has relevance to habitat quality in the Upper River and tributaries where juvenile steelhead rear primarily in pools. Monitoring of fastwater habitat would be most appropriate in the Lower and Middle River.

Recommendation GR-6: Expand existing streamflow monitoring efforts during low flow season at key locations on the San Lorenzo and tributaries. The quantity of streamflow during low flow summer and fall months have been identified as a key limiting factor in many areas, yet little is known about the daily or seasonal variation in flow conditions on portions of the mainstem San Lorenzo and in many of the tributaries. Many people in the scientific community and especially the USGS are alarmed by the widespread loss of hydrological monitoring networks over the last 10-15 years throughout most of North America (Lanfear and Hirsch, 1999; Rodda, 1998). In a region where water resources are overtaxed and municipal water must be supplied while protecting threatened fish species, continuous, long-term monitoring of streamflow is a critical component of any future water resource plan. The following recommendations, if implemented, will provide data to more completely monitor streamflow so that better predictions of impacts to streamflow from water extraction can be made and so that better relationships may be developed between streamflow and juvenile steelhead densities.

- Gage tributaries to Boulder Creek and Clear Creek that are not currently gaged by the San Lorenzo Valley Water District to determine the portion of streamflow that is diverted for municipal water supply.
- Re-establish a stream gage on lower Boulder Creek at Highway 9.
- Establish a stream gage at the mouth of Bean Creek near the confluence with Zayante Creek.
- Establish a stream gage on Zayante Creek, just upstream of the confluence with Bean Creek, at Woodwardia.
- Take monthly flow measurements in the summer and fall on Bean and Zayante Creeks just upstream of the contact between the Santa Margarita and Monterey formations.
- Annually measure the end-of-the-summer baseflow at fish sampling locations in the San Lorenzo River watershed, prior to the first fall stormflow.

If permanent streamflow gages are not feasible at some of these sites, gages can be established during the low flow summer and fall months that can be removed during the winter months.

Recommendation GR-7: Monitor water temperature during the summer in key reaches to determine if restoration goals for temperature are being met.

Recommendation GR-8: Monitor and evaluate the impacts of invasive non-native species on the riparian corridor and aquatic habitat. Invasive non-native species may reduce the food value of leaf litter entering the stream environment or may have other adverse impacts on aquatic resources. Research could be conducted locally or monitored from other areas to provide greater insight into this potential impact. Consider prohibiting the sale of non-native invasives or other measures to reduce their spread in the watershed.

CHAPTER 5 - MONITORING PLAN

SECTION 5.1 - AQUATIC CONDITIONS

Aquatic habitat conditions and fish populations have been monitored annually since 1994 by D.W. Alley and Associates. Initially, data was only collected from the mainstem. Beginning in 1998 the effort was expanded to include 10 primary tributaries to the San Lorenzo River to obtain a more accurate count of the steelhead population and to better estimate an index of adult returns. We recommend continuing habitat and population surveys on the San Lorenzo River in order to monitor future trends in steelhead numbers and evaluate whether coho salmon could be restored.

Table 5.1 summarizes the recommended monitoring plan for the San Lorenzo River.

SECTION 5.2 - GEOMORPHIC/CHANNEL/SEDIMENT CONDITIONS

The presence of excessive fine sediment loads in the San Lorenzo River have been identified as a major contributing factor in the apparent decline in steelhead and coho salmon numbers. Excessive fine sediment input impacts all phases of the salmonid life cycle including spawning, fry emergence and rearing of juvenile and smolt-size fish by filling available habitat and burying spawning gravels. Impacts are present throughout the watershed in both tributaries and the mainstem.

In addition to excessive inputs of fine sediment, geomorphic and channel conditions have been impacted throughout the watershed by road building, removal of bank stabilizing riparian vegetation, channel straightening, loss of structural elements such as large woody material and higher peak flows due to increases in impervious surfaces. These impacts have reduced the geomorphic functioning of the system by reducing hydraulic variability, inducing channel downcutting and limiting in-channel and floodplain storage of sediment. In particular, the lack of large woody material reduces local scour and pool development and produces velocity heterogeneity that allows sorting of fine-grained sediment from gravels.

Though the timeframe for in-channel and floodplain sediment storage can be on the order of 10’s to 1,000’s of years, much of the fine-sediment that fills pools, smothers gravels and reduces overall biological productivity is transient in nature. Therefore, reductions in delivery should result in significant improvements in pool volume and gravel quality that are measurable and quantifiable. Conversely, some channel characteristics and habitat parameters such as entrenchment, bank stability, bankfull width and depth, and woody material density and recruitment require longer periods of time to respond to improved conditions in the watershed or policy changes.

To account for issues such as response time, data resolution, and scales of measurement, we have developed a comprehensive monitoring plan that includes multiple variables, a description of the importance of the variable, literature references defining the method of measurement, and the frequency of measurement required. Each of these components is presented in Table 5.2.

It is expected that several agencies would contribute the time and materials required to effectively monitor conditions on the San Lorenzo. These agencies would include Santa Cruz County Environmental Health, Regional Water Quality Control Board, the City of Santa Cruz, and the San Lorenzo Valley Water District. Since several agencies would be collecting monitoring parameter data, a central clearinghouse should be established for compilation and storage. This will require cooperation between agency stakeholders and development of a data management plan.

Table 5.1. Aquatic Conditions Monitoring Plan

Monitoring Parameter	Description	Frequency of Measurement	Protocol
In-channel large woody material density	Large woody material (>1 ft diameter, > 6 ft in length) provides important sediment storage and habitat generating elements. Woody material should be counted within the active channel (bankfull to bankfull) and not include recruitment.	Should be measured every 3-5 years or in the summer following a large flow event. Woody material surveys could be combined with habitat or bank surveys.	Flosi et. al. (1998)
Habitat Assessment	A habitat assessment consists of walking target stream channels and characterizing the habitat. This includes a description of the habitat type, geometry, substrate conditions, and other factors that influence the quality of each habitat.	Habitat conditions should continue to be monitored on an annual basis. Data currently exists from 1994 to present. Adding to that dataset on an annual basis will provide a good dataset to understand the relationship between fish populations, habitat conditions, and physical factors in the watershed.	Flosi et. al. (1998)
Fish population estimate	A basin-wide fish population estimate involves intensive direct sampling of the habitat at representative sites that can be used to extrapolate to the entire watershed. Sampling can involve either electrofishing or snorkeling depending on pool depth, etc.	A population assessment should be conducted annually to develop a data series that can be related back to physical conditions such as sediment inputs or climatic factors.	Flosi et. al. (1998)
Spawning habitat surveys	The Middle River was identified as an area that lacked sufficient spawning habitat based on YOY numbers. To quantify the magnitude to which this factor may be limiting, spawning habitat surveys should be conducted which involves walking the Middle River and quantifying the total area that can act as potential spawning sites.	Initially, the spawning habitat survey should be conducted biannually to develop a baseline dataset. Future surveys could be more infrequent.	Flosi et. al. (1998)

Table 5.2. Geomorphic and Sediment Conditions Monitoring Plan

Monitoring Parameter	Description	Numeric Target	Frequency of Measurement	Protocol
Discrete Measurements				
Percent fines <0.85	Should be measured at tail of pools, head of riffles where spawning gravels are present to determine spawning gravel quality.	≤ 21% by wet volume using a McNeil (bulk) sampler.	Biannually during low-flow period. Five to seven samples should be collected along the reach at randomly selected locations to obtain an average. Data collection should be coordinated with a spawning survey to identify potential sampling locations.	McNeil and Ahnell (1964)
Percent fines < 6 mm	Should be measured at tail of pools, head of riffles where spawning gravels are present to determine spawning gravel quality.	≤ 30% by wet volume using a McNeil (bulk) sampler.	Biannually during low-flow period. Five to seven samples should be collected along the reach at randomly selected locations to obtain an average. Data collection should be coordinated with a spawning survey to identify potential sampling locations.	McNeil and Ahnell (1964)
Residual Pool Volume (V*)	V* is defined as the fraction of the total pool volume that is filled with fine sediment.	≤ 0.21 (mean) and ≤ 0.45 (max) using V*.	Biannually during low flow period. V* is very intensive a required random sampling of 7-10 pools per reach. An alternative method would be to repeat samples at persistent pools, 1-2 per reach depending on their size.	Lisle and Hilton (1992)
Median particle size diameter (D_{50}) from pool tail or riffle crest	Pebble counts are a standard technique used to depict surface bed conditions and should be measured within the wetted channel width to estimate grain-size distribution of spawning beds.	> 37 mm minimum and > 69 mm maximum.	Biannually during low-flow periods. Five to seven samples should be collected along the reach at randomly selected locations to obtain an average. Data collection should be coordinated with a spawning survey to identify potential sampling locations.	Wolman (1954)
Pool Embeddedness	Pool Embeddedness relates to available escape cover for juveniles under cobbles and boulders (> 100 mm in diameter). Highly embedded pools support less escape cover due to siltation of interstices. This variable is an estimate averaged over the entire pool.	≤ 25 percent based on ocular estimate	Biannually during low-flow periods. This variable should be estimated at the same locations where V* is measured as a complement to data collected from other methods.	Flosi et. al. (1998)

Monitoring Parameter	Description	Numeric Target	Frequency of Measurement	Protocol
Estimated percent fines in pools	This variable provides another piece of valuable information that can be quickly estimated. The combination of V*, Pool Embeddedness, and estimated percent fines will provide a complete picture of the impairing sediment characteristics of the pool.	≤ 30% percent based on ocular estimate	Biannually during low-flow periods. This variable should be estimated at the same locations where V* is measured as a complement to data collected from other methods.	Flosi et. al. (1998)
Reach-scale Measurements				
Bankfull width and depth	Defined as the flow at which the water begins to access the floodplain. Bankfull is hypothesized to occur during the 1.5 – 2.33 year flood. Often indicated by a break in slope from a streambank to a floodplain depositional surface.	N/A. Should be compared to reference reaches or historic conditions to determine impacts or improvements	An initial survey should be conducted on the reach of interest defining these variables. Surveys should be repeated every 5 years.	Rosgen (1994), Flosi et. al. (1998)
Channel Entrenchment	The ratio between the bankfull width and the width at 2 times the bankfull depth. Is an indicator of the confinement of the channel and the width of the floodplain surface. Some channels can become unnaturally entrenched causing excessive bank erosion and reduced sediment deposition on floodplain surfaces.	N/A. Should be compared to reference reaches or historic conditions to determine impacts or improvements.	An initial survey should be conducted on the reach of interest defining these variables. Surveys should be repeated every 5 years.	Rosgen (1994), Flosi et. al. (1998)

Monitoring Parameter	Description	Numeric Target	Frequency of Measurement	Protocol
Rosgen Channel Type	Rosgen channel type is based on a combination of gradient, dominant substrate, bankfull width to depth ratio, and channel entrenchment. The Rosgen classification is the most common system used on streams.	N/A. Should be compared to reference reaches or historic conditions to determine impacts or improvements.	An initial survey should be conducted on the reach of interest defining these variables. Surveys should be repeated every 5 years.	Rosgen (1994), Flosi et. al. (1998)
Linear distance of eroded banks	Measured distance of actively eroding bank length. Height and assumed cause should also be noted for each discrete bank failure.	N/A. Improvements could be measured through time. Problematic areas could be targeted for restoration.	An initial survey should be conducted on the reach of interest defining these variables. Surveys should be repeated every 5 years.	Rosgen (1994), Flosi et. al. (1998)
Linear distance of modified banks	Measured distance of modified bank length. Type of modification should be noted.	N/A. Improvements could be measured through time. Problematic areas could be targeted for restoration.	An initial survey should be conducted on the reach of interest defining these variables. Surveys should be repeated every 5 years.	Rosgen (1994), Flosi et. al. (1998)
In-channel large woody material density	Large woody material (>1 ft diameter, > 6 ft in length) provides important sediment storage and habitat generating elements. Woody material should be counted within the active channel (bankfull to bankfull) and not include recruitment.		Should be measured every 3-5 years or in the summer following a large flow event. Woody material surveys could be combined with habitat or bank surveys.	Flosi et. al. (1998)

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APPENDIX A – METHODS FOR FISH HABITAT ASSESSMENT AND SALMONID POPULATION CENSUSING AND STATISTICAL ANALYSIS OF POPULATION DATA

DETAILED METHODS DESCRIPTION

Habitat typing by reach that began in 1997 in the mainstem and 1998 in tributaries improved extrapolation from fish densities at individual sites to reach densities. Tributary sites were sampled in all of the years, and changes in their habitat conditions and fish densities were assessed. However, tributaries were not sampled by reach with habitat typing and production estimates until 1998. Since these estimates are essential in assessing and understanding overall population trends and watershed-wide habitat conditions, many of the analyses and conclusions are based on three years of data (1998-2001). Interesting impacts of the El Niño storm events of 1997-98 and thereafter were detected. However, only limited conclusions were forthcoming for the watershed as a whole, considering the complicated, multi-year life cycle that characterizes steelhead and coho populations.

The methods used to conduct habitat surveys and population estimates are consistent with standard methods outlined in the California Department of Fish and Game's California Salmonid Stream Habitat Restoration Manual (Flosi et al., 1998). Deviations from the method described in the CDFG manual include measurements of escape cover, estimation of an index of adult returns, and embeddedness. Standard methods will be generally discussed with deviations being discussed in further detail. For more information about a particular method please consult the CDFG manual or refer to the monitoring reports by D.W. ALLEY and Associates (1995-2002).

Reach Delineations

The mainstem of the San Lorenzo River was divided into 12 reaches with the breaks selected based on changes in channel conditions, stream gradient, or hydrologic conditions (Figure 1.2). At a coarser scale, the mainstem of the river can be divided into the Lower, Middle, and Upper River with the divisions occurring at Zayante Creek confluence (between reaches 5 and 6) and at the confluence of Boulder Creek (between reaches 9 and 10).

Nine tributaries were included in the monitoring effort including Branciforte, Carbonera, Zayante, Bean, Fall, Newell, Boulder, Bear, and Kings creeks (Figure 1.1). Tributaries were also divided into multiple reaches for the purpose of the habitat assessment and juvenile population estimates, though this report analysis only considers conditions at the tributary level. The uppermost extent of anadromy was determined for each tributary based on known barriers, topographic map assessment, or upstream extent of perennially flowing water during drier years. However, in Zayante Creek the upper boundary of study was the Mt. Charlie Gulch confluence, though steelhead use habitat further upstream in all but the driest years.

Habitat Quality Assessment

Habitat surveys were conducted on all reaches of the San Lorenzo (1-12) and on the 9 tributaries defined for the study from their confluence with the San Lorenzo River to the upstream end of anadromy by sub-sampling a portion of each reach. Approximately ½ mile segments were habitat typed within each reach. Habitat surveys were conducted using Level IV of the California Salmonid Stream Habitat Restoration Manual (Flosi et al., 1998) with certain modifications to specific parameters to better reflect existing habitat conditions. Modified parameters included instream escape cover, total habitat unit embeddedness and canopy closure.

Instream shelter, referred to as escape cover, was expressed for fish-sampled habitats as the ratio of the linear distance under submerged objects within the habitat that fish greater than 75 mm Standard Length (SL) could hide under, divided by the perimeter distance of the habitat. Escape cover for a habitat type within a reach was also expressed as a ratio of the linear distance under submerged objects within the habitat type that fish greater than 75 mm Standard Length (SL) could hide under, divided by the total length of that habitat type surveyed within the reach. Objects considered as escape cover include unembedded boulders, submerged woody debris, undercut banks, overhanging vegetation, bubble curtains and other man-made objects that allow the fish to hide completely from overhead view.

Total habitat embeddedness was measured for each habitat, including pools. As part of the habitat typing method, visual estimates of substrate composition and embeddedness were made for surveyed habitats. The observer looks at the habitat and makes mental estimates based on what he sees with his trained eye. Therefore, these estimates are somewhat subjective, with consistency between data collectors requiring calibration from one to the other. An assumption is that the same data collector will be consistent in visual estimates from habitat to habitat and from year to year. Another assumption is that if more than one data collector contributes to the same study, the original observer trains the others to be consistent with the original data collector's visual estimates. In this study, Alley has collected all habitat data through the years except in 1999 and 2000, when 6 reaches were assigned to Walter Heady in both years. Heady was calibrated to Alley for visual estimates each year.

Prior to 1999, embeddedness was visually estimated as the percent that cobbles and boulders greater than 100 mm in median diameter were buried with fine sediment. From 1999 to the present, the minimum particle size cutoff was increased to 150 mm. Embeddedness is an indicator of the loss of escape cover due to sedimentation of larger streambed elements and is a good indicator of the level of impact that cumulative watershed impacts leading to sedimentation are having on habitat quality.

For 1994-98, tree canopy closure was measured at fish-sampling sites using a densiometer. Canopy closure was not measured in 1999-2000 because riparian cover was deemed similar to previous years. Tree canopy cover may be underestimated relative to peak summer conditions since sampling was conducted in September and early October when some leaf drop may have occurred.

Juvenile Population Estimates

Based on the habitat typing conducted in each reach prior to fish sampling, representative habitat units were selected for sampling to determine fish densities by habitat type, using a representative reach extrapolation technique (RRET). In mainstem reaches of the lower and middle River, riffles and runs that were close to the average width and depth for the reach were sampled by electrofishing. Pools in these reaches were divided into long pools (greater than 200 feet long) and short pools (less than 200 feet) and at least one pool of each size class was either snorkel censused or electrofished. For reaches in the upper River and all tributaries, the location of representative pools determined the non-pool habitat that was sampled. Pools were deemed representative if they had escape cover ratios and water depths similar to the average values for all pools in the habitat typed segment of each reach. This was termed the Average Habitat Quality Method (AHQ) of sampling. Therefore, pools that were much deeper or much shallower than average or had much less or much more escape cover than average were not sampled. Once the pools were chosen for electrofishing, adjacent riffles, step-runs, runs and glides were sampled, as well. In these smaller channel situations, these latter habitat types showed great similarity between individual habitats of those types. Namely, riffles runs, step-runs and glides were all about the same in depth and escape cover. Since habitat conditions may change from year to year and locations of individual habitat units may shift depending on winter storm conditions, sampled units may also change.

An assumption in this method is that fish sampling of representative habitat will reflect the mean habitat quality for the reach and provide average fish densities for specific habitat types throughout the reach. It was assumed that juveniles did not move from the vicinity where they were captured during the growing season. This was reasonable because it has been observed at sites in close proximity, but one being in the larger mainstem and one being in a smaller tributary, juveniles are consistently larger in the mainstem. In addition, Davis (1995) marked juvenile steelhead in June in Waddell Creek and captured the same fish in the same habitats they had been marked in from June to September during a study of growth rates in different habitats. Another assumption is that there is a correlation between fish density and habitat quality in that better habitat has more fish. Past modeling has indicated that densities of yearling-sized juveniles are well correlated with water depth and escape cover (Smith 1984). In this case, yearling-sized fish are smolt-sized =>75 mm Standard Length. Alley (unpublished) has also developed a predictive model for yearling-sized juvenile steelhead based on the habitat parameters of water depth and escape cover from empirical data collected in Santa Rosa Creek, San Luis Obispo County. The fish density for each habitat type was estimated as the number of fish per linear foot of that habitat type. Thus, the number of fish estimated for each censused pool in the reach was divided by the linear feet of pool habitat sampled.

Once fish densities were determined for representative habitat types within a reach, they were incorporated with the proportion of habitat types within the reach to extrapolate to a fish population estimate for the reach. Then population estimates for tributaries or segments of the mainstem by adding up the reach estimates.

Populations were sampled using a combination of electrofishing and snorkeling. Either a 2-pass (Knable, 1978) or 3-pass depletion method of electrofishing was used to sample fish populations for the 1994 and 1995 survey years. After 1995, the 3-pass method was used exclusively for electrofishing sampling units that could be adequately sampled with the backpack equipment, and block nets were used to isolate sampled habitats. If poor depletion occurred, 4 passes were made in some habitats. Deeper pools in the lower and middle mainstem were sampled using standard snorkeling techniques from 1998 onward.

As an example of sampling intensity, in 2000, a total of 17 mainstem sampling sites were electrofished in 13 reaches, representing 3.3% of the 26.7 miles of mainstem, and another 3.5% (18 deep pools) were snorkel-censused. A total of 20 tributary sites were electrofished in 20 tributary reaches, representing 2.7% of the 33.7 miles of 9 tributaries being censused.

Statistical Analysis of Annual Differences in Juvenile Densities at Sampling Sites in 2000 and 2001

The trend in fish densities between 2000 and 2001 was analyzed by using a paired t-test (Snedecor and Cochran 1967; Sokal and Rohlf, 1995) on the fish densities of 34 sites for each age and size class (SC1,SC2,AC1,AC2). Site 14c (upper Bean Creek) was not used because the specific site was changed between 2000 and 2001 because the site location in 2000 was dry in 2001. The paired t-test is among the most powerful of statistical tests. This test was possible because the data were taken at the same site each year as opposed to re-randomizing each year. The null hypothesis for the test was that among all sites, the site-by-site difference from year 2000 to 2001 was zero. The lower mainstem River (Sites 0b-9) was analyzed in a separate t-test and the upper mainstem plus the tributaries (Sites 10-21b) in a separate t-test. The p-value is the probability that the data (fish densities) are consistent with that hypothesis. Hence a p-value of .05 means that there is only a 5% probability that the difference between densities was zero. A 2-tailed test means that an increase or a decrease was tested for. The confidence limits tell us the limits of where the true mean difference was. The 95% confidence interval means that there is a 95% probability that the true mean difference lies between these limits. If these limits included zero, then it could not be ruled out that there was no difference between 2000 and 2001 densities. The 95% confidence limits are standard and a p-value of < 0.05 is considered significant.

Age and Size Class Divisions

Juvenile population estimates were divided into year classes and size classes. Separation of sampled fish into a young-of-the-year (YOY) and yearling and older age classes provided important information about the growth rates of juveniles in different parts of the watershed. YOY fish represent fish in the 0+ age class while yearling and older fish are mostly in the 1+ age class with a few in the 2+ age class. Because growth rate is faster in middle and lower River reaches compared to tributaries, a particular size cutoff could not be used as a threshold to distinguish between the two age classes. The age class break was determined by analyzing a length frequency distribution (histogram) of captured fish at each sampling site. Typically along a length continuum of 5 mm length increments, there was a gap between lengths of YOY fish and the lengths of yearling in which little or no fish were captured at intermediate lengths. This gap was used to divide age classes. Using this method, two distinct age categories could be identified as individual peaks in the histograms. Yearling fish were much larger in the lower and middle River than in the upper River and tributaries. YOY's in the mainstem could reach the size of yearlings from the tributaries in their first growing season.

