A Preliminary Assessment of Potential Steelhead Habitat in Sinbad Creek, Alameda County

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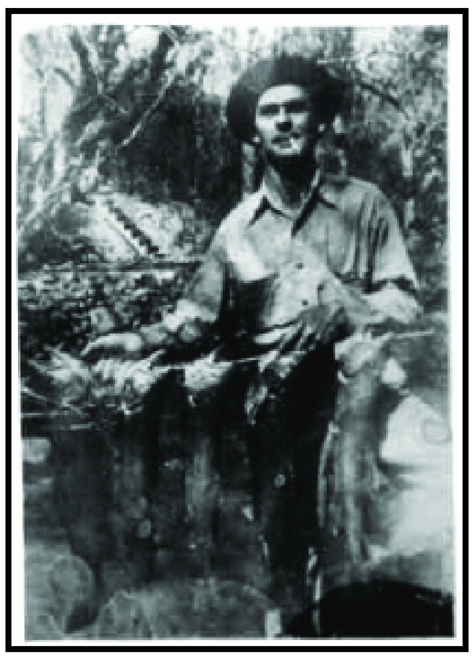

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Abstract

Steelhead (*Oncorhynchus mykiss*) historically inhabited Alameda Creek and its tributaries, including Sinbad Creek. Currently the Alameda Creek Fisheries Restoration Working Group is working to restore steelhead habitat throughout the watershed by removing barriers to fish migration on the main stem of Alameda Creek. Once steelhead are able to migrate upstream past barriers on Alameda Creek, Sinbad Creek may provide habitat for spawning and rearing. This study assesses the suitability of Sinbad Creek for steelhead based on three parameters: gravel, flow, and migration barriers. Representative stream reaches had gravel suitable for steelhead spawning, but Sinbad Creek's flow regime is likely to only intermittently support steelhead migration during the November to April in-migration period. Low flows during dry seasons cause sections of the creek to dry up, potentially limiting Sinbad Creek's suitability as year-round habitat for juveniles. Further, there are 12 potential steelhead migration barriers along the lower 3.5 miles of Sinbad Creek, including five concrete box culverts and six low check dams. Additional flow studies and more detailed analyses of each potential barrier would help planners decide whether or not to prioritize restoring Sinbad Creek for steelhead habitat, or instead to direct resources towards other parts of the Alameda Creek Watershed.

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I. Introduction

Sinbad Creek is a first order tributary to Arroyo de la Laguna, which, approximately one-half mile downstream of its confluence with Sinbad Creek, enters Alameda Creek, the largest tributary in the south San Francisco Bay (Figure 2). Sinbad Creek is 7.5 miles long, and drains 6.44 square miles. It flows south from its headwaters through Pleasanton Ridge Park, along a wooded residential road (Kilkare Road), and through the small town of Sunol. Historical evidence shows that steelhead (*Oncorhynchus mykiss*) once inhabited Alameda Creek and its tributaries, including Arroyo de la Laguna and Sinbad Creek (Figure 1 shows steelhead caught in Sinbad Creek in the 1950s; Alameda Creek Alliance 2000.) But currently, twelve dams and weirs block steelhead and other anadramous fish from migrating upstream into their historic spawning grounds in the Alameda Creek watershed.

In 1999, the Alameda Creek Alliance (a grassroots non-profit organization) and fifteen federal, state, and local government agencies formed the Alameda Creek Fisheries Restoration Workgroup, with the goal to restore steelhead habitat throughout the Alameda Creek watershed. The group discovered that steelhead attempting to migrate upstream in Alameda Creek are genetically associated with Central California Coast steelhead, which the US Fish and Wildlife Service listed as a federally threatened species in 1997. This federal listing and public support for steelhead restoration have provided a stronger impetus for government agencies to mobilize funds for fish passage restoration on Alameda Creek. Because Alameda Creek currently supports one of the most intact native fisheries in the region, including a viable population of rainbow trout (which are the same species as steelhead but do not migrate to the ocean), there is reason to believe that Alameda Creek and its tributaries might once again provide viable habitat for steelhead (Gunther 2000). But there is little data on current stream conditions in smaller tributaries to Alameda Creek watershed, such as Sinbad Creek, and whether or not these areas are suitable for steelhead spawning and rearing (Jeff Miller, Alameda Creek Alliance, personal communication, February 2004). Sinbad Creek is one of the first tributaries to Alameda Creek in its upper watershed, and would be one of the first areas that steelhead could use once passage is restored on the eight barriers downstream on Alameda Creek.