Juvenile population estimates were divided into size classes as a way to census the number of smolt-sized fish (Size Classes 2 and 3) produced that would out-migrate to the ocean over the winter and spring after sampling. These are the most important juveniles in terms of producing adult returns. Smolt-size fish were censused separately from smaller fish (Size Class 1) that would require two more winters before out-migrating. Based on out-migrant smolt trapping data from the San Lorenzo in 1987-89, the size cutoff for smolt size was 75 mm SL used to separate Size Class 1 from smolt-sized Size Class 2 and 3 fish (Smith and Alley, unpublished data). In addition, population estimates in terms of 3 size classes could be inputted to a model to predict an index of adult returns. From the San Lorenzo trapping study in 1987, it was found that 94% of 147 randomly picked 1-year old smolts were 75 mm SL or more in length. In 1989 it was found that 99% of 100 randomly picked 1-year old smolts were 75 mm SL or more in length. Therefore, nearly all juveniles have to be at least 75 mm SL to smolt. Of the 2-year old smolts, it was found that 95% were at least 60 mm SL at their first annulus, indicating that juveniles less than 60 mm SL had considerable trouble overwintering. Smith also looked at scales of 200 adult steelhead from Waddell Creek during three winters, 1991-92 through 1993-94. He found that 97% of the first year smolts were 75 mm SL or longer when they smolted.

Predicting Adult Returns

An effective trapping program for spawning adults from which to estimate adult returns has been lacking. Therefore, the Dettman population model (Kelley and Dettman, 1987) has been used to provide an index of adult returns on a reach-by-reach basis for the mainstem River since 1994 and for the watershed since 1998. This allowed annual comparisons between mainstem versus tributary reaches, between tributaries and detection in trends. The model input was densities of juvenile size classes by habitat type by reach, and the model was based on effective adult trapping data from Waddell Creek (Shapovalov and Taft 1954).

The basic assumption of the model is that the survival rate from smolt to a returning adult is positively related to the size of the smolt. Data on smolt size and returning adult numbers from 1933 to 1942 on Waddell Creek (Shapovalov and Taft, 1954) were used to develop an equation to predict adult returns. Based on the data from Waddell Creek the survival rates for adult steelhead increased exponentially with increased smolt size.

The results produced from the Dettman model produce two categories of returning adults, one for first time spawner and one for the total number of returning adults assuming a repeat spawning rate of 20%. The model output of returning adults was reduced by 50% based on the apparently reduced survival rate in the early 1990's. Smith's (1992) estimate of adult returns on Waddell Creek in winter 1991-92 was half the average adult return for 9 consecutive years in the 1930's and 1940's. The underlying assumption was that juvenile production in recent times is similar to juvenile production in earlier times for Waddell Creek.

PAIRED T-TEST RESULTS FOR JUVENILE PRODUCTION DATA

Table A-1. Statistical results of paired t-tests between adjacent years, comparing the difference in juvenile production by size class and reach between years, dividing the watershed into two groupings; 1) the Mainstem reaches and 2) the 9 major tributaries.

Sizeclass1, tributaries	98-99	99-00	00-01
Mean difference	-2295.56	-1608.89	1206.44
Variance of the difference	20615759.3	48659820.4	29698246.8
Hypothesized Mean Difference	0	0	0
df	8	8	8
t Stat	-1.51673	-0.69193	0.66415
P-value (2-tail)	0.16781	0.50856	0.52527
95% CL (lower)	-5785.66	-6970.86	-2982.5
95% CL (upper)	1194.55	3753.08	5395.39

Sizeclass2, tributaries	98-99	99-00	00-01
Mean difference	1065.56	-1018.78	-346.33
Variance of the difference	2848998	785147.2	517530
Hypothesized Mean Difference	0	0	0
df	8	8	8
t Stat	1.89387	-3.44925	-1.44427
P-value (2-tail)	0.09486	**0.0087**	0.18666
95% CL (lower)	-231.88	-1699.88	-899.31
95% CL (upper)	2362.99	-337.67	206.64

Sizeclass1, mainstem	97-98	98-99	99-00	00-01
Mean difference	-3451.83	-330.67	-435.42	928.5
Variance of the difference	16074208.7	9970161.33	4340311.54	1038624.27
Hypothesized Mean Difference	0	0	0	0
df	11	11	11	11
t Stat	-2.98247	-0.36277	-0.72399	3.15605
P-value (2-tail)	**0.01246**	0.72365	0.48418	**0.00914**
95% CL (lower)	-5999.2	-2336.88	-1759.11	280.98
95% CL (upper)	-904.47	1675.55	888.28	1576.02

Sizeclass2, mainstem	97-98	98-99	99-00	00-01
Mean difference	37.67	-67.67	-1111.7	23.42
Variance of the difference	363201.7	3126571	3295575	318940.3
Hypothesized Mean Difference	0	0	0	0
df	11	11	11	11
t Stat	0.21651	-0.13257	-2.12145	0.14364
P-value (2-tail)	0.83255	0.89693	0.05743	0.88839
95% CL (lower)	-345.25	-1191.1	-2265.1	-335.41
95% CL (upper)	420.58	1055.8	41.68	382.24

APPENDIX B – TEMPERATURE AND OXYGEN REQUIREMENTS FOR SALMONIDS

Water Temperature Considerations- Steelhead in the San Lorenzo River

The relationship between water temperature and metabolic rate (measured as oxygen consumption) is basic to fish physiology and important in understanding fish distribution and ecology. Fish being ectotherms (cold-blooded), their body temperatures increase along with metabolic rate as water temperature increases. At higher temperatures, steelhead oxygen requirements and food demands increase, and steelhead are forced to fastwater habitat or other sources of abundant food. References that indicate that oxygen consumption by fishes increases with water temperature include Fry (1947), Beamish (1964) and Beamish (1970). Many fisheries textbooks refer to this relationship. An example is The Chemical Biology of Fishes by Malcolm Love (1970). The positive relationship between water temperature and metabolic rate in fishes leads to higher oxygen requirements as water temperature increases (Nikolsky 1963).

In the San Lorenzo River, water temperature is primarily a food issue. In the mainstem, water temperature is probably not directly lethal. But higher temperatures increase food demands and restrict the steelhead to faster habitats for feeding, especially above 21ºC (70ºC) (Smith and Li 1983). The lethal level for steelhead would probably be above 26-28ºC (79-82ºF) for several hours during the day. But this is rarely, if ever reached. Even so, warmer temperatures could result in slow growth or starvation in steelhead if food supply becomes very limited. As part of annual steelhead monitoring on the San Lorenzo River in 1997-2001, Alley (2001) measured water temperatures of 21ºC+ in August and September in the lower and middle River from Paradise Park to Brookdale in a number of reaches, except during the cool and high-flow summer of 1998. Cool water from tributaries aided in reducing mainstem temperatures. These mainstem reaches often provide habitat for large yearling steelhead and fast-growing young-of-the-year fish. The high growth rate in the lower mainstem and in the middle River during high baseflow years often leads to relative high densities of smolt-sized juveniles.

A water quality goal should be to maintain water temperature at 21ºC or cooler in the San Lorenzo mainstem. Cooler temperatures may not be possible in the lower River (downstream of the Zayante Creek confluence) and in portions of the middle River (downstream of the Boulder Creek confluence) due to the wide stream channel and lack of riparian canopy closure, even where the riparian corridor is intact. Therefore, maintaining fastwater feeding habitat by protecting maximum streamflow in the mainstem is especially important. Where the river passes through canyons and is narrow, cooler water may be obtained through adequate protection of the riparian corridor and maintenance of adequate summer baseflow. Water temperature in San Lorenzo River tributaries remains well below 21ºC throughout the summer and is not a water quality issue for steelhead as long as the riparian corridor is protected.

Fortunately, steelhead in the San Lorenzo River do not face competition or predation from more warm water adapted species, either introduced or native species such as the pikeminnow (Ptychocheilus grandis) (formerly none as the squawfish). Though pikeminnow is absent from the San Lorenzo River, in other drainages where pikeminnow is present, steelhead abundance in warmer habitats has been significantly reduced, especially in pools.

Supporting Evidence For High Temperature Tolerance in Steelhead

There are many central coast examples of steelhead surviving and growing well at water temperatures above 21ºC. Many of these come from coastal lagoons and lower reaches of unshaded drainages, but only where food is abundant. When food is abundant, growth is actually better at warmer temperatures because digestive rate is increased, allowing fish to consume more food and grow more quickly.

The Soquel Creek Lagoon in Santa Cruz County is inhabited by juvenile steelhead each summer and is valuable nursery habitat. As a typical example, on 22 July 1988 at 0820 hr the minimum lagoon temperature was 20.8º C, and by 1449 hr the minimum lagoon temperature was 22-23º C at all stations throughout the water column, (Habitat Restoration Group 1990). Large, fast-growing steelhead were collected from this lagoon in fall, 1988, indicating their survival well above 21º C. In late July 1989, Smith observed 300+ steelhead juveniles at the mouth of Noble Gulch in Soquel Lagoon where the water column temperature ranged from 21.4 to 22.4º C at 1555 hr.

On 21 July 1992 in Soquel Lagoon, the minimum temperature measured at 4 sites before 0700 hr was 21.2º C (Alley 1993). At 3 of the 4 monitoring sites the minimum was 23º C. By 1700 hr on that day, the minimum water temperature measured was 25.2º C at one site and 26º C at the other monitored site. These sites were representative of the entire lagoon. Large, fast-growing steelhead were collected in abundance in Soquel Lagoon in fall, 1992, after these warm summer conditions.

On two occasions (August and September) in Soquel Lagoon in 1993, steelhead juveniles fed at the surface in early morning with minimum water temperature above 20.6 º C (Alley 1994). Water temperature was likely to increase at least 2º C through the day. More than 1,100 juvenile steelhead were captured in the lagoon in fall 1993 (Alley 1994).

Steelhead have been detected at water temperatures as high as 26º C in Pescadero Creek Lagoon (San Mateo County) and at 24º C on a regular basis in Pescadero and San Gregorio Lagoons (San Mateo County) (Smith 1990) and Uvas Creek in Santa Clara County (J. Smith, pers. observation).

It has been reported that rainbow trout (same species as steelhead but with a freshwater life history pattern) survive temperatures from 0 to 28ºC, provided that they are gradually acclimated to higher temperatures and that saturated oxygen conditions exist (Moyle 1976). Rainbow trout in Big Sulphur Creek, tributary to the Russian River, are often exposed to stream temperatures in excess of 20ºC (Price et al. 1978). This is particularly the case in Big Sulphur Creek below Little Geysers Creek where daily minimum temperatures sometimes exceed 20ºC. Daily stream temperatures fluctuate up to, and perhaps greater than 28ºC in Big Sulphur Creek in summer rainbow trout habitat (Price et al. 1978). Steelhead inhabited the Creek, downstream of where these data were collected. More than 100 rainbow trout/ steelhead were observed during snorkeling in pools, runs and riffles on 24 July 1976 in Deer Creek, Tehama County, where water temperature fluctuated daily between 19 and 24º C (Alley 1977).

Water Temperature Considerations- Coho Salmon in the San Lorenzo River

Because of the existing spawning challenges for coho and typical summer water temperatures found in the mainstem below the Boulder Creek confluence, no acceptable water temperature goal can realistically be attained for coho. It is highly unlikely that coho salmon can successfully spawn in the mainstem below the Boulder Creek confluence in most years. With their early spawning period and the sandy conditions, their redds are extremely vulnerable to scour and sedimentation from later winter and spring storms. In drier years when scour is less likely, passage through the gorge may be very difficult and much of the watershed may be inaccessible to most adult coho. However, if there was successful spawning in these mainstem reaches or if juveniles produced by spawning in tributaries moved down into these reaches, juvenile coho would easily starve because they cannot utilize productive fastwater habitat as steelhead do. Although the lethal temperature limit for coho is similar to steelhead, they would likely starve at temperatures above 18-20ºC (65-68ºF) in the lower and middle mainstem. Coho can potentially tolerate temperatures nearly as high as steelhead, but usually are found at much cooler temperatures. In Washington, stocked coho were found to do well in streams where temperatures exceeded 24.5ºC for more than 100 hours and reached 29.5ºC (Bisson et al. 1988). However, those were very productive sites, and other species (including steelhead) were scarce. The warm lagoon at Waddell Creek failed to support coho in 1996, even though it was productive, and coho were present immediately upstream of the lagoon. Apparently coho could not compete with steelhead in this warm, large pool situation. However, in smaller and/or cooler pools, coho tended to successfully exclude young-of-the-year steelhead (Smith unpublished). Even if water temperatures below 18ºC could be attained in some portions of the middle mainstem, few coho would likely survive in the long pools where food is in short supply.

In some years, coho might successfully spawn and rear in the cooler, low gradient tributaries on the east side of the watershed (lower Branciforte, lower Zayante, Bean, lower Bear and Kings creeks), as well as in the low gradient mainstem reaches above Boulder Creek. Here, more food would be available in the pools that coho could utilize. In the Mattole River system (northern California) coho were found only in tributaries where the maximum weekly average water temperatures were 16.7ºC (62ºF) or less and the maximum weekly maximum temperatures were 18.0ºC (64ºF) or less (Welsh et al. 2001). To arrive at these temperature criteria, they determined the average daily water temperature for the weeks under consideration and determined the average maximum daily water temperature for those weeks. Then they correlated the maximum for all of the average weekly temperatures and the maximum for all of the average maximum weekly temperatures to coho presence or absence. Because of the generally sandy substrate in the San Lorenzo River system, and the presence of steelhead, the temperature limits found in the Mattole River are probably the appropriate goal for re-establishing coho in San Lorenzo tributaries and the mainstem, upstream of the Boulder Creek confluence. In Scott and Waddell creeks in Santa Cruz County, coho have been found at warmer sites, but only where the pools were very productive (small pools, abundant algae, extensive, productive riffles upstream of the pools, etc.) (Smith pers. observation). There are productive reaches of some San Lorenzo tributaries where coho might survive at warmer water temperatures, such as in middle Bean, Zayante and middle Bear creeks. The mainstem San Lorenzo River, upstream of the Kings Creek confluence, might also provide coho habitat. Sediment input from Kings Creek and the paucity of riffles in the mainstem San Lorenzo below Kings Creek make habitat and food supply especially poor there.

Oxygen Considerations- Steelhead and Coho Salmon

Steelhead can likely survive oxygen levels in the cooler, early morning as low as 2 mg/l. However, the water quality goal for the San Lorenzo River should be to maintain oxygen levels above 5 mg/l because activity is likely restricted at lower oxygen levels. This goal is easily met in flowing stream habitat where riffles recharge oxygen, but may not be in the lagoon under conditions in which saltwater has been trapped by sandbar closure without sufficient lagoon inflow. Artificial sandbar breaching after the initial sandbar formation has been shown to cause both temperature and dissolved oxygen problems (Smith 1990).

Local field data are lacking for establishing the minimum oxygen requirements for coho salmon juveniles. However, it is highly likely that warm water temperature associated with starvation would become limiting to coho in the San Lorenzo River system long before low oxygen levels would become a factor. It is probable that oxygen levels in flowing stream and riverine habitat would be ample for coho salmon, as is the case for steelhead. Saline lagoon conditions may reduce oxygen levels in deeper portions of the water column below the tolerance for coho, as with steelhead. The 5 mg/l oxygen goal for steelhead in the San Lorenzo system would also be adequate for coho salmon.

Supporting Evidence for Low Oxygen Tolerance in Steelhead

Steelhead have been observed at oxygen levels below 4 mg/l in many locations along the central coast. Steelhead were captured from isolated pools (stream discontinuous) at 3-4 mg/l oxygen and 16º C water temperature in 1988 in Waddell and Redwood creeks in Santa Cruz and Marin counties, respectively (J. Smith, pers. observation), but coho were absent from the pools in Redwood Creek where levels dropped to 3 mg/l. In August 1989 on the Carmel River, juvenile steelhead were observed in pools at three different sites where oxygen ranged from a minimum of 2-4 mg/l at the different sites before dawn to a maximum of 14-15.5 mg/l (super saturation) in the afternoon, with water temperature ranging from 61º F (16.1º C) in the morning to 72º F (22.2º C) in late afternoon (D. Dettman personal comm.).

In San Simeon Creek Lagoon in 1993, steelhead survived to at least mid-August, despite morning oxygen levels in the 1.7-2.8 mg/l range. Juvenile steelhead were observed on 10 June, and 29 July at the same location (Alley, pers. observation). On 11 June the maximum oxygen concentration at that station was

2.7 mg/l at 0603hr (at the surface), with water being 14º C (Alley 1995). On 8 July the maximum oxygen level was 1.7 mg/l with water at 16º C at 0525 hr (Alley 1995). On 29 July the oxygen concentration was at a maximum of 2.8 mg/l with water temperature of 17.5º C at 0530 hr (Alley 1995). An adult steelhead was observed in the lagoon during sampling on 10-11 August (J. Nelson, CDFG, personal comm.).

At low temperatures, it was reported that rainbow trout withstand oxygen concentrations of 1.5 to 2 mg/l (Moyle 1976). Rainbow trout were found in Penitencia Creek (Santa Clara County) at 3 mg/l oxygen and 20º C water temperature (J. Smith personal comm.).

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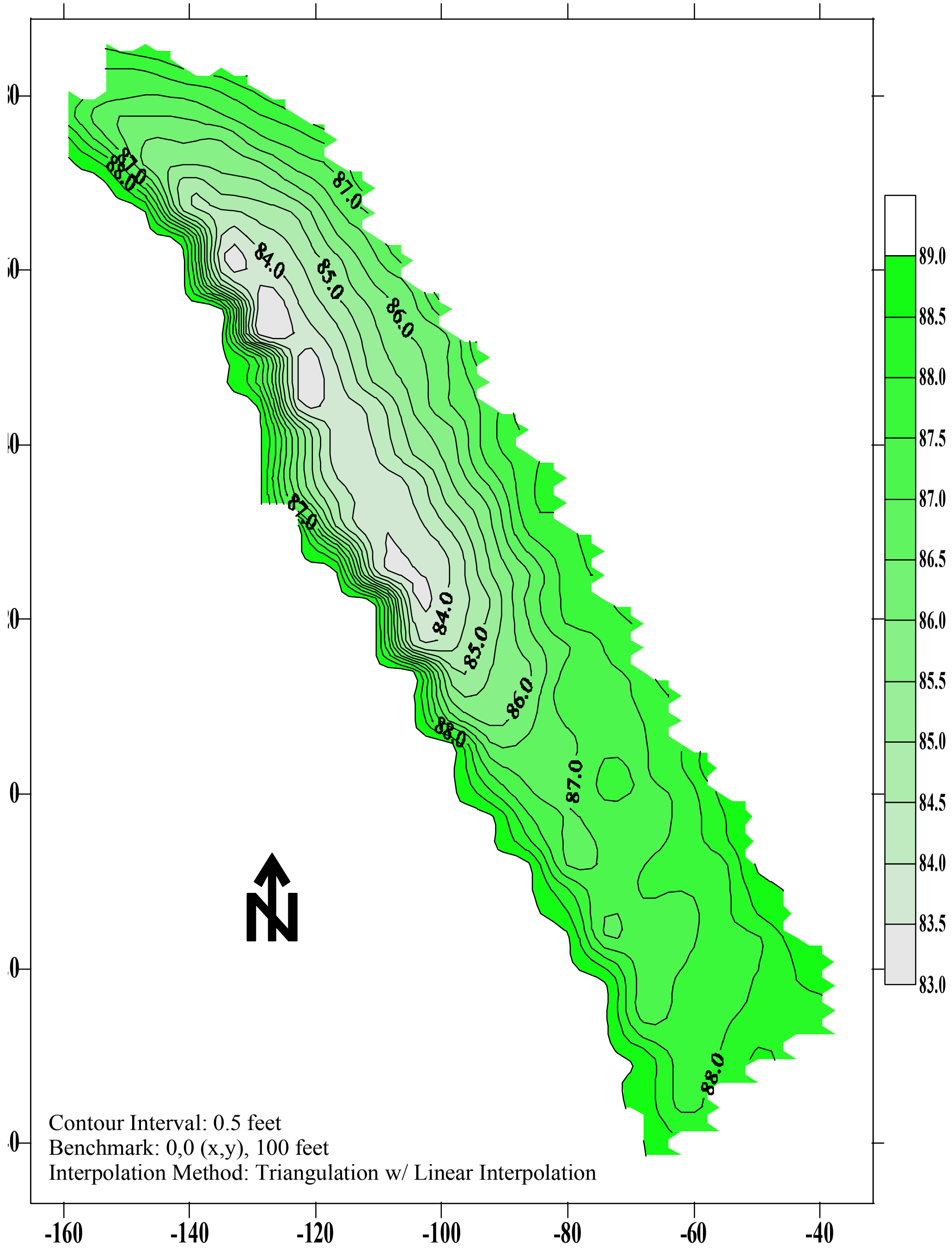
APPENDIX C – POOL VOLUME MAPS