In this study, we assess the viability of Sinbad Creek as habitat for steelhead by answering the following questions:

1) Are there physical barriers to fish passage on Sinbad Creek that would prevent adult steelhead from migrating upstream?
2) Is gravel in the creek suitable for steelhead spawning?
3) Is flow in the creek adequate to allow adult steelhead to migrate upstream to spawn and to provide habitat for juvenile fish throughout the year?

Our fieldwork consisted of measuring potential barriers to steelhead migration up Sinbad Creek, and more closely analyzing channel form, gravel size and distribution, and flow, on two representative reaches. Steelhead have a variable life history, and although there is little detailed information on habitat requirements of steelhead in the Alameda Creek watershed, we made some assumptions about these requirements based on multi-year studies of steelhead in other San Francisco Bay area watersheds (Shapovalov and Taft 1954, in Gunther 2000). Specific assumptions we made in conducting this study include:

- Adult steelhead (approximately 20-28 inches) will migrate upstream to spawn in Alameda Creek and its tributaries between November and April, with the majority of in-migration occurring between December and March (Gunther 2000);
- Juvenile steelhead will inhabit Alameda Creek and its tributaries from one to four years before migrating to the ocean as smolts, usually between April and June (Gunther 2000) or during the first rains of the Fall (Pete Alexander, East Bay Regional Parks, personal communication, March 2004);
- Steelhead will spawn at depths of 0.3 to 5.0 feet, current velocities of 0.75 to 5 feet per second, and in gravel of 6.4 to 127 millimeters in diameter (Barnhart 1986);
- Steelhead in the San Francisco Bay area often use intermittent streams for spawning and rearing (Gunther 2000).

II. Barrier Assessment

Barrier Assessment Methods

On March 28, 2004, we walked from south to north from the confluence of Sinbad Creek with Arroyo de la Laguna to the point at which the creek enters Pleasanton Ridge Park. We noted and photographed any features or structures in the creek that appeared to be potential barriers to fish migration, and identified representative locations for our study reaches. On April 3, 2004, we continued walking along the creek, from the Pleasanton Ridge Park boundary to a point approximately 1.5 miles upstream, also visually observing the presence or absence of barriers to steelhead movement.

We evaluated each potential barrier along the creek based on whether it could pose an obstruction to the passage of adult steelhead swimming upstream to spawn. We based our assessment on several criteria:

1. Water level in culverts: We evaluated culverts to determine whether or not they provided sufficient flow and depth at the time of our survey for steelhead to swim through them.
2. Height of check dams and depth of jumping pools: Steelhead generally require a 1.25:1 pool-to-jump ratio in order to jump a barrier; with sufficient pool depth, an adult steelhead can jump up to six to nine feet (Gunther 2000). We measured pools below potential barriers and the height of each barrier (the distance between the water surface below the barrier to the top of the barrier) to determine whether it was too high for steelhead to jump.

We evaluated each potential barrier based on whether we believed it would pose an obstruction to fish movement during the flow at the time of our survey. While we did not evaluate each barrier during specific instances of high and low flow, we estimated the volumes that would constitute a range of flows that could be used to assess each potential barrier more closely (see flow discussion, below). Because our fieldwork took place several weeks after heavy storms in the area, we assumed that the flow observed during our fieldwork represented low-to-moderate flow.