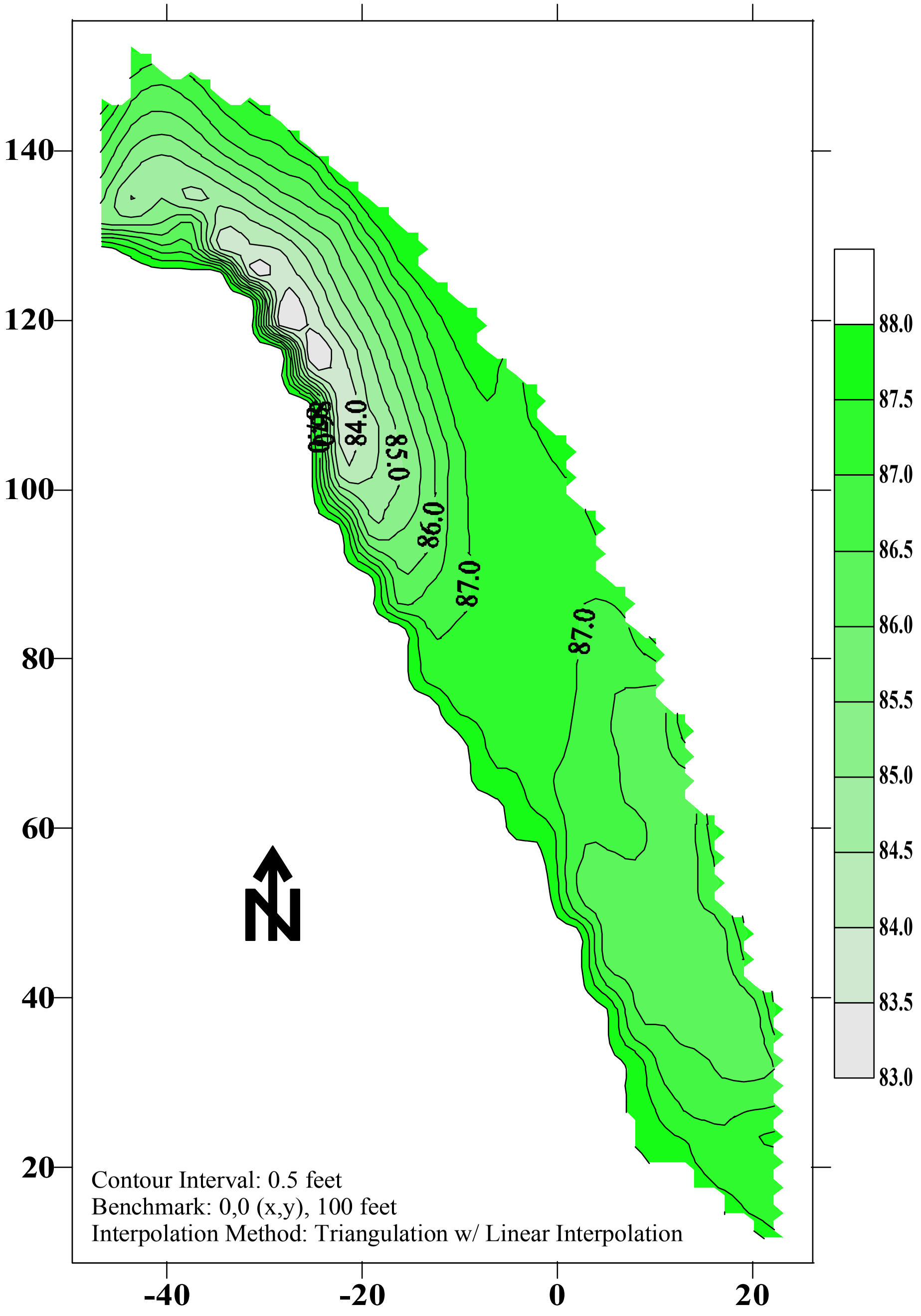
Figure C-1



Contour Interval: 0.5 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Stream Name:San Lorenzo River
Pool ID: 3.1
Survey Date: December 19, 2000
Pool Volume: 11,823 cubic feet
Flow: 8.86 cubic feet per second
Location: Just upstream of Larkspur
Road Bridge off Highway 9
in Brookdale
Maximum Depth: 5.9 feet

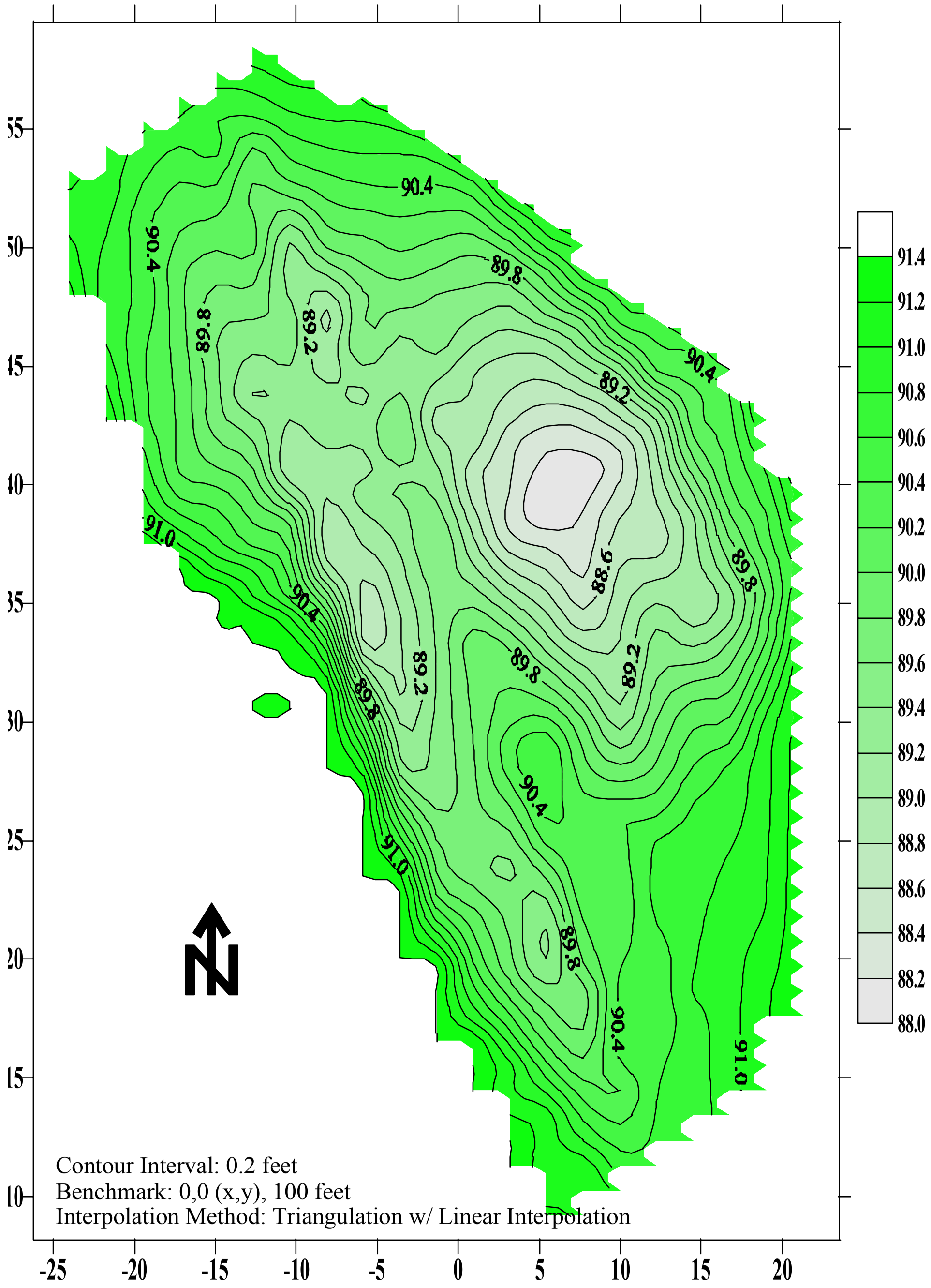
Figure C-2



Contour Interval: 0.5 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Photo Not Available

Stream Name:San Lorenzo River
Pool ID: 4.1
Survey Date: December 21, 2000
Pool Volume: 5,514 cubic feet
Flow: 2.54 cubic feet per second
Location: From Hwy 9 to Spring Creek Road
to Shady Lane. Access through
320 Shady Lane then walk upstream
Maximum Depth: 5.0 feet

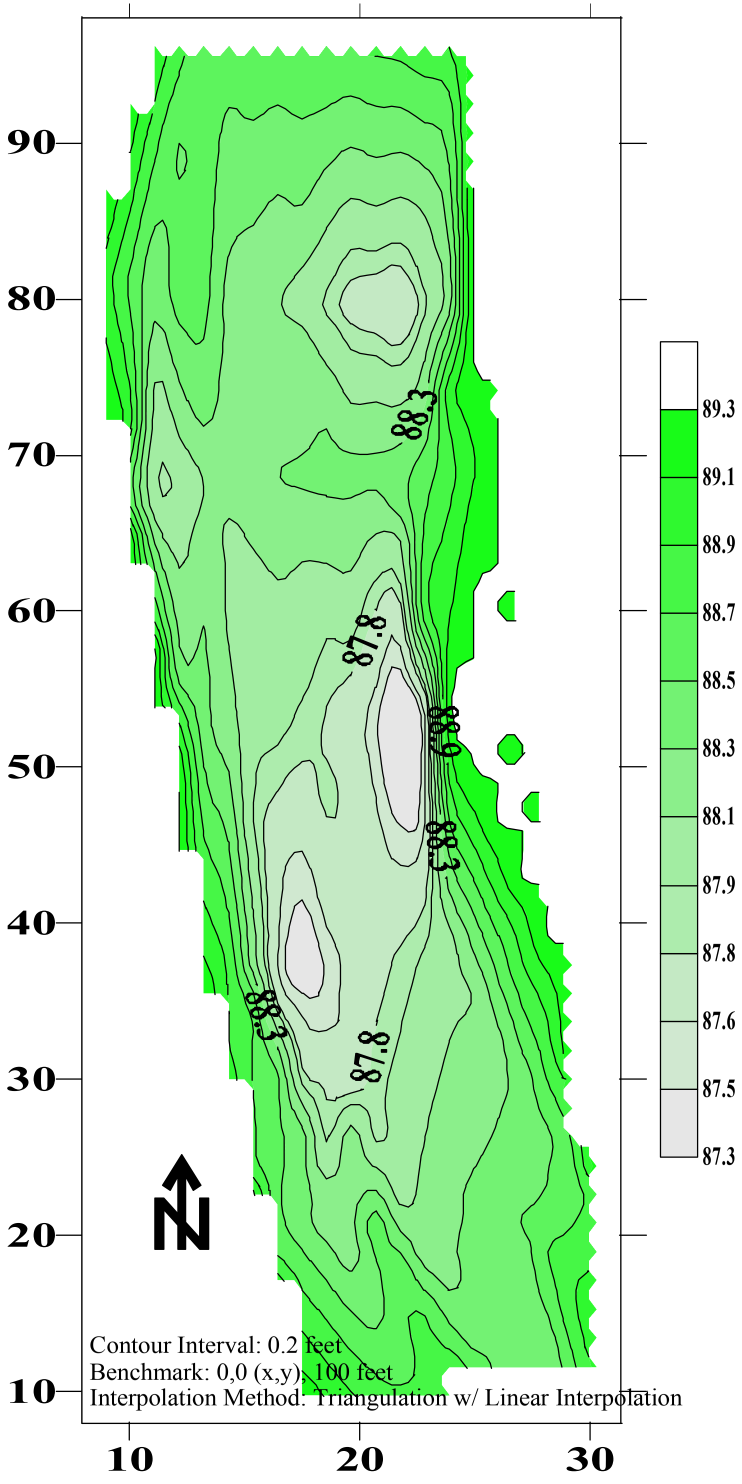


Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Figure C-3

Stream Name: Carbonera Creek
Pool ID: 5.1
Survey Date: December 7, 2000
Pool Volume: 1,887 cubic feet
Flow: 1.52 cubic feet per second
Location: Access through upper parking
lot of county hospital/old dirt road
Maximum Depth: 3.4 feet

Figure C-4



Stream Name: Branciforte Creek
Pool ID: 6.1
Survey Date: December 7, 2000
Pool Volume: 1,264 cubic feet
Flow: 1.47 cubic feet per second
Location: Access from turnout on North
Branciforte Drive just downstream
of Granite Creek Bridge
Maximum Depth: 2.0 feet

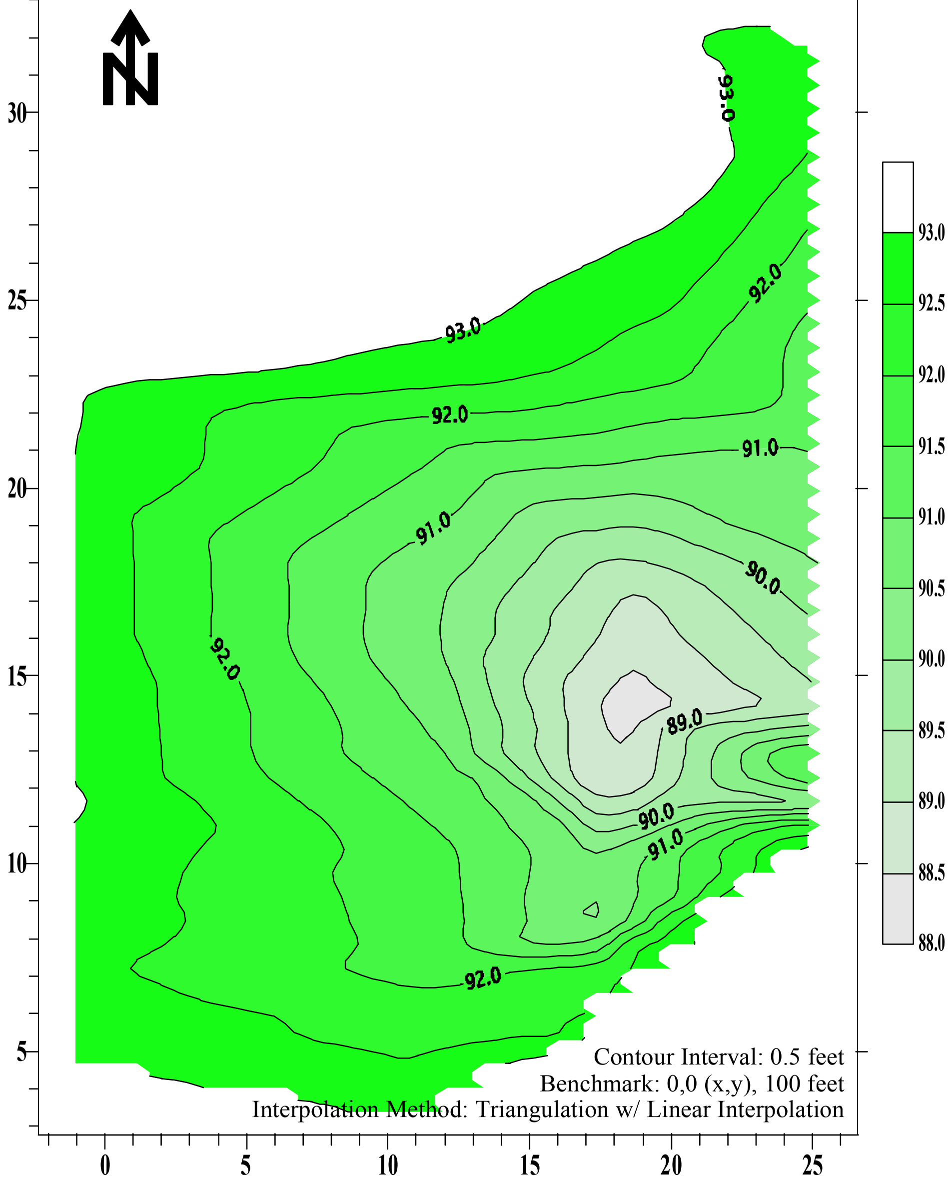
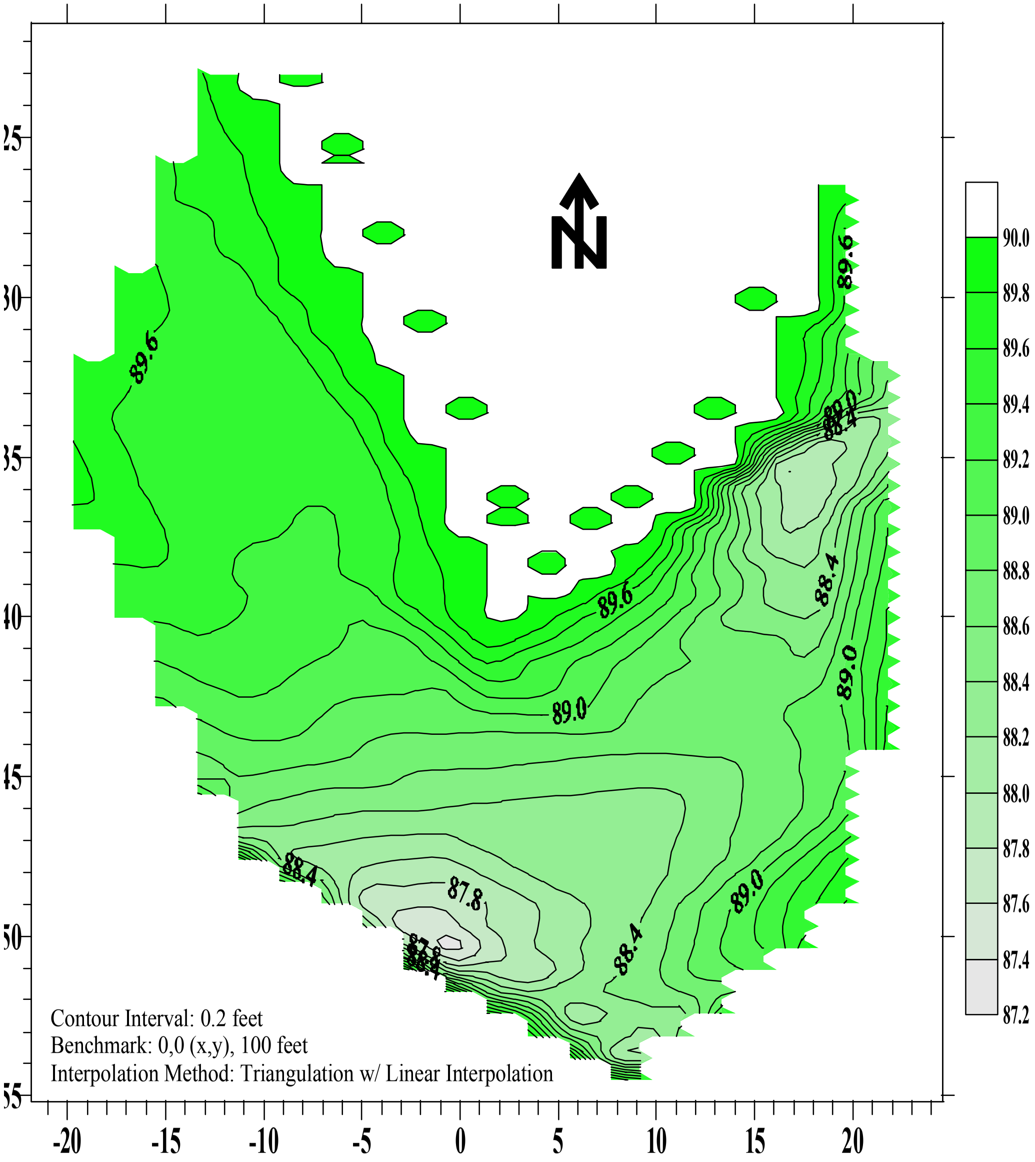


Figure C-5

Stream Name: Bean Creek
Pool ID: 7.1
Survey Date: December 7, 2000
Pool Volume: 1,034 cubic feet
Flow: 3.21 cubic feet per second
Location: Trailhead at Mt.Hermon Conference
Center above the baseball field.
Just upstream of trail crossing.
Maximum Depth: 5.1 feet

Figure C-6

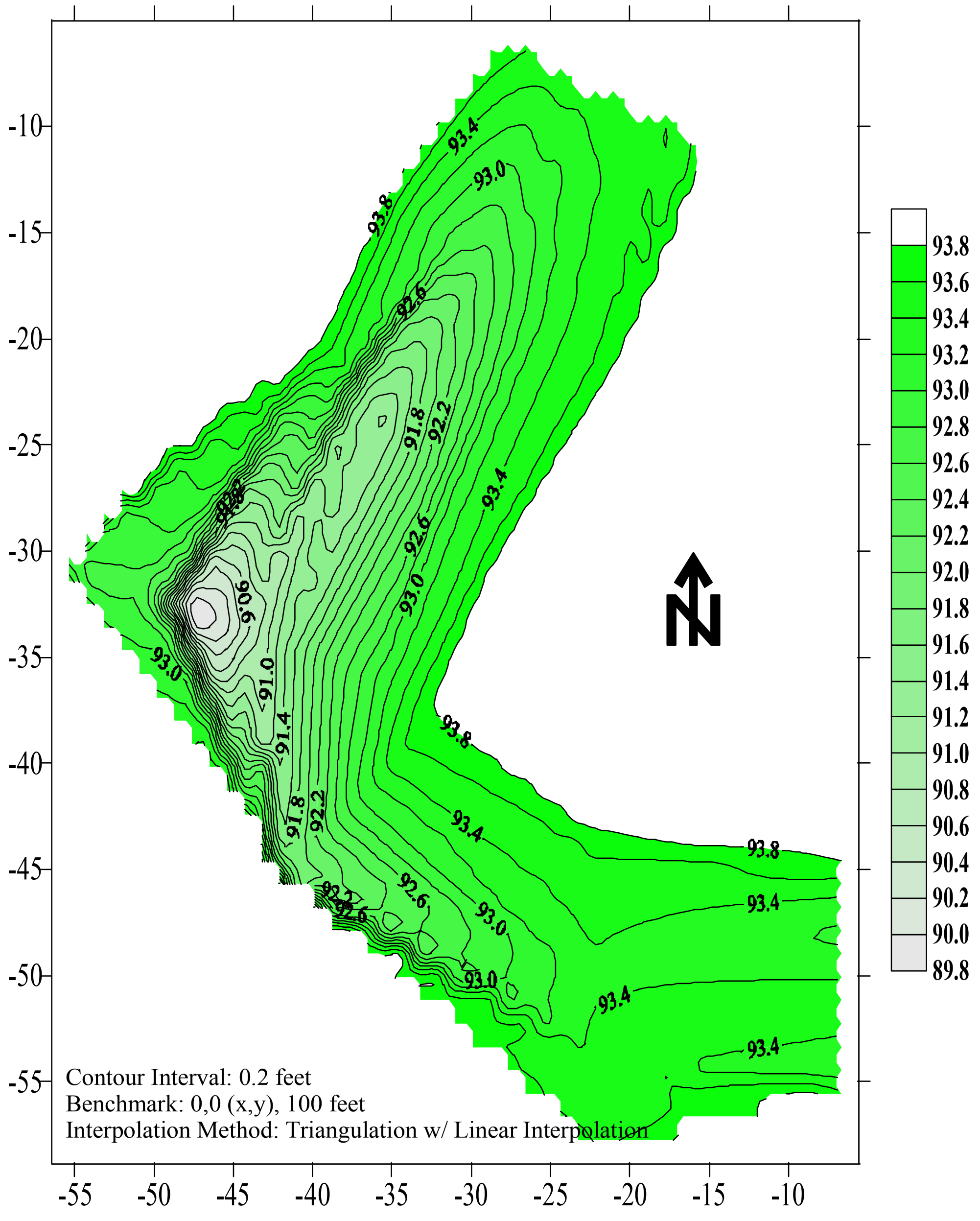


Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Photo Not Available

Stream Name:Bean Creek
Pool ID: 7.2
Survey Date: December 7, 2000
Pool Volume: 730 cubic feet
Flow: 3.21 cubic feet per second
Location: Just upstream of Pool 13.1 at rootwad and river bend.
Maximum Depth: 2.6 feet