Barrier Assessment Results and Discussion

Table 1 shows the results of our assessment of potential barriers to steelhead upstream migration in Sinbad Creek. We recorded several different types of potential barriers to fish movement, including the following:

- Dry reaches. We observed one reach with no flowing water, at the confluence of Sinbad Creek with Arroyo de la Laguna Creek.
- Waterfalls. We observed several natural waterfalls.
- Check dams. We observed six concrete and stone dams along the creek, concentrated in the residentially developed section of the creek.
- Culvert road-crossings. We observed five road-crossings over Sinbad Creek that all had a similar design – a bridge over a concrete box culvert, at least eight feet wide and 37 feet long. Water depth in these culverts was less than one inch to three inches during our fieldwork.

We determined that, for the most part, natural features such as waterfalls did not present major obstructions to steelhead movement. We observed 11 man-made structures that we judged to be potential barriers to fish movement, based on our assessment of low water depth or height of the jump and/or depth of the pool. The concrete box culverts might present a barrier to fish migration at low flows, because they may be too shallow to allow a fish to swim through them, and at high flows because water velocity may be too high for too long. The check dam and stepped-stone dams located approximately at Mile Markers 3.0 and 3.1, respectively, are particularly likely to be barriers to upstream fish migration at moderate to low flows because the pools below these barriers are too shallow to allow a fish to overcome the barriers. Within the park, we observed no potential barriers to fish migration.

III. Selection of Study Reaches

Selection of Study Reaches: Methods

In order to conduct our assessments of gravel, channel form, and flow, we first selected a lower and an upper study reach. We chose parts of the creek that appeared to have representative morphology, vegetation, and substrate. We also wanted to include reaches that were representative of the conditions in both the upper watershed flowing through Pleasanton Regional Park, and the lower watershed flowing along Kilkare Road through private, residential property. For each site, we drew a sketch map of instream features such as pools, runs, and riffles, as well as shading and vegetation (Figures 4 and 5). We also took photographs of both reaches (Figures 9 and 10). We conducted a gravel count on both reaches, and surveyed and measured flow on the lower reach (we present details of these steps in sections IV and V, below).

Selection of Study Reaches: Results and Discussion

We identified a 100-foot long upper reach approximately 1.5 miles upstream of where Kilkare Road dead-ends at Pleasanton Regional Park. The reach was located in the middle of a long curve around a broad meadow, which extended across the flood plain on the right bank of Sinbad Creek. The reach had a pool-riffle sequence, with non-uniform substrate of gravel, sand, cobbles, boulders, and some silt. The left bank sloped steeply up from the creek edge to a high ridge. Riparian vegetation included oak, bay, and elm trees, grass, ivy, poison oak and coyote brush. The creek was well shaded (approximately 70%) by large overhanging trees (photos, Figure 9).

We identified a 150-foot long lower reach approximately 2.5 miles upstream of the confluence with Arroyo de la Laguna, adjacent to Kilkare Road. Both banks were steeply sloped. Riparian vegetation included oak and bay trees, poison oak, grass, ivy, moss and other plant species. This reach was also approximately 70% shaded by large, overhanging trees. The stream channel was composed primarily of step pools, with fewer riffles than the upper reach. The top 30 feet of the reach was a long, wide glide. The streambed was dominated by boulders and cobble (photos, Figure 10).

IV. Gravel Assessment

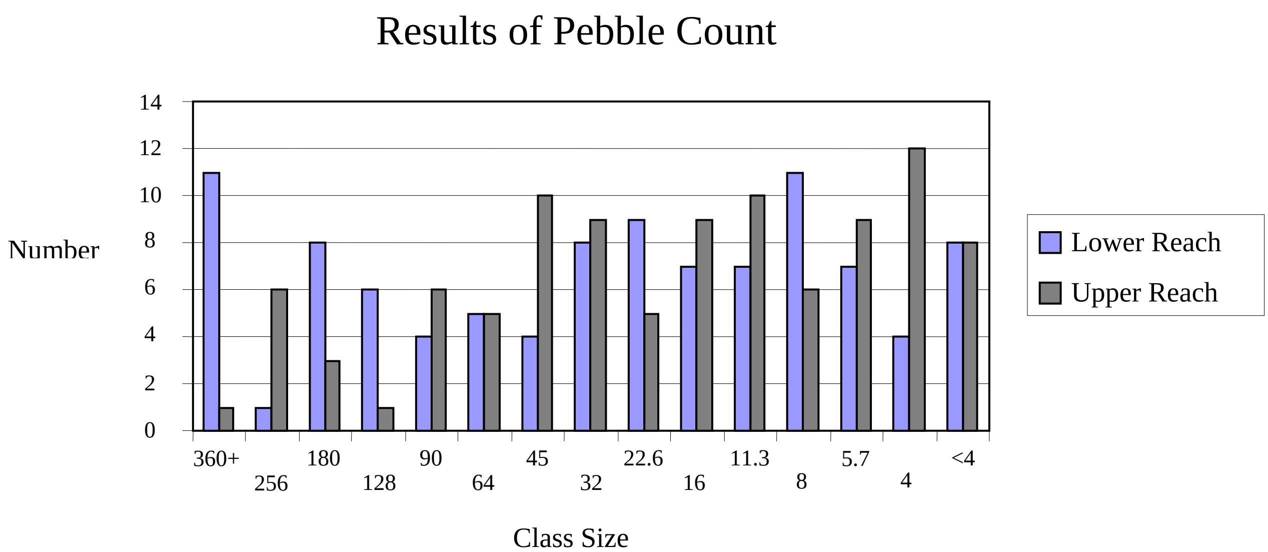
Gravel Assessment: Methods

At both the upper and lower reaches, we conducted a pebble count to determine whether or not the creek had gravel suitable for steelhead spawning. Our visual observations revealed that bed material in both reaches was relatively homogenous, consistent, and poorly sorted (with the exception of the glide in the lower section – see below). Because bed material was not sorted by size, but rather mixed together throughout the bed, we conducted the pebble count across the length of the study reaches. We first placed a survey tape along the streambed from the lower to upper end of the study reach. The designated “counter” then proceeded across the bed and blindly sampled 10 grains along a transect perpendicular to the survey tape at increments of 10 feet. The counter then passed the grains through a gravelometer and measured the intermediate axis, and the “recorder” noted the grain size classes. We recorded interlocked grains that we were unable to remove from the bed as embedded, using the notation “E” rather than the standard tick mark. In the lower reach, we wanted to be sure to include the upper glide section of the reach, which had a noticeably different streambed composition than the rest of the reach. We therefore used the above method to sample 10 pebbles from every 10th station up to station 90, and then skipped to station 130, so that our sample of 100 would include samples from the glide section of the reach.

Gravel Assessment: Results and Discussion

The results of our pebble count reveal a smaller median particle size (d_{50}) and geometric mean (d_g) at the upper reach (d_{50} = 16mm; d_{16} = 4mm; d_{84} = 90mm; d_g = 18.97mm) than at the lower reach (d_{50} = 22.6mm; d_{16} = 5.7mm; d_{84} = 180mm; d_g = 32.03mm). The percent of embedded stones was the same at both reaches (8%). At the upper reach, however, all embedded stones were greater than 45mm, while at the lower reach embedded stones were greater than 128mm. Bed material in both reaches was relatively homogenous, consistent, and poorly sorted. In other words, bed materials varied in size and were not sorted by size across the bed, but rather mixed together throughout the bed. The results of the pebble count are presented in Tables 4 and 5, and in the histogram below.

In our gravel assessment, we assumed that conducting pebble counts across the relatively homogenous upper and lower reaches would yield representative subsamples of the populations (Kondolf 1997). However, to conduct a more precise analysis of the stream's gravel composition, it would be possible to divide the reaches into several distinct populations, and/or stratify by geomorphic feature, such as pools and riffles, then conduct individual pebble counts on each section and provide a weighted average (Kondolf 1997).