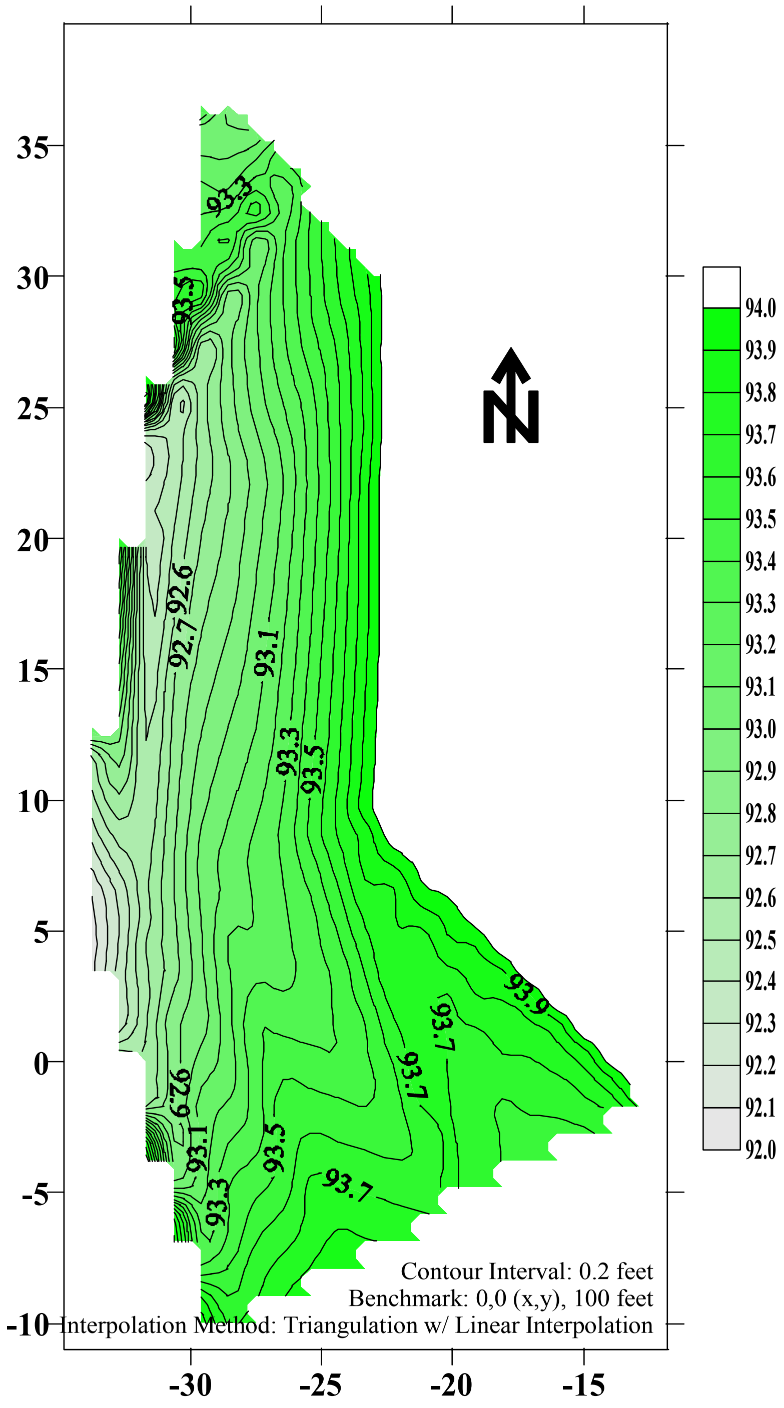
Figure C-7



Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

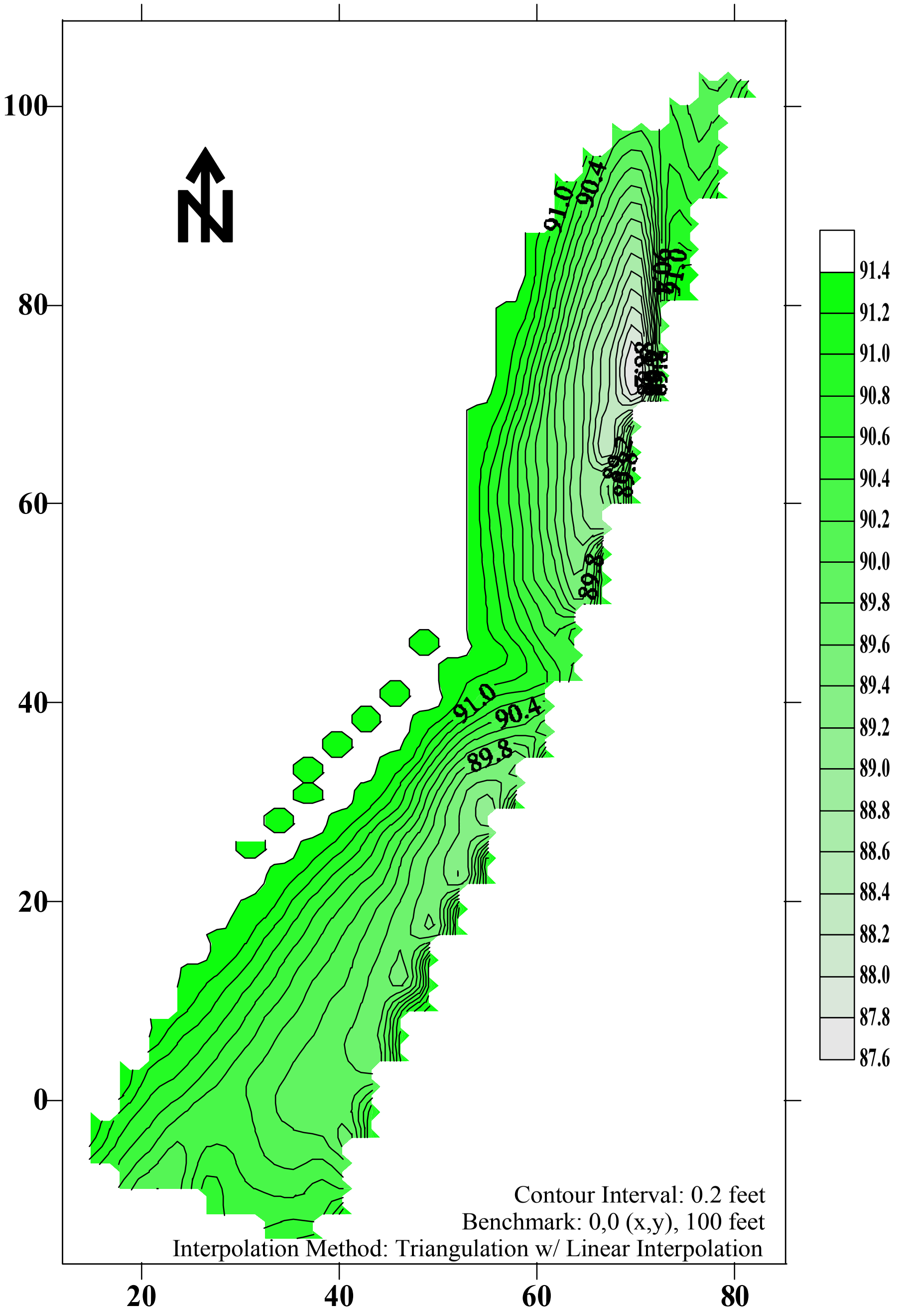
Stream Name: Bean Creek
Pool ID: 8.1
Survey Date: December 8, 2000
Pool Volume: 1,097 cubic feet
Flow: 1.65 cubic feet per second
Location: Downstream of Pool 12.2
(approximately 500 feet)
Maximum Depth: 3.9 feet

Figure C-8



Stream Name: Bean Creek
Pool ID: 8.2
Survey Date: December 8, 2000
Pool Volume: 424 cubic feet
Flow: 1.65 cubic feet per second
Location: Below Lockhart Gulch Bridge just upstream of log revetment project
Maximum Depth: 2.0 feet

Figure C-9



Stream Name: Zayante Creek
Pool ID: 9.1
Survey Date: December 7, 2000
Pool Volume: 2,558 cubic feet
Flow: 5.22 cubic feet per second
Location: From East Zayante Road take
West Zayante Road about 1/4 mile.
Park in turnout just opposite horse
corral.
Maximum Depth: 3.8 feet

Figure C-10

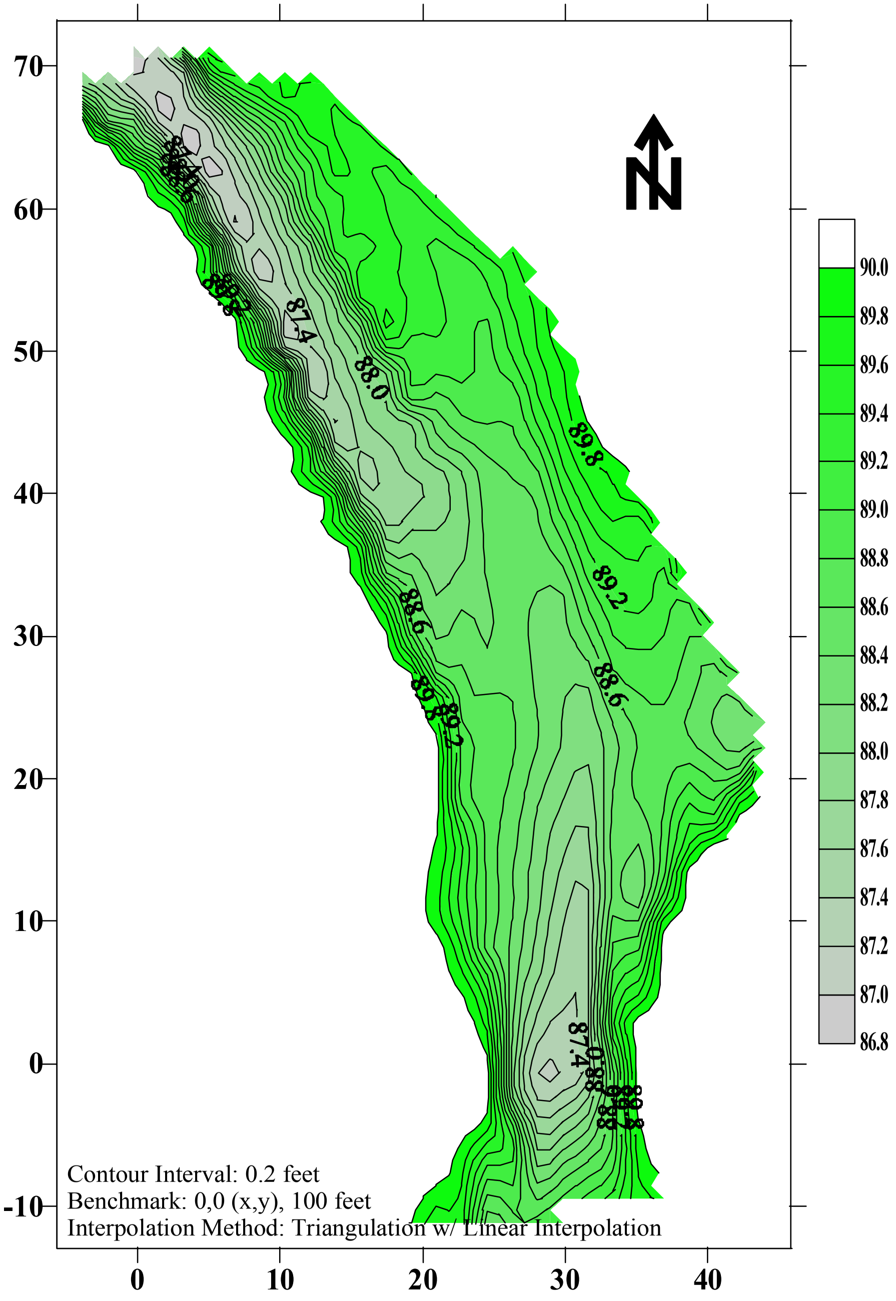
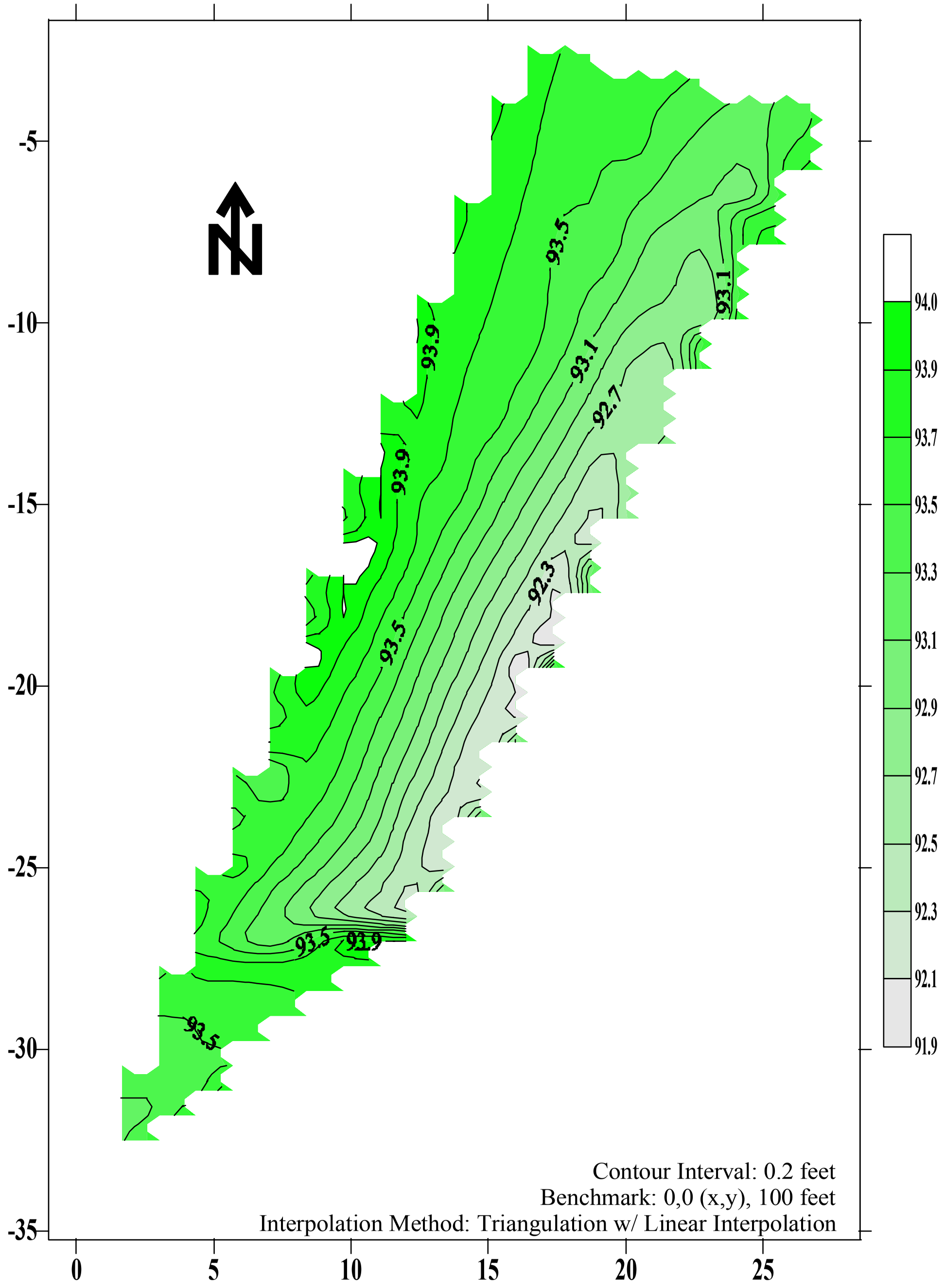


Photo Not Available

Stream Name: Zayante Creek
Pool ID: 10.1
Survey Date: December 8, 2000
Pool Volume: 2,300 cubic feet
Flow: 1.53 cubic feet per second
Location: Access through Matt McVeigh's
property on Waner Rd off of
E. Zayante Rd.
Maximum Depth: 3.2 feet

Figure C-11

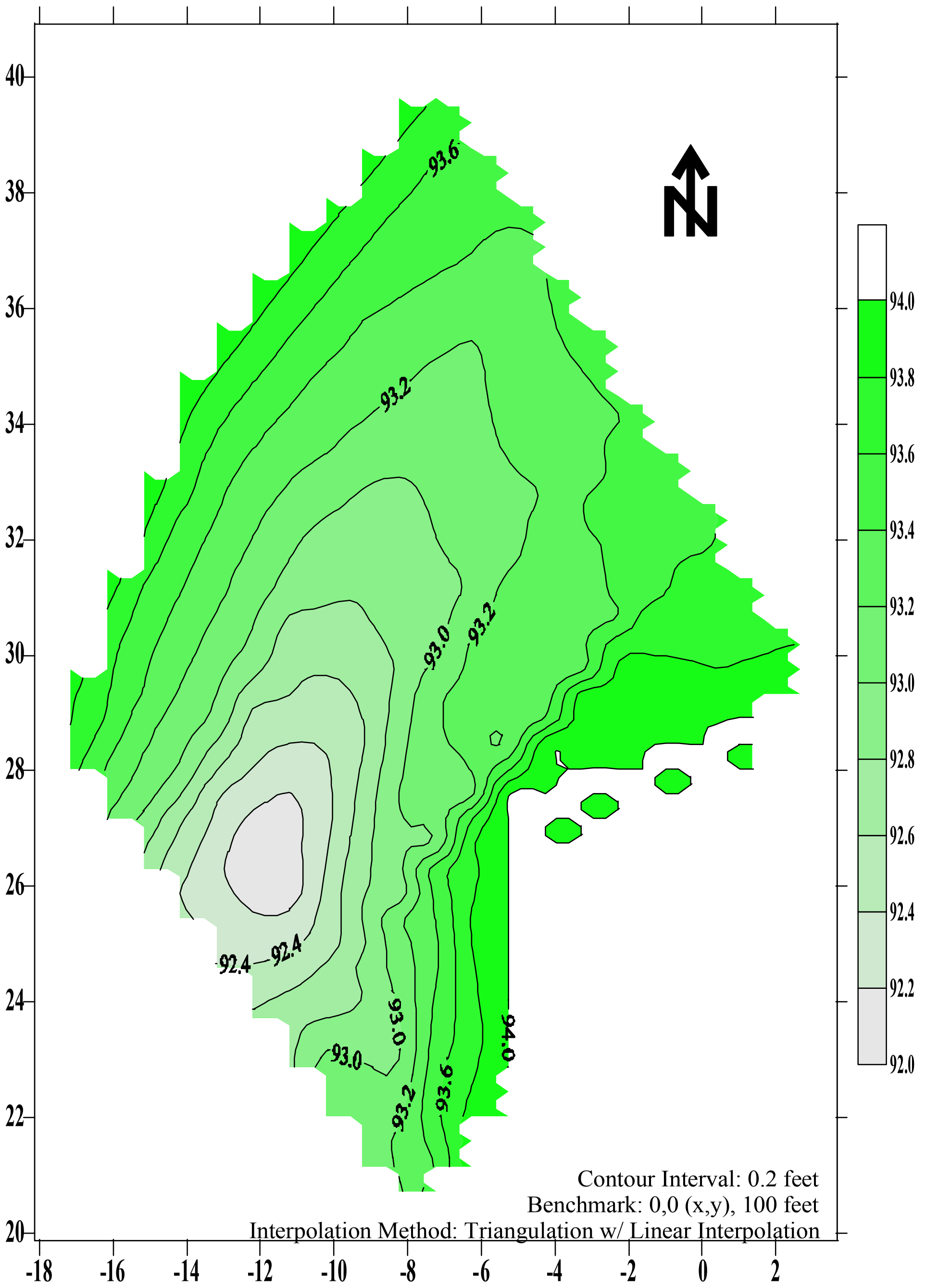


Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Photo Not Available

Stream Name:Fall Creek
Pool ID:11.1
Survey Date: December 8, 2000
Pool Volume: 225 cubic feet
Flow: 2.87 cubic feet per second
Location: Access from Henry Cowell State Park - Fall Creek Unit parking lot. Hike down trail then proceed downstream approximately 500 feet.
Maximum Depth: 2.0 feet