The size of adult steelhead expected to spawn in Alameda Creek and its tributaries ranges from 20 to 28 inches (Pete Alexander, pers. comm., March 2004; Love 2001). Steelhead generally spawn in gravels 6.4 mm to 127.0 mm in size (USFWS and Coastal Ecology Group 1986, Barnhart 1986). The largest size gravel fish 20-28 inches (about 510 –710 mm) can move ranges between median diameters (d_{50}) of approximately 20 and 30 mm (Kondolf 2000; Kondolf and Wolman 1993). Gravel in our upper reach falls below that upper limit (d_{50} = 16mm) and therefore may be suitable spawning gravel for 20-28 inch steelhead, as well as smaller steelhead. Gravel in the lower reach falls within that range (d_{50} = 22.6mm), and therefore may be suitable spawning gravel for 20-28 inch steelhead.

The gravel needs of steelhead change over their lifecycle (Kondolf 2000). Our study focused on assessing whether or not Sinbad Creek has gravel that would be movable by adult steelhead when constructing redds (depressions in gravel created by steelhead and other salmonids to lay eggs in). We did not measure interstitial fine sediment, which can interfere with incubation of eggs and emergence of fry (Kondolf 2000). Although we did not quantitatively measure fine sediments, we did note that overall the stream substrate was primarily gravel or larger cobble, and we only counted sand or silt once during our pebble count, and turbidity was low.

Both our study reaches and the entire 4.5 miles of creek we walked had gravel beds. Our study reaches were good representations of Sinbad Creek's bed material, and were we to conduct additional pebble counts, we would expect to find similar gravel composition at other reaches. Our gravel assessment thus indicates that both representative reaches have gravel suitable for steelhead spawning, and also that the entire lower five miles of the creek has gravel suitable for steelhead spawning.

V. Flow Assessment

Flow Assessment: Methods

Because Sinbad Creek is not gauged, we relied on various direct and indirect methods to assess the creek's flow regime. First, we gathered secondary data regarding stream flow (Love 2001; Pete Alexander, pers. comm., March 2004; Gunther 2000).

Next, we directly observed stream flow conditions on March 28, 2004 and on April 4, 2004, and used the orange peel method to measure stream flow, which was 0.6 cfs (Table 6). We surveyed the lower reach, observing water depth, high water marks, and bank full width, and plotted longitudinal and cross section profiles of the reach (Figures 6 and 7). We back-calculated Manning's n using our longitudinal and a cross-section data, and used Manning's n to calculate the flow at the observed high water marks (Table 7), at 130 cfs. Then, we obtained online USGS stream flow data from the Alameda Creek at Niles gauge, which is the closest gauge downstream of Sinbad Creek. We found that the most recent high flow at the gauge, 1660 cfs, occurred on February 26, 2004. This peak flow corresponded approximately to a 1.4 -year flood, which we determined using a flood frequency curve for Alameda Creek (Kondolf 1992).

Next, we used regional flood frequency relations developed by Rantz (1971), Waananen and Crippen (1977), and Love (2001) to estimate peak flows for Sinbad Creek. To make use of these relations, we first measured Sinbad Creek's drainage area with a planimeter and a custom USGS quadrant map, and measured Sinbad Creek's drainage area, 6.44 square miles. Using Saah's 1989 precipitation map for the San Francisco Bay area, we calculated the mean annual precipitation for the basin to be 23.2 inches.

The Rantz (1971) method uses drainage area and average precipitation to measure small basins (0.2-196 mi.^{2}) in the SF bay area. Using the formula $Q_T=KA^aP^b$, where K, a, and b are constants, A is area in square miles, and P is mean annual basin-wide precipitation in inches, we calculated that the two year flood for Sinbad Creek is 182 cfs, the ten year flood is 760 cfs, and the 50 year flood is 1933 cfs. The second regional relationship method we used was developed by Waananen and Crippen (1977) and is similar to the Rantz method but it factors in elevation, in addition to drainage area and average precipitation, and was developed to calculate runoff for the entire state of California. The equation used is $Q_T=KA^aP^bH$, where H is the average of the stream's elevation measured at 10% and 85% of the distance from the gauge to the divide. Using this method, Sinbad Creek's two year return flood is 106 cfs, the ten year flood is 534 cfs, the 50 year flood is 1156 cfs, and the 100 year flood is 1485 cfs.