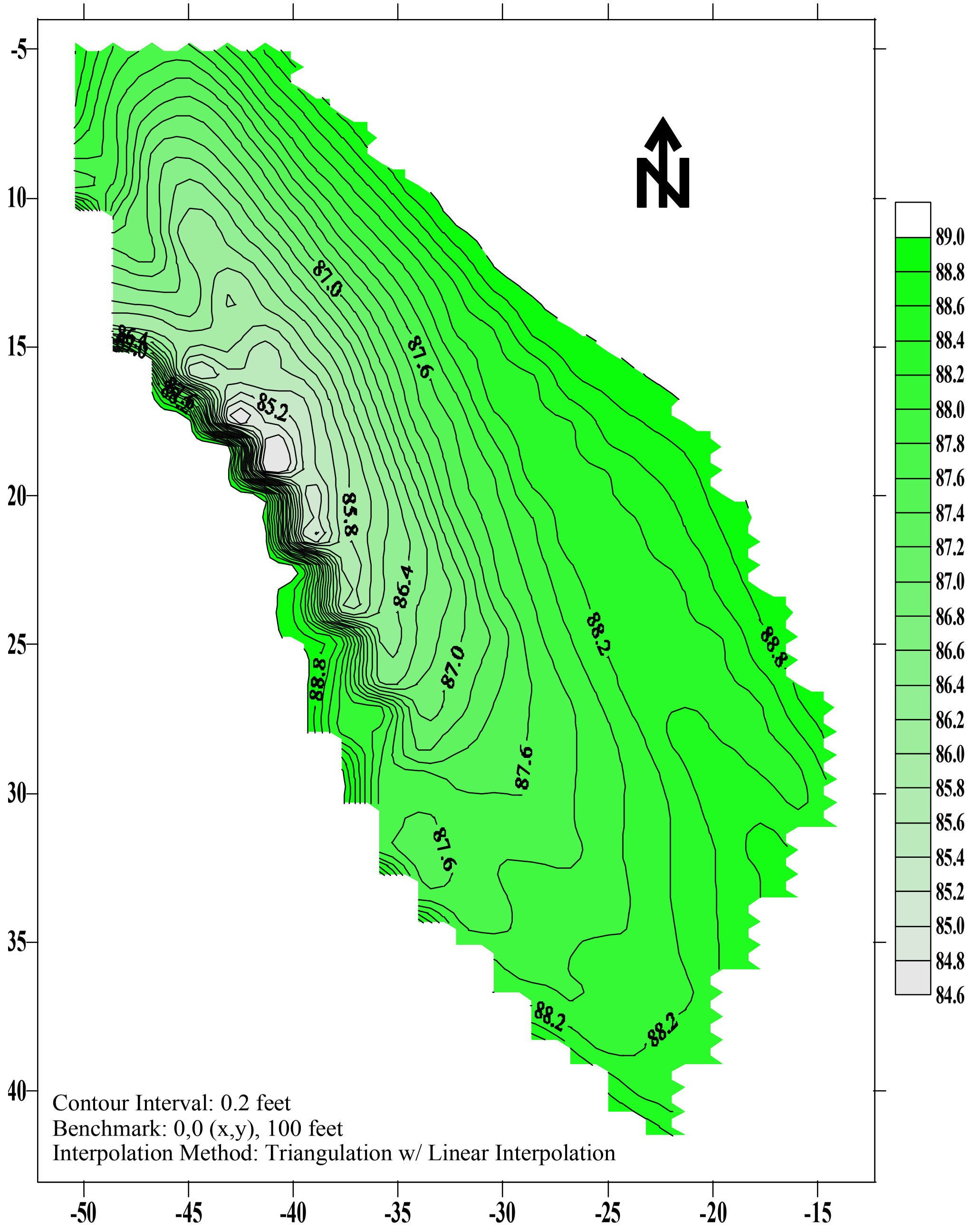
Figure C-12



Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Stream Name:Fall Creek
Pool ID: 11.2
Survey Date: December 8, 2000
Pool Volume:159 cubic feet
Flow: 2.87 cubic feet per second
Location: Located approximately 300 feet downstream of Pool 11.1
Maximum Depth: 1.9 feet

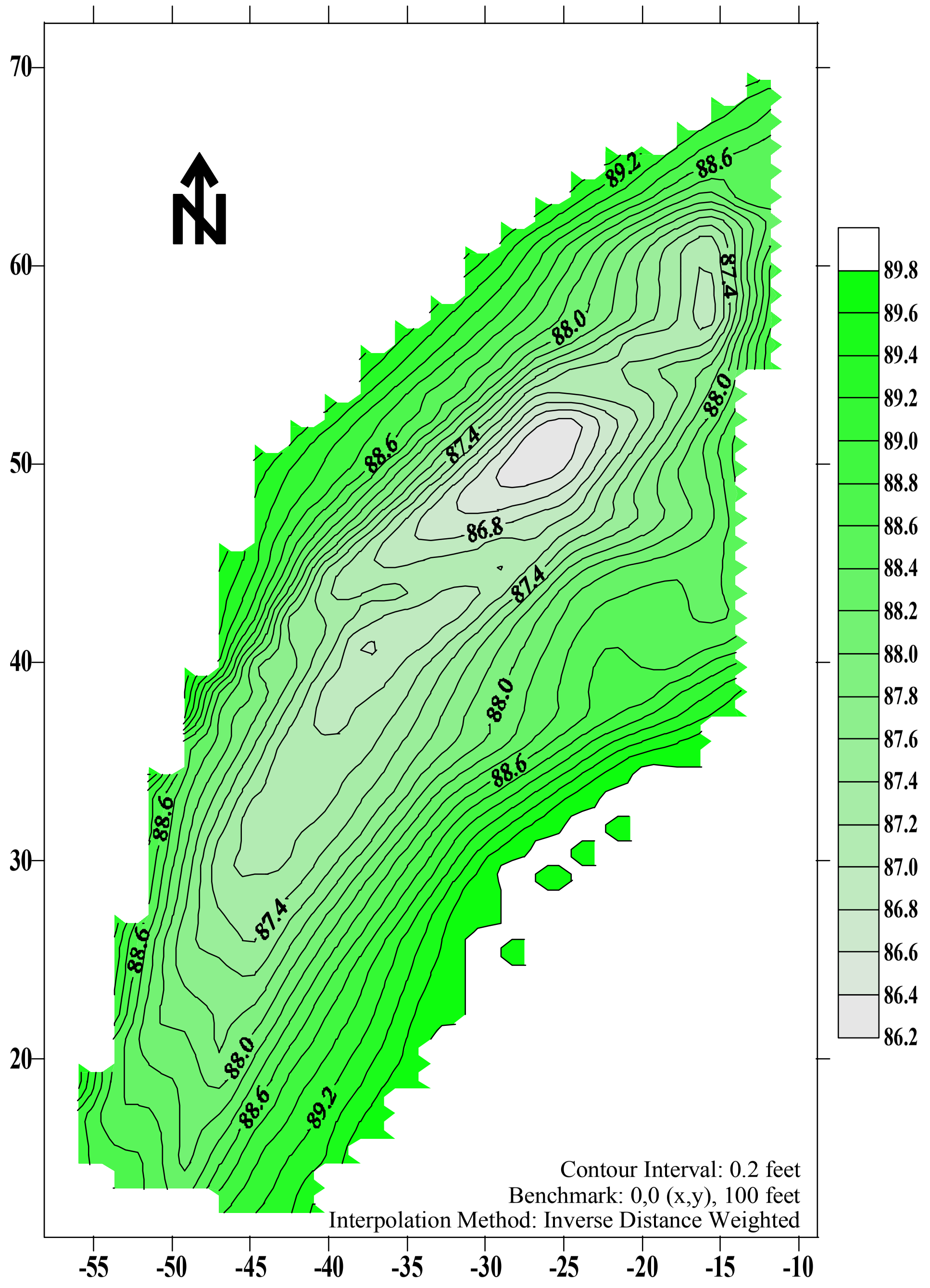
Figure C-13



Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Stream Name: Bear Creek
Pool ID: 12.1
Survey Date: December 19, 2000
Pool Volume: 982 cubic feet
Flow: 1.99 cubic feet per second
Location: From Hwy 9 to Bear Creek Road.
Cross creek at road just before
Hopkins Gulch. Park at bend
just after bridge.
Maximum Depth: 4.4 feet

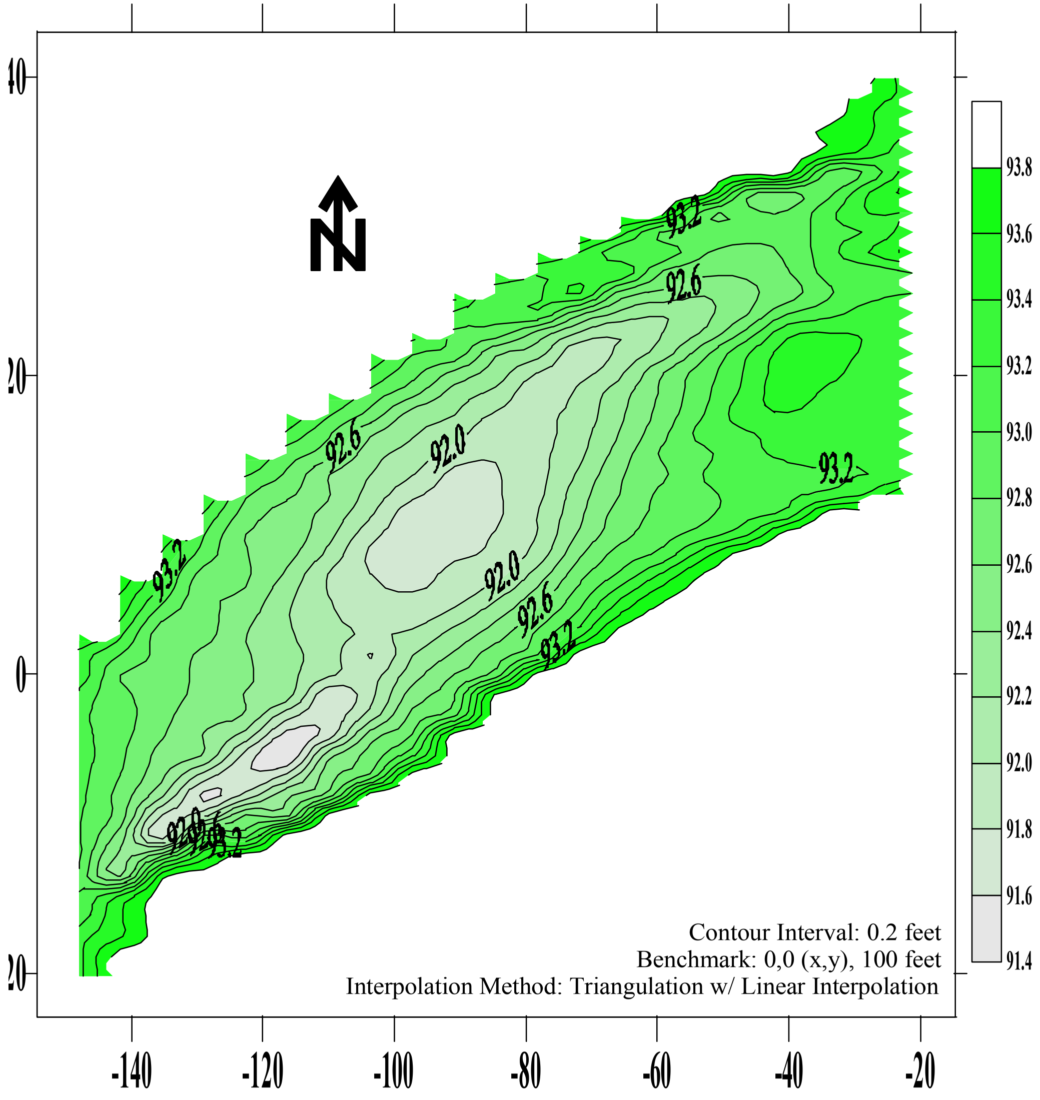
Figure C-14



Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Inverse Distance Weighted

Stream Name: Bear Creek
Pool ID: 12.2
Survey Date: December 19, 2000
Pool Volume: 2,300 cubic feet
Flow: 1.99 cubic feet per second
Location: From Hwy 9 to Bear Creek Road.
Cross creek at road just before
Hopkins Gulch. Park at bend
just after bridge.
Maximum Depth: 3.6 feet

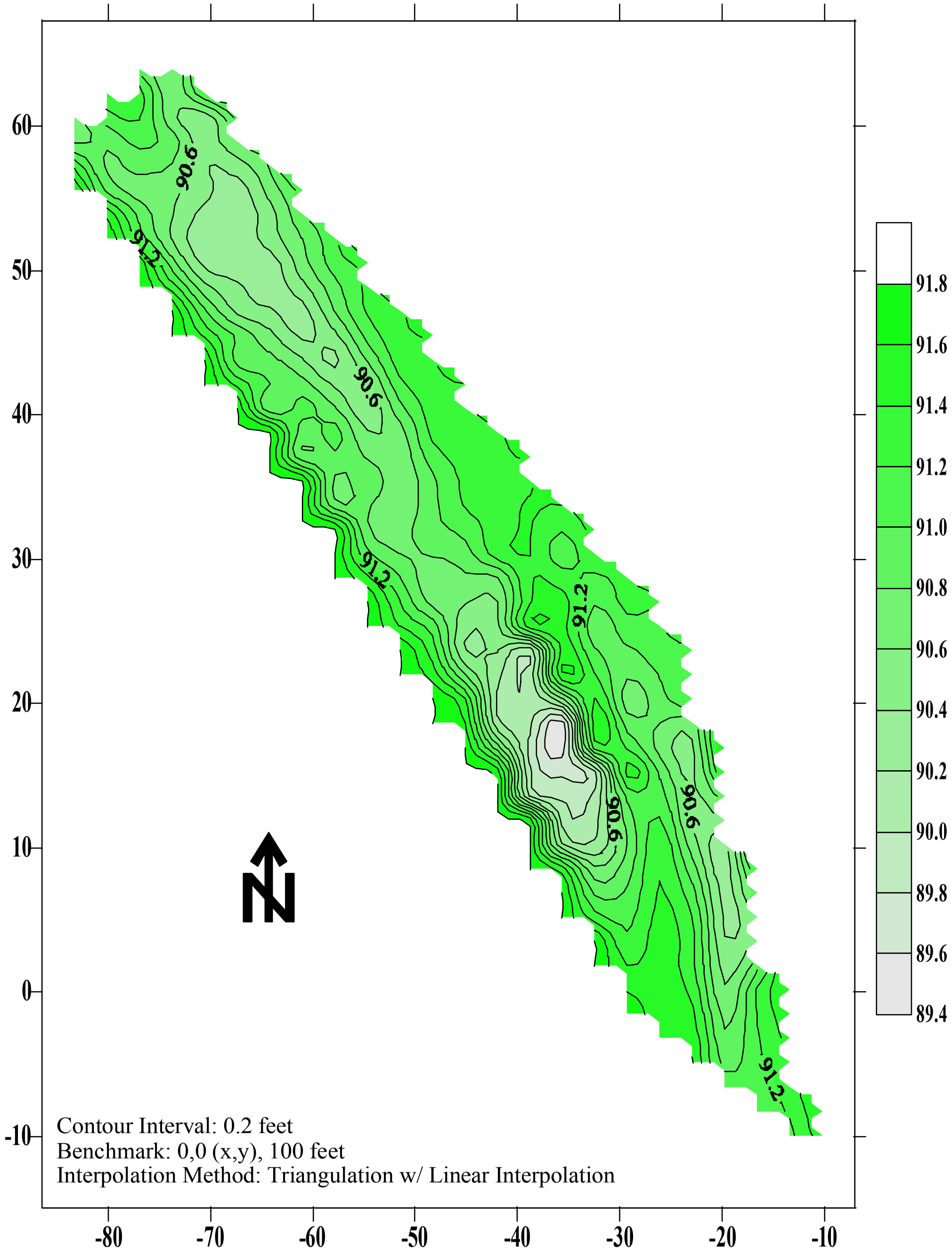
Figure C-15



Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Stream Name: Boulder Creek
Pool ID: 13.1
Survey Date: December 19, 2000
Pool Volume: 4,213 cubic feet
Flow: 3.0 cubic feet per second
Location: Pool is located just upstream
of the Highway 9 Bridge. Access
from left bank down trail.
Maximum Depth: 2.5 feet

Figure C-16



Contour Interval: 0.2 feet
Benchmark: 0,0 (x,y), 100 feet
Interpolation Method: Triangulation w/ Linear Interpolation

Photo Not Available

Stream Name: Kings Creek
Pool ID: 14.1
Survey Date: December 19, 2000
Pool Volume: 1,397 cubic feet
Flow: 0.90 cubic feet per second
Location: From Hwy 9 to Kings Creek Road.
Just after 2nd bridge over Kings Creek.
Maximum Depth: 2.3 feet

APPENDIX D – EXCEEDENCE PROBABILITY CHARTS

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	325.2	37.1	21.7	13.5		February	95	468.8	68.3	26.4	13.3
	90	351.1	40.1	22.2	14.2			90	507.3	77.0	27.1	13.8
	80	402.8	46.2	23.1	15.3			80	585.2	96.2	28.7	14.8
	70	455.4	52.2	23.7	16.0			70	681.1	117.6	30.5	15.8
	60	548.1	62.0	24.3	17.1			60	777.1	138.6	34.2	17.3
	50	640.8	73.0	25.2	18.2			50	935.1	163.5	37.8	18.8
March	95	361.0	75.6	32.2	15.0		April	95	217.1	45.1	27.3	13.5
	90	381.2	82.1	34.6	16.1			90	230.9	49.7	27.9	14.2
	80	421.6	95.5	39.3	18.4			80	258.3	57.9	29.2	15.6
	70	462.0	109.8	44.0	21.0			70	285.7	65.6	30.5	18.9
	60	502.4	128.4	48.0	22.3			60	313.2	75.7	31.8	20.0
	50	584.3	152.0	52.0	23.5			50	349.2	86.6	33.4	21.1
May	95	96.4	30.2	20.5	11.2		June	95	58.0	20.5	14.6	8.9
	90	100.2	31.7	20.8	11.8			90	59.5	21.8	14.8	9.2
	80	107.7	35.0	21.4	12.9			80	63.4	24.1	15.2	10.0
	70	117.1	39.0	22.2	15.6			70	66.9	26.5	16.2	11.8
	60	128.0	44.2	23.0	16.8			60	70.1	29.7	16.4	12.8
	50	140.8	49.8	23.7	17.6			50	75.1	33.9	16.8	13.0
July	95	38.9	14.6	10.8	6.5		August	95	28.3	12.1	9.8	6.5
	90	39.6	15.4	11.0	7.1			90	28.7	12.4	9.9	6.7
	80	42.3	17.2	11.6	8.1			80	30.0	13.4	10.1	7.5
	70	44.2	18.8	11.7	9.0			70	32.1	15.5	10.4	8.4
	60	45.9	20.9	11.8	9.3			60	33.0	16.7	10.5	8.7
	50	47.9	23.4	12.6	9.6			50	33.9	19.4	10.6	8.9
September	95	25.2	12.4	9.4	7.0		October	95	28.4	14.2	10.5	8.0
	90	25.9	12.9	9.4	7.3			90	32.3	14.6	10.6	8.2
	80	27.3	14.0	9.6	8.2			80	40.0	15.6	10.7	8.5
	70	28.6	15.0	10.1	8.5			70	47.8	16.3	10.9	8.8
	60	30.0	15.5	10.4	8.6			60	55.6	17.4	11.5	9.0
	50	31.4	16.1	10.5	8.6			50	63.3	18.4	11.6	9.3
November	95	44.3	19.8	13.0	9.4		December	95	102.5	25.6	20.4	10.2
	90	48.2	20.5	13.3	9.6			90	113.4	26.8	20.6	10.7
	80	56.0	21.5	13.9	10.1			80	135.2	29.0	20.9	11.6
	70	63.7	22.4	14.6	10.4			70	157.1	32.2	21.2	12.4
	60	72.3	24.5	15.1	11.7			60	191.1	35.9	22.0	12.9
	50	90.2	25.9	15.5	11.8			50	232.8	40.1	22.3	13.5

Table D-1: San Lorenzo River Monitoring Station #1 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	313.9	35.9	21.1	12.9		February	95	458.3	66.3	25.5	12.9
	90	338.8	38.8	21.5	13.3			90	497.6	74.7	26.3	13.4
	80	388.7	44.7	22.3	14.3			80	576.1	93.1	27.9	14.3
	70	438.5	50.5	22.9	15.2			70	669.4	113.5	29.6	15.3
	60	528.7	59.9	23.5	16.2			60	776.3	134.2	33.2	16.8
	50	618.9	70.4	24.4	17.2			50	883.2	158.5	36.6	18.2
March	95	349.8	73.3	30.8	14.5		April	95	210.4	43.7	26.4	13.1
	90	369.4	79.5	32.6	15.6			90	223.7	48.2	27.1	13.8
	80	408.5	92.6	37.8	17.8			80	250.3	56.1	28.3	15.2
	70	447.7	106.4	42.7	20.3			70	276.9	63.6	29.5	18.3
	60	486.8	124.4	46.5	21.6			60	303.5	73.3	30.8	19.4
	50	566.2	147.3	50.4	22.8			50	338.4	83.9	32.4	20.4
May	95	93.4	29.3	19.9	10.9		June	95	56.2	19.9	14.1	8.6
	90	97.1	30.7	20.2	11.4			90	57.6	21.2	14.3	9.0
	80	104.3	33.9	20.7	12.5			80	61.4	23.4	14.8	9.7
	70	113.5	37.8	21.6	15.1			70	64.8	25.7	15.7	11.4
	60	124.1	42.8	22.3	16.3			60	67.9	28.8	15.9	12.4
	50	136.4	48.2	23.0	17.1			50	72.7	32.8	16.3	12.6
July	95	37.7	14.2	10.5	6.3		August	95	27.4	11.7	9.5	6.3
	90	38.4	14.9	10.7	6.9			90	27.9	12.0	9.6	6.5
	80	41.0	16.7	11.2	7.9			80	29.1	13.0	9.9	7.3
	70	42.8	18.2	11.3	8.6			70	31.1	15.0	10.1	8.1
	60	44.5	20.2	11.4	8.9			60	32.0	16.2	10.2	8.4
	50	46.4	22.7	12.2	9.2			50	32.9	18.8	10.3	8.6
September	95	23.4	12.0	9.1	6.8		October	95	27.5	13.8	10.2	7.8
	90	24.1	12.5	9.2	7.1			90	31.3	14.1	10.3	7.9
	80	25.4	13.5	9.4	7.9			80	38.8	15.1	10.4	8.2
	70	26.8	14.5	9.8	8.2			70	46.3	15.8	10.6	8.5
	60	28.2	15.4	10.1	8.3			60	53.9	16.8	11.1	8.7
	50	29.5	16.6	10.2	8.4			50	61.4	17.9	11.2	9.0
November	95	43.0	19.2	12.6	9.1		December	95	99.3	24.8	19.8	9.9
	90	46.7	19.8	12.9	9.4			90	109.9	25.9	20.0	10.4
	80	54.2	20.8	13.5	9.8			80	131.1	28.1	20.3	11.2
	70	61.7	21.7	14.2	10.1			70	152.2	31.2	20.5	12.0
	60	70.0	23.7	14.7	10.9			60	185.1	34.7	21.3	12.5
	50	87.4	25.1	15.0	11.0			50	225.6	38.9	21.6	13.1

Table D-2: San Lorenzo River Monitoring Station #2 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	161.8	18.1	10.6	6.6		February	95	230.8	33.4	12.9	6.5
	90	177.6	19.6	10.8	6.9			90	250.6	37.6	13.3	6.7
	80	209.2	22.5	11.3	7.5			80	290.1	46.9	14.0	7.2
	70	240.8	25.5	11.6	7.8			70	337.1	57.1	14.9	7.7
	60	272.3	30.3	11.9	8.3			60	391.0	67.6	16.7	8.5
	50	314.6	35.7	12.3	8.9			50	444.8	79.8	18.5	9.2
March	95	176.2	36.9	15.5	7.3		April	95	106.0	22.0	13.3	6.6
	90	186.0	40.0	16.4	7.8			90	112.7	24.3	13.6	6.9
	80	205.8	46.6	19.0	9.0			80	126.1	28.2	14.3	7.6
	70	225.5	53.6	21.5	10.2			70	139.4	32.0	14.9	9.2
	60	245.2	62.7	23.4	10.9			60	152.8	36.9	15.5	9.8
	50	285.1	74.2	25.4	11.5			50	170.4	42.3	16.3	10.3
May	95	47.1	14.7	10.0	5.5		June	95	28.3	10.0	7.1	4.3
	90	48.9	15.5	10.2	5.8			90	29.0	10.7	7.2	4.5
	80	52.5	17.1	10.4	6.3			80	30.9	11.8	7.4	4.9
	70	57.1	19.0	10.9	7.6			70	32.7	13.0	7.9	5.8
	60	62.5	21.6	11.2	8.2			60	34.2	14.5	8.0	6.3
	50	68.7	24.3	11.6	8.6			50	36.6	16.5	8.2	6.3
July	95	19.0	7.1	5.3	3.2		August	95	13.8	5.9	4.8	3.1
	90	19.3	7.5	5.4	3.5			90	14.0	6.0	4.8	3.3
	80	20.6	8.4	5.7	4.0			80	14.7	6.6	4.9	3.7
	70	21.6	9.2	5.7	4.3			70	15.6	7.5	5.1	4.1
	60	22.4	10.2	5.8	4.5			60	16.1	8.2	5.1	4.2
	50	23.4	11.4	6.2	4.6			50	16.6	9.4	5.2	4.3
September	95	11.8	6.0	4.6	3.4		October	95	13.9	6.9	5.1	3.9
	90	12.1	6.3	4.6	3.6			90	15.8	7.1	5.2	4.0
	80	12.8	6.8	4.7	4.0			80	19.5	7.6	5.2	4.1
	70	13.5	7.3	4.9	4.1			70	23.3	8.0	5.3	4.3
	60	14.2	7.8	5.1	4.2			60	27.1	8.5	5.6	4.4
	50	14.9	8.4	5.2	4.2			50	30.9	9.0	5.7	4.5
November	95	21.6	9.7	6.4	4.6		December	95	50.0	12.5	10.0	5.0
	90	23.5	10.0	6.5	4.7			90	55.4	13.1	10.1	5.2
	80	27.3	10.5	6.8	4.9			80	66.0	14.2	10.2	5.6
	70	31.1	10.9	7.2	5.1			70	76.7	15.7	10.3	6.1
	60	35.3	12.0	7.4	5.7			60	93.2	17.5	10.7	6.3
	50	44.0	12.6	7.6	5.8			50	113.6	19.6	10.9	6.6

Table D-3: San Lorenzo River Monitoring Station #3 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	31.6	2.7	1.4	0.9		February	95	62.0	4.6	2.1	1.0
	90	35.6	3.1	1.5	0.9			90	67.7	5.1	2.1	1.1
	80	43.8	4.0	1.5	1.0			80	79.1	6.3	2.3	1.2
	70	51.9	4.8	1.7	1.0			70	90.6	7.4	2.6	1.3
	60	60.1	5.7	1.7	1.0			60	112.6	9.8	2.8	1.3
	50	68.2	7.1	1.8	1.1			50	135.5	12.7	2.9	1.4
March	95	52.0	10.8	3.3	1.6		April	95	21.7	4.9	2.4	1.2
	90	56.5	11.5	3.7	1.8			90	24.6	5.5	2.5	1.3
	80	65.6	12.8	4.4	1.9			80	30.4	6.3	2.6	1.5
	70	77.8	15.0	5.1	2.0			70	36.2	7.1	2.8	1.6
	60	98.0	16.9	5.6	2.1			60	42.5	7.9	3.0	1.9
	50	123.0	18.7	6.6	2.3			50	51.7	9.4	3.1	2.0
May	95	10.3	2.4	1.5	0.6		June	95	6.3	1.3	0.8	0.4
	90	10.8	2.6	1.6	0.7			90	6.5	1.4	0.8	0.4
	80	11.7	3.1	1.6	0.8			80	6.7	1.6	0.9	0.5
	70	12.6	3.6	1.7	0.9			70	7.0	2.0	0.9	0.5
	60	13.6	4.0	1.7	1.0			60	7.4	2.2	1.0	0.6
	50	16.5	5.2	1.8	1.1			50	7.8	2.4	1.0	0.6
July	95	3.1	0.6	0.4	0.2		August	95	1.6	0.4	0.2	0.1
	90	3.2	0.6	0.4	0.2			90	1.6	0.4	0.2	0.1
	80	3.7	0.7	0.4	0.2			80	1.7	0.4	0.3	0.2
	70	4.0	0.8	0.4	0.2			70	1.7	0.5	0.3	0.2
	60	4.6	0.9	0.5	0.2			60	1.8	0.6	0.3	0.2
	50	5.3	1.0	0.5	0.3			50	1.9	0.7	0.3	0.2
September	95	1.2	0.3	0.2	0.1		October	95	1.4	0.4	0.2	0.1
	90	1.2	0.3	0.2	0.1			90	1.6	0.4	0.2	0.1
	80	1.2	0.3	0.2	0.1			80	1.8	0.4	0.2	0.2
	70	1.3	0.4	0.2	0.2			70	1.9	0.5	0.2	0.2
	60	1.6	0.5	0.2	0.2			60	2.1	0.5	0.2	0.2
	50	1.9	0.5	0.2	0.2			50	2.2	0.6	0.3	0.2
November	95	5.2	0.8	0.5	0.2		December	95	11.8	1.7	1.0	0.6
	90	5.6	0.9	0.5	0.2			90	13.0	1.9	1.1	0.6
	80	6.3	1.0	0.6	0.3			80	15.4	2.1	1.2	0.7
	70	7.0	1.1	0.6	0.3			70	17.7	2.4	1.4	0.7
	60	7.7	1.3	0.6	0.3			60	20.8	2.8	1.5	0.8
	50	10.1	1.4	0.6	0.4			50	27.7	3.2	1.5	0.8

Table D-4: San Lorenzo River Monitoring Station #4 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	6.1	1.1	0.6	0.3		February	95	8.1	1.3	1.0	0.4
	90	6.9	1.1	0.6	0.3			90	9.0	1.4	1.0	0.5
	80	8.5	1.2	0.8	0.4			80	10.9	1.6	1.0	0.6
	70	10.1	1.3	0.9	0.4			70	12.7	1.8	1.0	0.7
	60	11.7	1.5	0.9	0.4			60	15.6	2.1	1.0	0.8
	50	14.3	1.7	0.9	0.4			50	19.0	2.6	1.1	0.8
March	95	6.2	1.4	1.0	0.5		April	95	3.6	1.1	0.7	0.5
	90	6.7	1.5	1.0	0.6			90	3.9	1.1	0.7	0.5
	80	7.7	1.7	1.0	0.7			80	4.6	1.2	0.8	0.5
	70	8.6	2.0	1.0	0.8			70	5.2	1.4	0.8	0.5
	60	9.6	2.3	1.0	0.8			60	5.9	1.5	0.8	0.6
	50	11.7	2.6	1.1	0.9			50	6.5	1.7	0.9	0.6
May	95	1.8	0.8	0.4	0.3		June	95	1.2	0.5	0.3	0.2
	90	1.9	0.9	0.5	0.3			90	1.2	0.5	0.3	0.2
	80	2.1	0.9	0.5	0.3			80	1.3	0.6	0.3	0.2
	70	2.3	1.0	0.5	0.3			70	1.3	0.7	0.3	0.2
	60	2.5	1.0	0.6	0.4			60	1.4	0.8	0.3	0.2
	50	2.7	1.1	0.6	0.4			50	1.4	0.9	0.4	0.2
July	95	1.0	0.3	0.2	0.1		August	95	0.9	0.3	0.2	0.1
	90	1.0	0.3	0.2	0.1			90	1.0	0.3	0.2	0.1
	80	1.1	0.4	0.2	0.1			80	1.0	0.3	0.2	0.1
	70	1.1	0.5	0.2	0.2			70	1.0	0.3	0.2	0.1
	60	1.1	0.5	0.2	0.2			60	1.0	0.4	0.2	0.1
	50	1.2	0.8	0.3	0.2			50	1.0	0.8	0.2	0.1
September	95	1.0	0.3	0.2	0.1		October	95	1.0	0.3	0.2	0.1
	90	1.0	0.3	0.2	0.1			90	1.0	0.3	0.2	0.1
	80	1.1	0.3	0.2	0.1			80	1.1	0.4	0.2	0.2
	70	1.2	0.3	0.2	0.2			70	1.1	0.5	0.2	0.2
	60	1.3	0.4	0.2	0.2			60	1.2	0.8	0.2	0.2
	50	1.4	0.8	0.2	0.2			50	1.2	0.8	0.3	0.2
November	95	1.2	0.5	0.3	0.1		December	95	3.0	0.9	0.4	0.3
	90	1.2	0.5	0.3	0.2			90	3.7	0.9	0.5	0.3
	80	1.4	0.7	0.3	0.2			80	5.2	1.0	0.5	0.3
	70	1.5	0.9	0.4	0.3			70	6.7	1.0	0.5	0.3
	60	1.6	0.9	0.4	0.3			60	8.2	1.0	0.5	0.3
	50	1.8	0.9	0.4	0.3			50	9.7	1.1	0.6	0.4

Table D-5: Carbonera Creek - Monitoring Station #5 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	14.7	2.6	1.4	0.8		February	95	19.5	3.2	2.3	0.9
	90	16.6	2.7	1.6	0.8			90	21.7	3.4	2.3	1.1
	80	20.4	2.9	1.9	0.9			80	26.1	3.8	2.4	1.5
	70	24.2	3.1	2.2	0.9			70	30.5	4.3	2.4	1.7
	60	28.0	3.5	2.2	1.0			60	37.5	5.1	2.5	1.8
	50	34.3	4.0	2.3	1.1			50	45.6	6.1	2.6	2.0
March	95	15.0	3.3	2.4	1.1		April	95	8.6	2.6	1.7	1.1
	90	16.1	3.6	2.4	1.5			90	9.4	2.7	1.8	1.1
	80	18.4	4.2	2.4	1.7			80	10.9	2.9	1.8	1.2
	70	20.7	4.8	2.4	1.9			70	12.5	3.3	2.0	1.3
	60	23.0	5.5	2.5	2.0			60	14.1	3.7	2.0	1.4
	50	28.2	6.2	2.6	2.1			50	15.6	4.1	2.1	1.4
May	95	4.3	2.0	1.1	0.7		June	95	2.9	1.2	0.7	0.5
	90	4.5	2.1	1.1	0.7			90	3.0	1.3	0.7	0.5
	80	5.0	2.3	1.2	0.8			80	3.1	1.4	0.7	0.5
	70	5.5	2.4	1.3	0.8			70	3.2	1.7	0.8	0.6
	60	5.9	2.5	1.3	0.9			60	3.3	2.0	0.8	0.6
	50	6.4	2.6	1.4	0.9			50	3.4	2.1	0.9	0.6
July	95	2.5	0.8	0.5	0.3		August	95	2.3	0.6	0.4	0.2
	90	2.5	0.8	0.5	0.3			90	2.3	0.7	0.4	0.3
	80	2.6	1.0	0.5	0.4			80	2.3	0.7	0.5	0.3
	70	2.6	1.1	0.5	0.4			70	2.4	0.8	0.5	0.3
	60	2.7	1.3	0.6	0.4			60	2.4	1.0	0.5	0.4
	50	2.8	2.0	0.6	0.4			50	2.5	1.8	0.5	0.4
September	95	2.3	0.6	0.4	0.3		October	95	2.4	0.7	0.5	0.3
	90	2.4	0.7	0.4	0.3			90	2.4	0.8	0.5	0.3
	80	2.6	0.7	0.5	0.4			80	2.6	0.9	0.5	0.4
	70	2.9	0.8	0.5	0.4			70	2.7	1.3	0.6	0.4
	60	3.1	0.9	0.5	0.4			60	2.8	1.9	0.6	0.4
	50	3.3	1.9	0.5	0.4			50	2.9	2.0	0.6	0.4
November	95	2.8	1.1	0.8	0.3		December	95	7.1	2.1	1.0	0.7
	90	3.0	1.2	0.8	0.4			90	8.9	2.2	1.1	0.7
	80	3.3	1.7	0.8	0.5			80	12.5	2.3	1.2	0.8
	70	3.6	2.0	0.9	0.6			70	16.1	2.4	1.2	0.8
	60	3.9	2.1	0.9	0.7			60	19.7	2.5	1.3	0.9
	50	4.3	2.2	0.9	0.7			50	23.3	2.7	1.4	0.9

Table D-6: Branciforte Monitoring Station #6 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	26.4	4.1	3.2	1.3		February	95	38.3	6.0	3.5	1.8
	90	29.9	4.3	3.2	1.5			90	42.1	6.6	3.6	2.0
	80	36.8	4.7	3.3	2.0			80	49.6	7.6	3.8	2.4
	70	43.7	5.0	3.3	2.2			70	57.4	9.0	3.9	2.9
	60	50.6	5.5	3.4	2.5			60	69.1	10.3	4.1	3.1
	50	64.1	6.3	3.4	2.6			50	80.7	11.9	4.3	3.2
March	95	27.6	6.5	3.8	3.0		April	95	15.7	4.5	3.3	2.6
	90	29.5	6.9	3.8	3.1			90	16.8	4.7	3.4	2.7
	80	33.4	7.6	4.0	3.2			80	19.2	5.2	3.4	2.8
	70	37.3	8.6	4.3	3.3			70	21.6	5.7	3.5	2.9
	60	41.2	9.8	4.5	3.3			60	24.0	6.3	3.7	2.9
	50	45.7	11.2	4.8	3.3			50	26.4	7.1	3.8	3.0
May	95	8.9	3.9	3.2	2.4		June	95	5.7	3.4	2.9	2.1
	90	9.4	4.1	3.2	2.5			90	5.8	3.4	2.9	2.1
	80	10.3	4.3	3.3	2.7			80	6.0	3.6	2.9	2.2
	70	11.3	4.6	3.4	2.7			70	6.2	3.7	3.0	2.3
	60	12.2	4.8	3.4	2.8			60	6.4	3.9	3.0	2.4
	50	13.2	5.1	3.5	2.8			50	6.8	4.1	3.1	2.5
July	95	4.4	2.9	2.6	2.0		August	95	3.7	2.8	2.4	2.1
	90	4.4	3.0	2.6	2.0			90	3.8	2.9	2.5	2.2
	80	4.6	3.1	2.6	2.1			80	3.8	2.9	2.5	2.2
	70	4.7	3.1	2.7	2.2			70	3.9	3.0	2.6	2.3
	60	5.0	3.2	2.8	2.2			60	4.0	3.0	2.7	2.3
	50	5.1	3.4	2.8	2.3			50	4.1	3.1	2.7	2.3
September	95	3.6	2.8	2.5	1.9		October	95	4.0	3.0	2.4	1.9
	90	3.7	2.9	2.5	1.9			90	4.4	3.0	2.5	2.0
	80	4.0	2.9	2.5	2.0			80	5.1	3.0	2.5	2.1
	70	4.2	3.0	2.6	2.1			70	5.9	3.1	2.6	2.2
	60	4.4	3.0	2.6	2.2			60	6.7	3.2	2.7	2.2
	50	4.6	3.1	2.7	2.2			50	7.5	3.2	2.7	2.3
November	95	4.5	3.0	2.5	1.9		December	95	8.9	3.4	3.0	1.9
	90	4.7	3.1	2.5	2.0			90	10.3	3.5	3.0	1.9
	80	5.2	3.2	2.5	2.0			80	13.1	3.6	3.1	2.1
	70	5.7	3.2	2.7	2.1			70	15.9	3.7	3.2	2.2
	60	6.2	3.3	2.7	2.1			60	18.7	4.0	3.2	2.4
	50	7.0	3.4	2.8	2.2			50	21.5	4.3	3.2	2.5

Table D-7: Bean Creek Monitoring Station #7 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	24.8	3.8	3.0	1.2		February	95	35.9	5.7	3.3	1.7
	90	28.1	4.0	3.0	1.4			90	39.5	6.2	3.4	1.9
	80	34.6	4.4	3.1	1.9			80	46.6	7.2	3.5	2.2
	70	41.0	4.7	3.1	2.1			70	53.9	8.4	3.7	2.7
	60	47.5	5.2	3.2	2.4			60	64.9	9.7	3.9	2.9
	50	60.2	6.0	3.2	2.4			50	75.8	11.2	4.0	3.0
March	95	25.9	6.1	3.5	2.9		April	95	14.7	4.2	3.1	2.5
	90	27.7	6.5	3.6	2.9			90	15.8	4.5	3.2	2.5
	80	31.4	7.2	3.8	3.0			80	18.0	4.9	3.2	2.6
	70	35.0	8.1	4.1	3.1			70	20.2	5.3	3.3	2.7
	60	38.7	9.2	4.2	3.1			60	22.4	5.9	3.5	2.8
	50	42.9	10.5	4.5	3.1			50	24.6	6.7	3.5	2.8
May	95	7.7	3.4	2.7	2.1		June	95	4.9	2.9	2.5	1.8
	90	8.1	3.5	2.7	2.2			90	5.0	3.0	2.5	1.9
	80	8.9	3.7	2.8	2.3			80	5.1	3.1	2.5	1.9
	70	9.7	3.9	2.9	2.3			70	5.3	3.2	2.6	2.0
	60	10.5	4.1	2.9	2.4			60	5.5	3.3	2.6	2.1
	50	11.4	4.4	3.0	2.4			50	5.9	3.5	2.7	2.1
July	95	3.8	2.5	2.2	1.7		August	95	3.2	2.4	2.1	1.8
	90	3.8	2.6	2.3	1.8			90	3.2	2.5	2.1	1.9
	80	3.9	2.6	2.3	1.8			80	3.3	2.5	2.2	1.9
	70	4.1	2.7	2.3	1.9			70	3.3	2.6	2.2	1.9
	60	4.3	2.8	2.4	1.9			60	3.5	2.6	2.3	2.0
	50	4.4	2.9	2.4	2.0			50	3.5	2.7	2.3	2.0
September	95	3.1	2.5	2.1	1.6		October	95	3.4	2.6	2.1	1.7
	90	3.2	2.5	2.1	1.7			90	3.8	2.6	2.1	1.7
	80	3.4	2.5	2.2	1.7			80	4.4	2.6	2.2	1.8
	70	3.6	2.6	2.2	1.8			70	5.1	2.7	2.3	1.8
	60	3.8	2.6	2.2	1.9			60	5.8	2.7	2.3	1.9
	50	4.0	2.7	2.3	1.9			50	6.4	2.8	2.3	2.0
November	95	4.2	2.8	2.3	1.8		December	95	8.3	3.2	2.8	1.7
	90	4.4	2.9	2.3	1.9			90	9.7	3.2	2.8	1.8
	80	4.9	3.0	2.4	1.9			80	12.3	3.3	2.9	1.9
	70	5.3	3.0	2.5	2.0			70	14.9	3.5	3.0	2.1
	60	5.8	3.1	2.6	2.0			60	17.6	3.7	3.0	2.2
	50	6.6	3.2	2.6	2.1			50	20.2	4.0	3.0	2.4

Table D-8: Bean Creek Monitoring Station #8 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	26.3	2.6	1.4	0.8		February	95	45.6	4.9	1.9	0.9
	90	30.5	2.9	1.4	0.8			90	51.2	5.5	2.0	0.9
	80	38.9	3.4	1.5	0.9			80	62.6	6.7	2.2	1.0
	70	47.3	3.9	1.5	1.0			70	74.0	8.6	2.5	1.1
	60	55.7	4.6	1.5	1.0			60	91.9	10.7	2.6	1.1
	50	64.0	5.3	1.6	1.1			50	112.6	12.8	2.8	1.2
March	95	35.8	6.2	2.2	0.9		April	95	21.3	3.3	1.8	0.6
	90	39.1	6.9	2.4	1.0			90	23.3	3.7	1.9	0.7
	80	45.8	8.0	2.7	1.1			80	27.4	4.3	2.0	0.8
	70	52.4	9.0	2.9	1.3			70	31.5	5.0	2.1	1.0
	60	59.0	10.3	3.2	1.4			60	35.6	5.8	2.2	1.1
	50	68.9	12.2	3.6	1.5			50	39.7	7.0	2.3	1.2
May	95	17.0	3.8	2.4	0.9		June	95	8.6	2.4	1.5	0.3
	90	18.2	4.1	2.5	1.1			90	8.8	2.5	1.5	0.4
	80	20.8	4.6	2.7	1.3			80	9.1	2.8	1.6	0.5
	70	23.3	5.2	2.8	1.5			70	9.8	3.0	1.7	0.6
	60	25.8	5.9	2.9	1.7			60	10.6	3.5	1.8	0.8
	50	28.3	3.7	3.0	1.9			50	11.2	4.1	1.9	0.9
July	95	5.0	1.3	0.6	0.1		August	95	3.1	0.9	0.4	0.0
	90	5.1	1.4	0.7	0.1			90	3.2	0.9	0.4	0.0
	80	5.4	1.6	0.8	0.2			80	3.5	1.0	0.4	0.1
	70	5.8	1.7	0.8	0.3			70	3.6	1.1	0.5	0.1
	60	6.4	1.9	0.8	0.3			60	3.8	1.4	0.6	0.2
	50	6.8	2.2	0.9	0.3			50	4.0	1.5	0.6	0.2
September	95	2.9	0.9	0.4	0.0		October	95	3.7	1.0	0.6	0.1
	90	3.2	0.9	0.4	0.0			90	4.8	1.1	0.6	0.2
	80	3.8	1.0	0.5	0.1			80	6.9	1.2	0.6	0.3
	70	4.5	1.0	0.5	0.1			70	9.1	1.4	0.7	0.3
	60	5.1	1.2	0.5	0.2			60	11.2	1.6	0.8	0.3
	50	5.7	1.4	0.6	0.2			50	13.3	1.7	0.8	0.4
November	95	3.6	1.1	0.7	0.4		December	95	8.8	1.6	1.1	0.5
	90	4.0	1.1	0.7	0.4			90	10.1	1.7	1.1	0.6
	80	4.8	1.2	0.7	0.4			80	12.7	1.8	1.2	0.8
	70	5.5	1.3	0.7	0.4			70	15.2	2.1	1.2	0.8
	60	6.3	1.4	0.8	0.5			60	17.8	2.7	1.3	0.8
	50	7.3	1.6	0.8	0.5			50	20.4	3.1	1.3	0.9

Table D-9: Zayante Monitoring Station #9 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	17.5	1.7	0.9	0.5		February	95	30.3	3.2	1.2	0.6
	90	20.3	1.9	1.0	0.6			90	34.1	3.6	1.3	0.6
	80	25.9	2.3	1.0	0.6			80	41.6	4.4	1.5	0.7
	70	31.4	2.6	1.0	0.6			70	49.2	5.7	1.6	0.7
	60	37.0	3.1	1.0	0.7			60	61.1	7.1	1.8	0.8
	50	42.6	3.5	1.1	0.7			50	74.8	8.5	1.9	0.8
March	95	23.8	4.1	1.5	0.6		April	95	14.1	2.2	1.2	0.4
	90	26.0	4.5	1.6	0.7			90	15.5	2.4	1.3	0.5
	80	30.4	5.3	1.8	0.8			80	18.2	2.9	1.3	0.6
	70	34.8	6.0	1.9	0.9			70	20.9	3.3	1.4	0.6
	60	39.2	6.8	2.1	0.9			60	23.7	3.8	1.5	0.7
	50	45.8	8.1	2.4	1.0			50	26.4	4.6	1.5	0.8
May	95	6.2	1.4	0.9	0.3		June	95	3.1	0.9	0.5	0.1
	90	6.6	1.5	0.9	0.4			90	3.2	0.9	0.6	0.1
	80	7.5	1.7	1.0	0.5			80	3.3	1.0	0.6	0.2
	70	8.4	1.8	1.0	0.6			70	3.5	1.1	0.6	0.2
	60	9.4	2.0	1.1	0.6			60	3.7	1.3	0.6	0.3
	50	10.3	2.4	1.1	0.7			50	3.9	1.5	0.7	0.3
July	95	1.8	0.5	0.2	0.0		August	95	1.1	0.3	0.1	0.0
	90	1.8	0.5	0.2	0.0			90	1.1	0.3	0.1	0.0
	80	2.0	0.6	0.3	0.1			80	1.2	0.4	0.2	0.0
	70	2.1	0.6	0.3	0.1			70	1.3	0.4	0.2	0.0
	60	2.3	0.7	0.3	0.1			60	1.4	0.5	0.2	0.1
	50	2.5	0.8	0.3	0.1			50	1.4	0.6	0.2	0.1
September	95	1.1	0.3	0.2	0.0		October	95	1.3	0.4	0.2	0.0
	90	1.2	0.3	0.2	0.0			90	1.7	0.4	0.2	0.1
	80	1.4	0.4	0.2	0.0			80	2.5	0.4	0.2	0.1
	70	1.6	0.4	0.2	0.0			70	3.3	0.5	0.3	0.1
	60	1.8	0.4	0.2	0.1			60	4.1	0.6	0.3	0.1
	50	2.1	0.5	0.2	0.1			50	4.8	0.6	0.3	0.1
November	95	2.4	0.7	0.5	0.2		December	95	5.9	1.0	0.8	0.4
	90	2.7	0.7	0.5	0.3			90	6.7	1.1	0.8	0.4
	80	3.2	0.8	0.5	0.3			80	8.4	1.2	0.8	0.5
	70	3.7	0.9	0.5	0.3			70	10.1	1.5	0.8	0.5
	60	4.2	0.9	0.5	0.3			60	11.8	1.7	0.8	0.6
	50	4.9	1.1	0.6	0.3			50	13.5	2.0	0.9	0.6

Table D-10: Zayante Monitoring Station #10 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	11.1	1.1	0.5	0.3		February	95	18.8	2.0	0.8	0.4
	90	12.1	1.2	0.5	0.3			90	20.5	2.1	0.9	0.4
	80	14.1	1.5	0.6	0.4			80	23.9	2.5	1.1	0.4
	70	16.1	1.8	0.6	0.4			70	28.1	2.8	1.2	0.4
	60	19.5	2.4	0.6	0.4			60	32.5	3.4	1.3	0.4
	50	24.4	3.0	0.7	0.4			50	40.7	4.0	1.4	0.5
March	95	18.9	4.1	1.1	0.5		April	95	8.1	2.1	0.8	0.3
	90	19.9	4.6	1.1	0.5			90	8.8	2.2	0.8	0.3
	80	21.8	5.7	1.2	0.6			80	10.2	2.4	0.9	0.3
	70	24.7	6.4	1.3	0.6			70	11.6	2.7	0.9	0.4
	60	31.1	7.1	1.5	0.8			60	13.5	3.0	1.1	0.4
	50	37.8	8.5	1.8	0.8			50	15.3	3.5	1.5	0.5
May	95	3.7	1.2	0.8	0.3		June	95	1.7	0.7	0.5	0.2
	90	3.9	1.2	0.8	0.3			90	1.7	0.8	0.5	0.2
	80	4.1	1.3	0.9	0.3			80	1.8	0.8	0.6	0.2
	70	4.4	1.4	0.9	0.3			70	2.1	0.9	0.6	0.3
	60	5.1	1.4	1.0	0.3			60	2.4	1.0	0.7	0.3
	50	5.9	1.6	1.0	0.4			50	2.6	1.1	0.7	0.3
July	95	1.0	0.5	0.3	0.2		August	95	0.7	0.4	0.3	0.2
	90	1.1	0.5	0.3	0.2			90	0.7	0.4	0.3	0.2
	80	1.2	0.6	0.4	0.2			80	0.7	0.4	0.3	0.2
	70	1.3	0.6	0.4	0.2			70	0.8	0.4	0.3	0.2
	60	1.3	0.6	0.4	0.2			60	0.8	0.5	0.3	0.2
	50	1.5	0.6	0.4	0.2			50	0.8	0.5	0.3	0.2
September	95	0.6	0.3	0.3	0.2		October	95	0.6	0.3	0.2	0.1
	90	0.6	0.3	0.3	0.2			90	0.6	0.3	0.2	0.2
	80	0.6	0.3	0.3	0.2			80	0.7	0.3	0.2	0.2
	70	0.6	0.3	0.3	0.2			70	0.7	0.3	0.2	0.2
	60	0.6	0.4	0.3	0.2			60	0.8	0.3	0.2	0.2
	50	0.7	0.4	0.3	0.2			50	0.8	0.4	0.2	0.2
November	95	1.4	0.4	0.3	0.2		December	95	4.5	0.6	0.4	0.3
	90	1.6	0.4	0.3	0.2			90	5.1	0.7	0.4	0.3
	80	2.0	0.4	0.3	0.2			80	6.4	0.8	0.4	0.3
	70	2.4	0.5	0.3	0.2			70	7.6	0.9	0.4	0.3
	60	2.8	0.5	0.3	0.2			60	9.0	1.1	0.4	0.3
	50	3.6	0.6	0.3	0.2			50	12.0	1.3	0.5	0.3

Table D-11: Fall Creek Monitoring Station #11 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	23.2	2.0	1.0	0.6		February	95	45.6	3.4	1.5	0.8
	90	26.2	2.3	1.1	0.7			90	49.8	3.8	1.6	0.8
	80	32.2	3.0	1.1	0.7			80	58.2	4.6	1.7	0.9
	70	38.2	3.6	1.2	0.7			70	66.6	5.5	1.9	0.9
	60	44.1	4.2	1.3	0.8			60	82.7	7.2	2.1	1.0
	50	50.1	5.2	1.3	0.8			50	99.6	9.4	2.2	1.0
March	95	38.2	7.9	2.4	1.2		April	95	15.9	3.6	1.8	0.9
	90	41.5	8.4	2.7	1.3			90	18.1	4.0	1.8	1.0
	80	48.2	9.4	3.2	1.4			80	22.3	4.6	1.9	1.1
	70	57.2	11.0	3.7	1.4			70	26.6	5.2	2.0	1.2
	60	72.0	12.4	4.1	1.5			60	31.2	5.8	2.1	1.4
	50	90.4	13.7	4.8	1.7			50	38.0	6.9	2.3	1.4
May	95	7.6	1.8	1.1	0.5		June	95	4.6	1.0	0.6	0.3
	90	7.9	1.9	1.2	0.5			90	4.8	1.1	0.6	0.3
	80	8.6	2.3	1.2	0.6			80	4.9	1.2	0.6	0.4
	70	9.3	2.6	1.2	0.7			70	5.1	1.5	0.7	0.4
	60	10.0	3.0	1.2	0.8			60	5.4	1.6	0.7	0.4
	50	12.1	3.8	1.3	0.8			50	5.7	1.8	0.8	0.4
July	95	2.3	0.4	0.3	0.1		August	95	1.1	0.3	0.2	0.1
	90	2.3	0.5	0.3	0.1			90	1.2	0.3	0.2	0.1
	80	2.7	0.5	0.3	0.1			80	1.2	0.3	0.2	0.1
	70	2.9	0.6	0.3	0.2			70	1.3	0.4	0.2	0.1
	60	3.4	0.6	0.3	0.2			60	1.3	0.4	0.2	0.1
	50	3.9	0.7	0.4	0.2			50	1.4	0.5	0.2	0.2
September	95	0.9	0.2	0.1	0.1		October	95	1.0	0.3	0.2	0.1
	90	0.9	0.2	0.1	0.1			90	1.1	0.3	0.2	0.1
	80	0.9	0.2	0.1	0.1			80	1.3	0.3	0.2	0.1
	70	0.9	0.3	0.1	0.1			70	1.4	0.3	0.2	0.1
	60	1.1	0.3	0.1	0.1			60	1.5	0.4	0.2	0.1
	50	1.4	0.4	0.1	0.1			50	1.6	0.4	0.2	0.1
November	95	3.8	0.6	0.4	0.2		December	95	8.7	1.3	0.8	0.5
	90	4.1	0.7	0.4	0.2			90	9.5	1.4	0.8	0.5
	80	4.6	0.7	0.4	0.2			80	11.3	1.5	0.9	0.5
	70	5.1	0.8	0.4	0.2			70	13.0	1.7	1.0	0.5
	60	5.7	0.9	0.5	0.2			60	15.3	2.0	1.1	0.6
	50	7.4	1.0	0.5	0.3			50	20.4	2.4	1.1	0.6

Table D-12: Bear Creek - Monitoring Station #12 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	28.8	2.8	1.4	0.9		February	95	48.8	5.1	2.2	0.9
	90	31.4	3.2	1.4	0.9			90	53.1	5.5	2.4	1.0
	80	36.6	3.8	1.5	0.9			80	61.8	6.5	2.9	1.0
	70	41.7	4.8	1.5	0.9			70	72.9	7.4	3.1	1.1
	60	50.6	6.2	1.6	1.0			60	84.2	8.8	3.4	1.1
	50	63.3	7.7	1.8	1.0			50	105.4	10.3	3.6	1.2
March	95	48.9	10.6	2.8	1.2		April	95	21.0	5.4	2.1	0.7
	90	51.5	11.9	2.9	1.3			90	22.8	5.6	2.1	0.7
	80	56.6	14.8	3.1	1.4			80	26.5	6.2	2.2	0.9
	70	64.0	16.6	3.4	1.7			70	30.1	7.0	2.4	1.0
	60	80.6	18.4	3.9	2.0			60	34.9	7.9	2.7	1.1
	50	98.0	22.0	4.6	2.1			50	39.6	9.0	4.0	1.2
May	95	9.6	3.0	2.1	0.7		June	95	4.4	1.9	1.4	0.6
	90	10.0	3.1	2.1	0.7			90	4.5	2.0	1.4	0.6
	80	10.7	3.3	2.3	0.8			80	4.8	2.2	1.5	0.6
	70	11.4	3.5	2.3	0.8			70	5.6	2.3	1.6	0.7
	60	13.2	3.8	2.5	0.9			60	6.1	2.5	1.7	0.7
	50	15.3	4.1	2.6	0.9			50	6.7	2.8	1.7	0.7
July	95	2.7	1.4	0.8	0.5		August	95	1.7	1.0	0.8	0.5
	90	3.0	1.4	0.8	0.5			90	1.7	1.0	0.8	0.5
	80	3.2	1.5	1.0	0.5			80	1.8	1.1	0.8	0.5
	70	3.3	1.6	1.0	0.5			70	2.0	1.1	0.8	0.5
	60	3.5	1.6	1.0	0.6			60	2.0	1.2	0.8	0.6
	50	3.8	1.7	1.1	0.6			50	2.1	1.2	0.9	0.6
September	95	1.5	0.8	0.7	0.5		October	95	1.5	0.7	0.5	0.4
	90	1.5	0.8	0.7	0.5			90	1.6	0.7	0.5	0.4
	80	1.6	0.8	0.7	0.5			80	1.7	0.8	0.5	0.4
	70	1.6	0.9	0.7	0.6			70	1.9	0.8	0.5	0.4
	60	1.7	0.9	0.7	0.6			60	2.0	0.9	0.6	0.4
	50	1.7	1.0	0.7	0.6			50	2.1	1.0	0.6	0.4
November	95	3.7	1.0	0.7	0.5		December	95	11.7	1.6	1.0	0.7
	90	4.2	1.1	0.7	0.5			90	13.3	1.8	1.0	0.7
	80	5.2	1.1	0.7	0.5			80	16.5	2.1	1.0	0.7
	70	6.2	1.2	0.8	0.5			70	19.8	2.4	1.0	0.8
	60	7.2	1.3	0.8	0.5			60	23.4	2.9	1.1	0.8
	50	9.2	1.4	0.9	0.6			50	31.0	3.4	1.2	0.9

Table D-13: Boulder Creek - Monitoring Station #13 flow frequency (in cfs) for wet, average, dry and drought conditions.

Month	Exceedence Probability	Wet	Average	Dry	Drought		Month	Exceedence Probability	Wet	Average	Dry	Drought
January	95	9.8	0.8	0.4	0.3		February	95	19.2	1.4	0.6	0.3
	90	11.1	1.0	0.5	0.3			90	21.0	1.6	0.7	0.3
	80	13.6	1.2	0.5	0.3			80	24.5	1.9	0.7	0.4
	70	16.1	1.5	0.5	0.3			70	28.1	2.3	0.8	0.4
	60	18.6	1.8	0.5	0.3			60	34.9	3.0	0.9	0.4
	50	21.1	2.2	0.6	0.3			50	42.0	4.0	0.9	0.4
March	95	16.1	3.3	1.0	0.5		April	95	6.7	1.5	0.8	0.4
	90	17.5	3.6	1.1	0.5			90	7.6	1.7	0.8	0.4
	80	20.3	4.0	1.4	0.6			80	9.4	1.9	0.8	0.5
	70	24.1	4.6	1.6	0.6			70	11.2	2.2	0.8	0.5
	60	30.4	5.2	1.7	0.6			60	13.2	2.4	0.9	0.6
	50	38.1	5.8	2.1	0.7			50	16.0	2.9	1.0	0.6
May	95	3.2	0.8	0.5	0.2		June	95	1.9	0.4	0.2	0.1
	90	3.3	0.8	0.5	0.2			90	2.0	0.4	0.2	0.1
	80	3.6	1.0	0.5	0.2			80	2.1	0.5	0.3	0.2
	70	3.9	1.1	0.5	0.3			70	2.2	0.6	0.3	0.2
	60	4.2	1.3	0.5	0.3			60	2.3	0.7	0.3	0.2
	50	5.1	1.6	0.6	0.3			50	2.4	0.7	0.3	0.2
July	95	1.0	0.2	0.1	0.0		August	95	0.5	0.1	0.1	0.0
	90	1.0	0.2	0.1	0.1			90	0.5	0.1	0.1	0.0
	80	1.2	0.2	0.1	0.1			80	0.5	0.1	0.1	0.1
	70	1.2	0.2	0.1	0.1			70	0.5	0.2	0.1	0.1
	60	1.4	0.3	0.1	0.1			60	0.6	0.2	0.1	0.1
	50	1.6	0.3	0.1	0.1			50	0.6	0.2	0.1	0.1
September	95	0.4	0.1	0.1	0.0		October	95	0.4	0.1	0.1	0.0
	90	0.4	0.1	0.1	0.0			90	0.5	0.1	0.1	0.0
	80	0.4	0.1	0.1	0.0			80	0.6	0.1	0.1	0.0
	70	0.4	0.1	0.1	0.1			70	0.6	0.1	0.1	0.0
	60	0.5	0.1	0.1	0.1			60	0.6	0.2	0.1	0.0
	50	0.6	0.2	0.1	0.1			50	0.7	0.2	0.1	0.1
November	95	1.6	0.3	0.2	0.1		December	95	3.7	0.5	0.3	0.2
	90	1.7	0.3	0.2	0.1			90	4.0	0.6	0.3	0.2
	80	1.9	0.3	0.2	0.1			80	4.8	0.6	0.4	0.2
	70	2.2	0.4	0.2	0.1			70	5.5	0.7	0.4	0.2
	60	2.4	0.4	0.2	0.1			60	6.4	0.9	0.5	0.2
	50	3.1	0.4	0.2	0.1			50	8.6	1.0	0.5	0.3

Table D-14: Kings Creek - Monitoring Station #14 flow frequency (in cfs) for wet, average, dry and drought conditions.

APPENDIX E –SECTION 2.5 ADDITIONAL FIGURES (Regression charts)

Appendix E. Regression Plots of Density of Young-of-the-Year Steelhead as a Function of Streamflow in the San Lorenzo River Drainage.

Figure 1. Relationship Between Averaged Mean Monthly Streamflow (May- September) at the Big Trees Gage and the Density of YOY Steelhead => 75 mm SL at the San Lorenzo River Gorge Site for 1994-97.

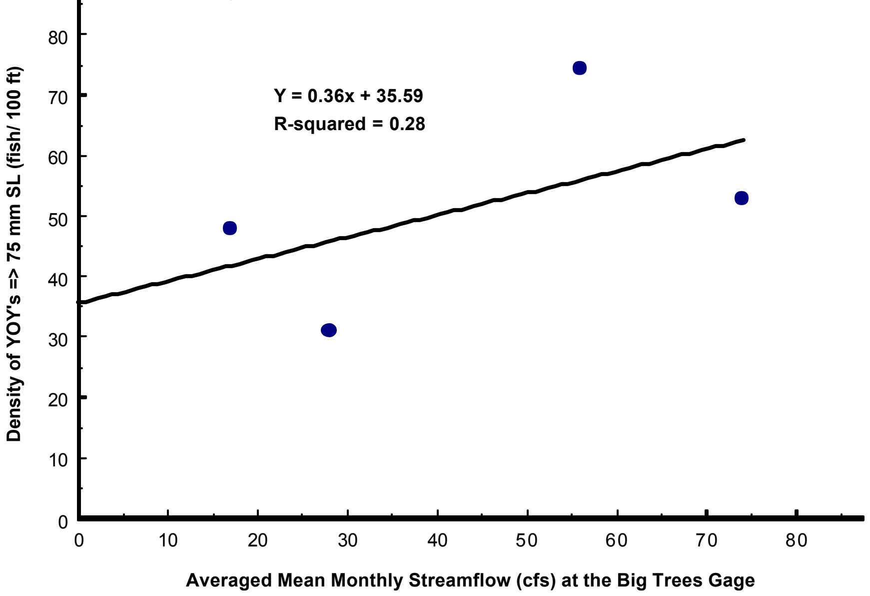


Figure 2. Relationship Between the Annual Minimum Daily Streamflow at the Big Trees Gage and the Density of YOY Steelhead => 75 mm SL at the San Lorenzo River Gorge Site in 1994-97.

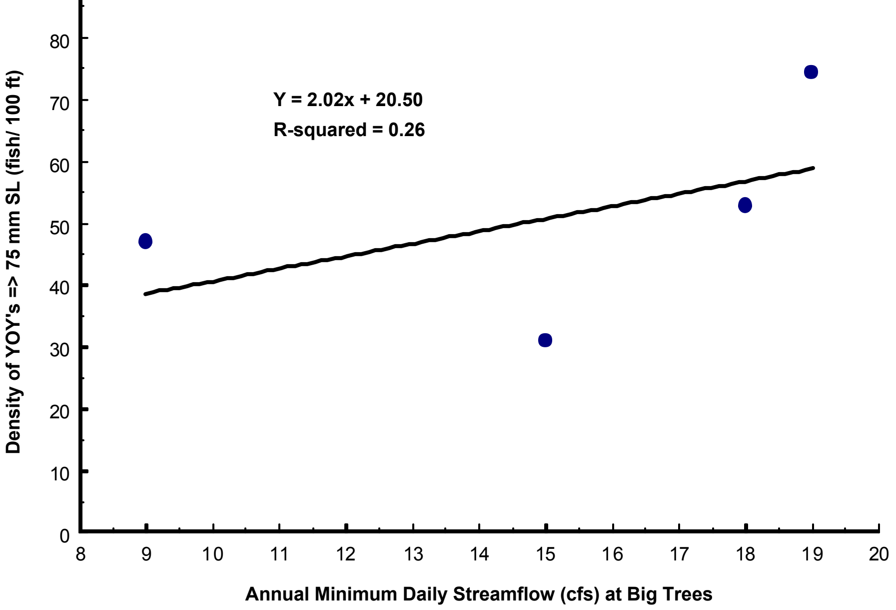


Figure 3. Relationship Between the Averaged Mean Monthly Streamflow (May- September) at the Big Trees Gage and the Density of YOY Steelhead => 75 mm SL at the Site Below the Henry Cowell Bridge on the San Lorenzo River in 1994-1997.

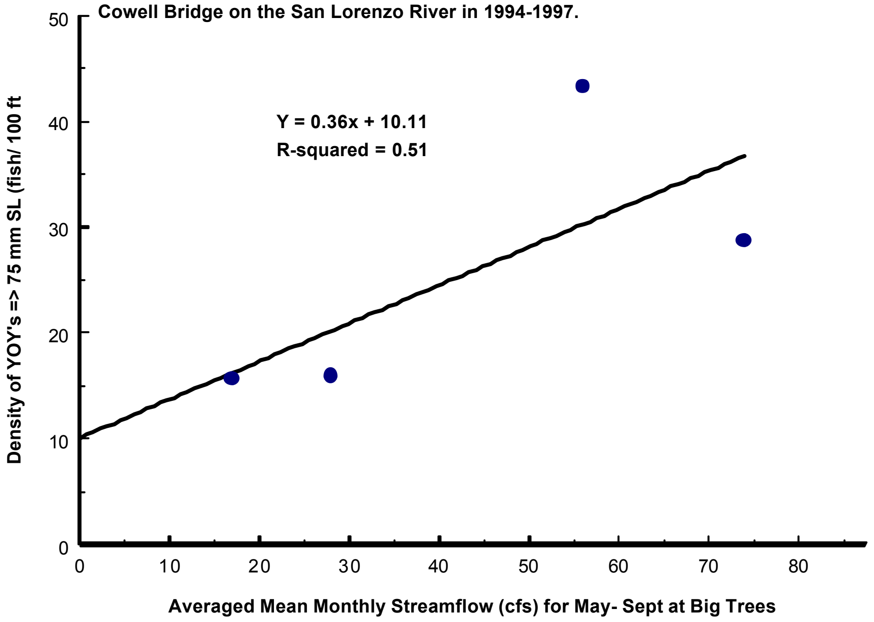


Figure 4. Relationship Between Annual Minimum Daily Streamflow at Big Trees and the Annual Density of YOY Steelhead => 75 mm SL at the Site Below the Henry Cowell Bridge Over the San Lorenzo River in 1994-97.

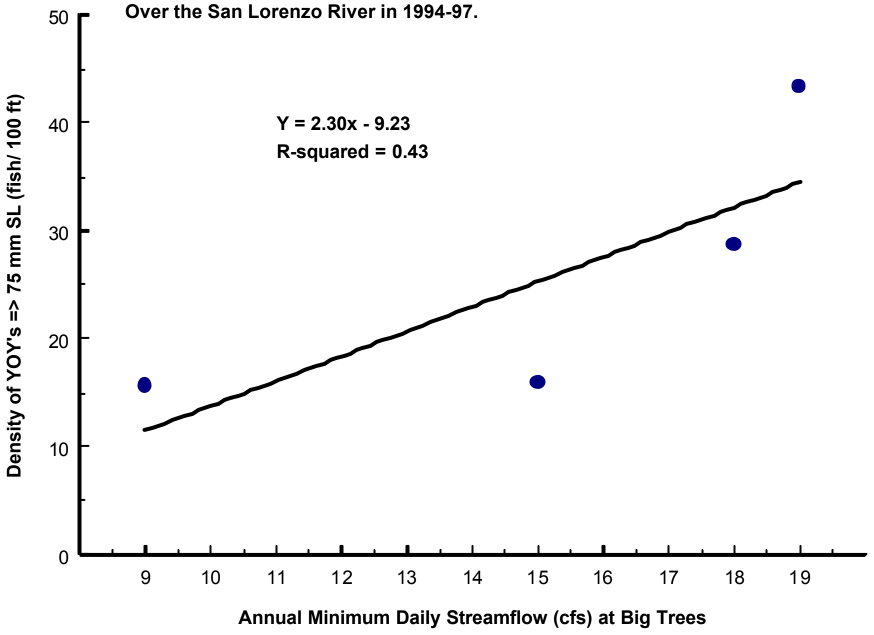


Figure 5. Relationship Between Averaged Mean Monthly Streamflow (May-September) at the Big Trees Gage and the Average Density of YOY Steelhead Reaching Yearling Size (=>75 mm SL) at Four Middle San Lorenzo River Sites in 1981 and 1994-97.

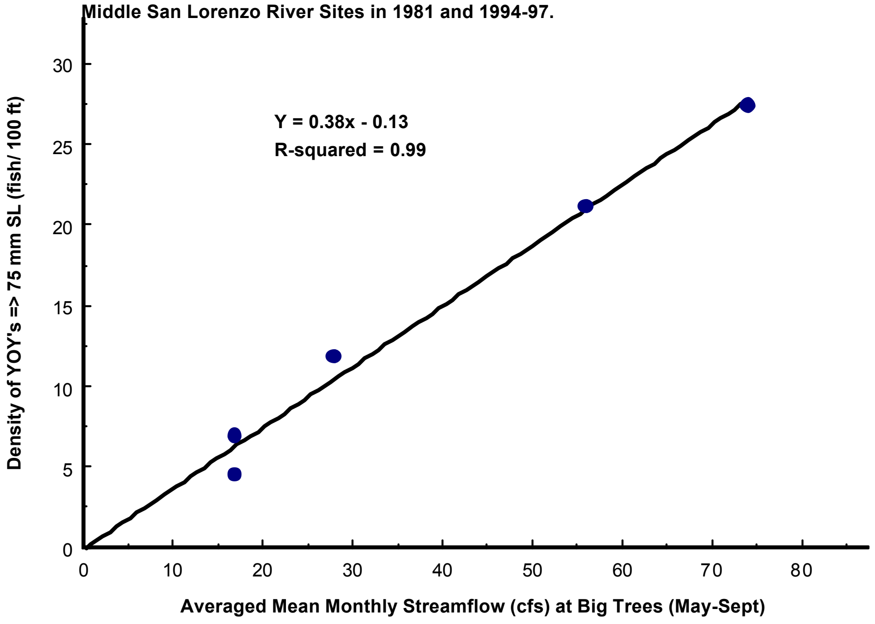


Figure 6. Relationship Between Annual Minimum Daily Streamflow at the Big Trees Gage and the Average Density of YOY Steelhead Reaching Yearling Size (=> 75 mm SL) at Four Middle San Lorenzo River Sites in 1981 and 1994-97.

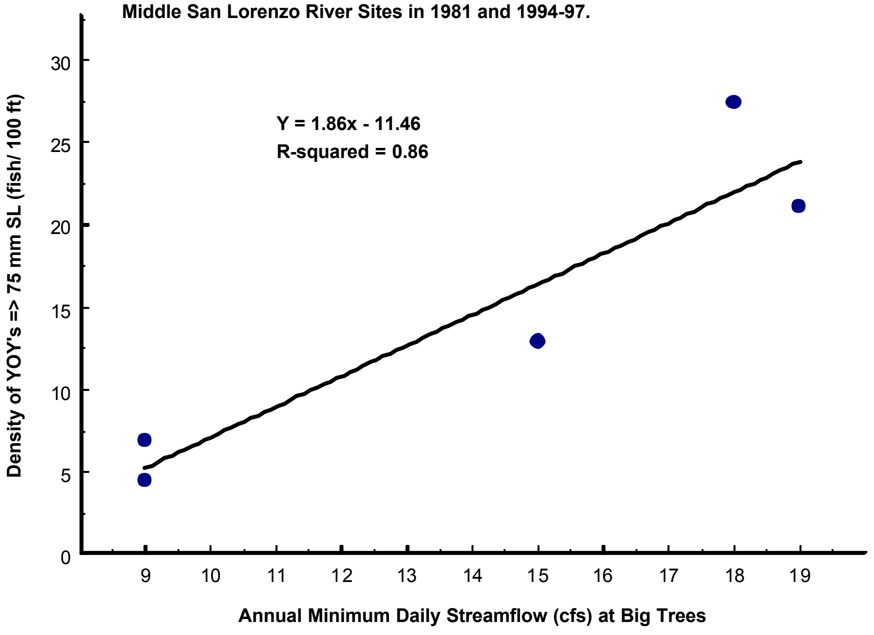


Figure 7. Relationship Between Annual Minimum Streamflow and the Density of YOY Steelhead Reaching Yearling Size (=> 75 mm SL) at the San Lorenzo River Site Below Fall Creek in 1981 and 1994-97.

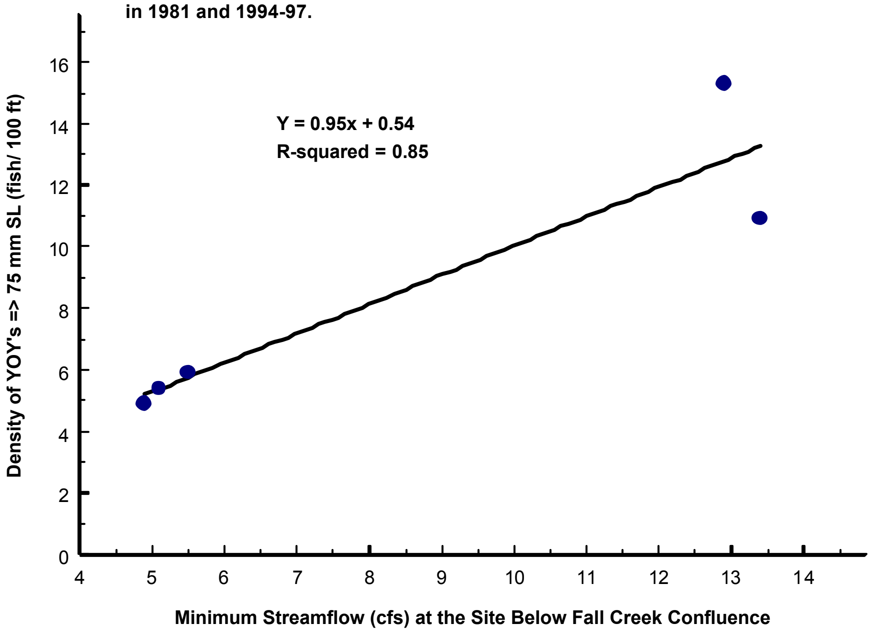


Figure 8. Relationship Between Annual Minimum Streamflow and the Density of YOY Steelhead Reaching Yearling Size (=> 75 mm SL) at the San Lorenzo River Site in Ben Lomond in 1981 and 1994-97.

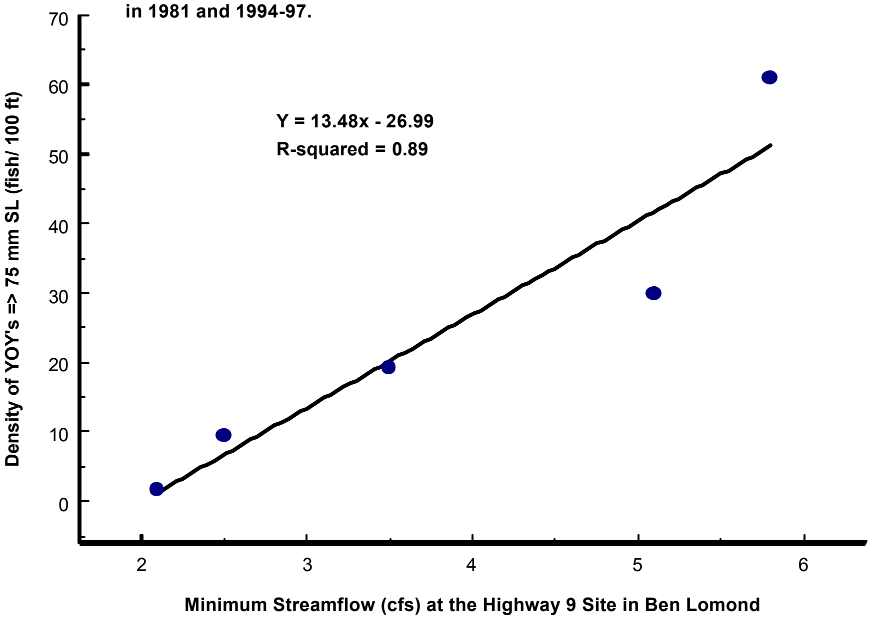


Figure 9. Relationship Between Annual Minimum Streamflow and the Density of YOY Steelhead Reaching Yearling Size (=> 75 mm SL) at the San Lorenzo River Site in Brookdale in 1981 and 1994-97.

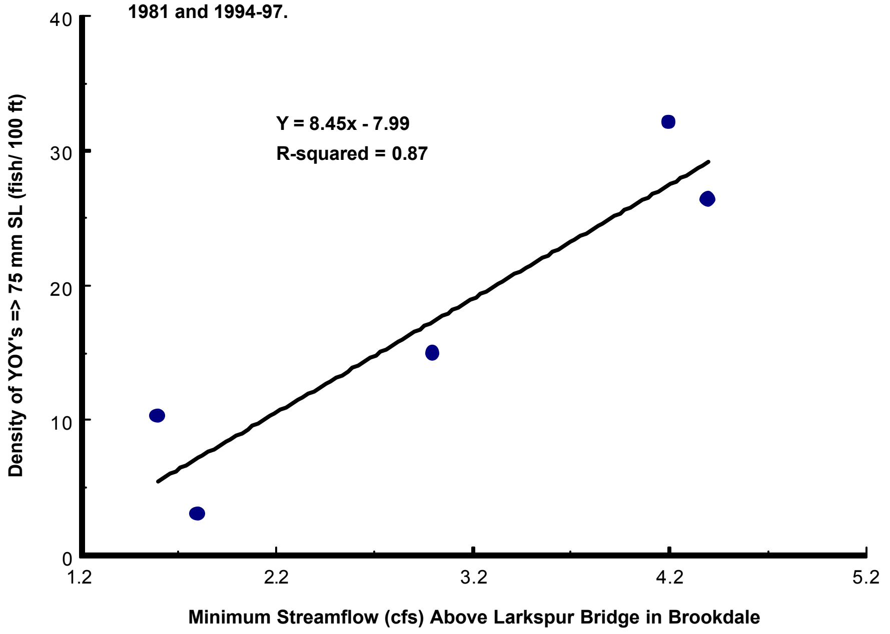
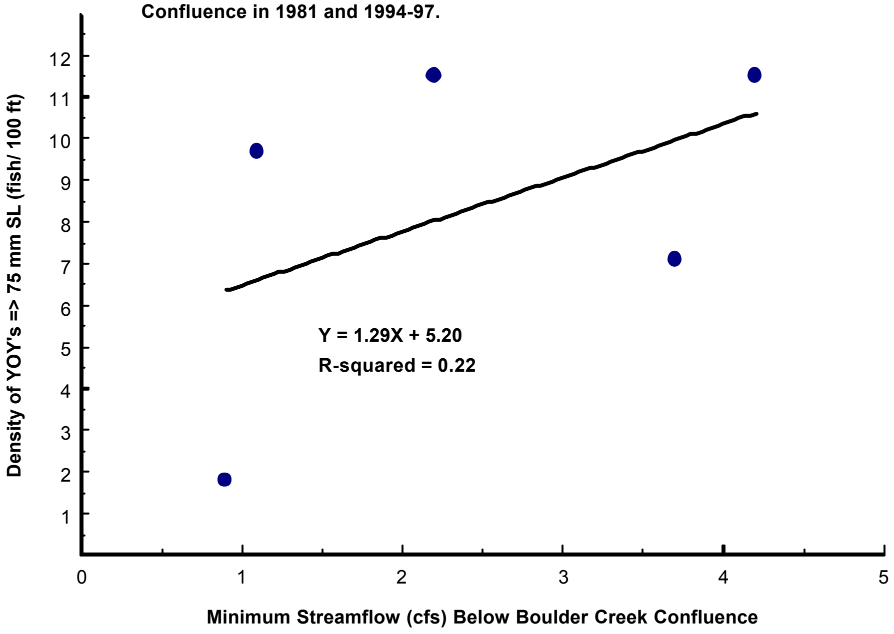


Figure 10. Relationship Between Annual Minimum Streamflow and the Density of YOY Steelhead Reaching Yearling Size (=> 75 mm SL) at the San Lorenzo Site below Boulder Creek Confluence in 1981 and 1994-97.



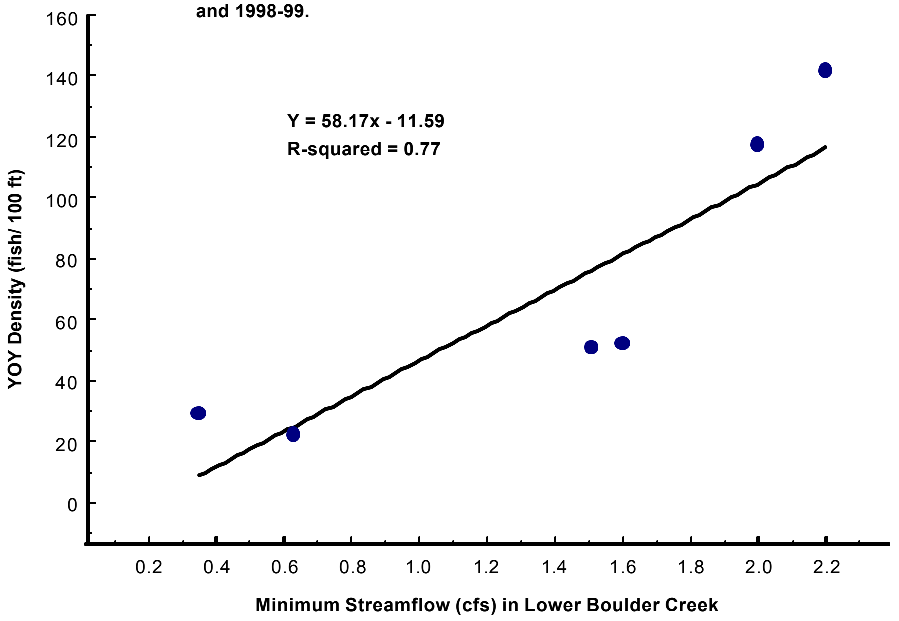


Figure 11. Relationship Between Annual Minimum Streamflow and YOY Steelhead Density at the Lower Boulder Creek Site Above Highway 9 in 1981, 1994-96 and 1998-99.

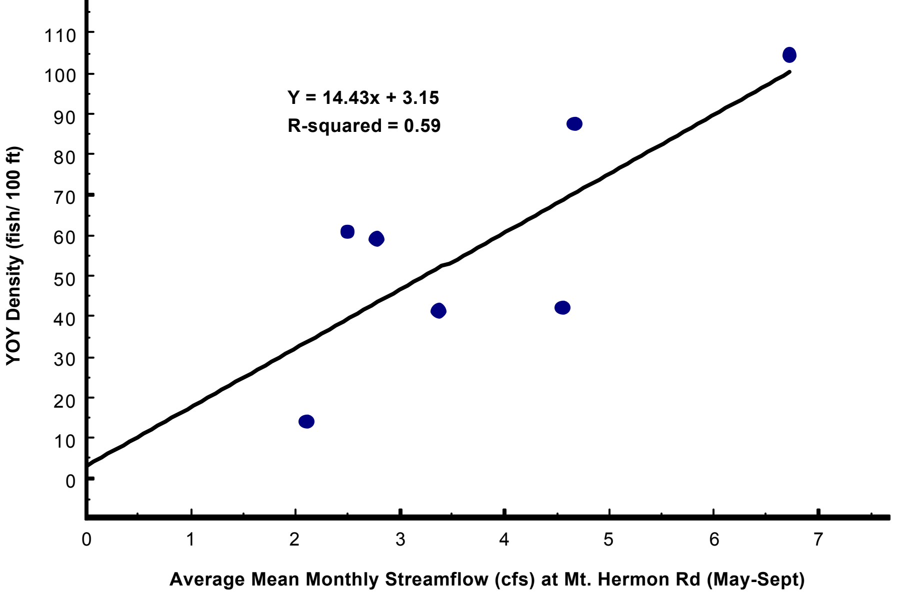


Figure 12. Relationship Between Averaged Mean Monthly Streamflow (May-September) at the Mt. Hermon Road Gage and Annual YOY Steelhead Density at the Bean Creek Site Below Lockhart Gulch in 1994-2000.

Figure 13. Relationship Between Annual Minimum Streamflow and YOY Steelhead Density in Bean Creek below Lockhart Gulch in 1994-2000.

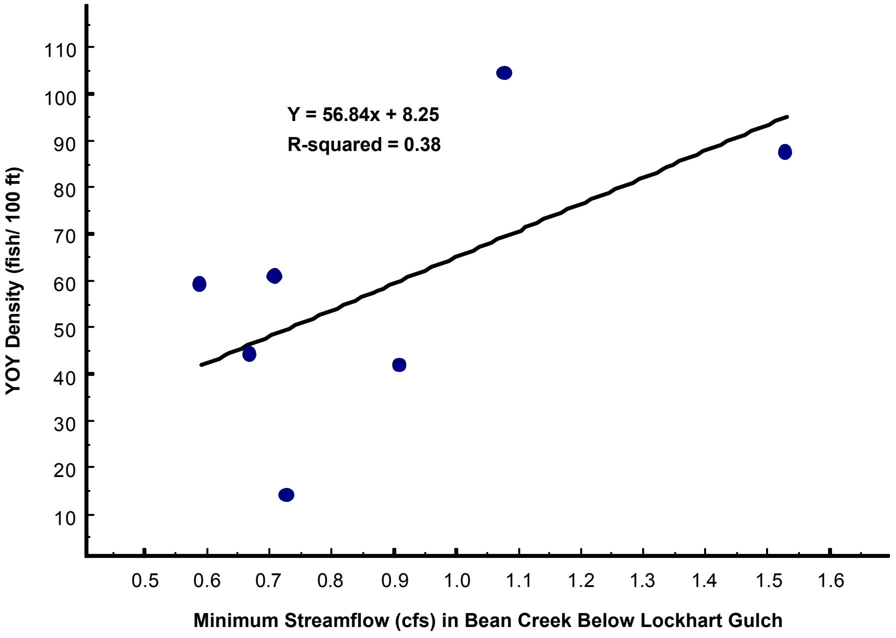


Figure 14. Relationship Between Annual Minimum Streamflow and YOY Steelhead Density in Zayante Creek below Bean Creek Confluence in 1981, 1994-96 and 1998-99. (No data in 1997.)