Love (2001) combined daily flow data from gauged streams near Stonybrook Creek, a 6.9 square mile watershed directly west of Sinbad Creek, to develop a regional flow duration curve for southwestern Alameda County and to predict a relationship between drainage size and peak flow return period (Appendix A). Specifically, Love took peak flow data from gauges on four Alameda Creek tributaries and four portions of the adjacent San Lorenzo Creek, found mean annual precipitation for the area using an isohyetal map developed by Rantz (2001), and estimated peak flows using the Log Pearson Type III distribution and the methods described by the USGS (1982) (Love 2001). Using this relationship, the estimated two year flood for Sinbad creek is 173 cfs, the ten year flood is 500 cfs, the 25 year flood is 1300 cfs, the 50 year flood is 2300 cfs, and the 100 year flood is 3000 cfs.

Finally, we compiled these varying estimates of Sinbad Creek's peak flow return periods (Table 7) and plotted them using Excel (Figure 8).

Flow Assessment: Results and Discussion

As described above, we calculated the results shown in Figure 8 using varying methods, all of which are fairly imprecise. We believe that the Rantz and Waananen and Crippen methods are the least precise, as they generalize relations for large hydrologic regions, and may not be able to convey the unique precipitation and flow conditions in the Alameda Creek watershed. We suspect that Love's drainage size/peak flow relationship method may be more precise, as it is specific to the Alameda Creek watershed. Therefore, we created the flood frequency curve shown in Figure 8 using the Love data points, as well as the flow we calculated from the high water marks we observed at the time of our survey.

The wide variation in our peak discharge estimates for Sinbad Creek demonstrates how inaccurate data generated using regional flood frequency relations may be. The flood frequency curve in Figure 8 is our best estimate of actual conditions based on the data we have, but it is much less reliable than determining peak flow return periods by directly measuring flow over an extended period of time. For the purposes of our study, however, our flood frequency curve allows us to understand the general character of Sinbad Creek's flow regime. Specifically, it shows a flood frequency curve that is typical of northern California coastal streams, with a predicted mean annual flood of slightly less than 100 cfs, a 50 year flood of more than 2000 cfs, and a 100 year flood of approximately 3000 cfs. The large order of magnitude difference between the flow we observed of 0.6 cfs, and predicted peak winter season flows, indicates streamflow for Sinbad Creek is largely dependant on rainfall rather than snowmelt or contributing aquifers.

Flow regime is an important parameter determining steelhead habitat suitability. Flows must be high enough during spawning season (November through April) to allow upstream passage of adult steelhead. Flow must also be adequate to allow juvenile steelhead to survive in the stream throughout the year. As described above, we calculated that on February 26, 2004, flow in Sinbad creek reached 130 cfs, corresponding with a 1.4-year return interval. We expect that storms such as the one that occurred on February 26, as well as less intense winter rains, may intermittently increase depth in Sinbad Creek enough to allow adult steelhead to migrate upstream.

While we did not have enough detailed data to create an accurate mean annual hydrograph for the creek, which would allow a more direct analysis of flow conditions for spawning and rearing throughout the year, our observations and calculations do provide some information that can be used to assess the viability of juvenile rearing habitat. On March 28, 2004, we observed that Sinbad Creek had dried up completely for a 150-foot stretch just upstream of its confluence with Arroyo de la Laguna. Upstream of this dry section, however, flow was continuous pool-riffle habitat, with some pools measuring 1-2 feet deep. We know that Alameda Creek often dries up in sections during the month of June, but that fish are still able to survive in the creek throughout the year (Gunther 2000). In addition, recent fish surveys conducted by the Alameda County Flood Control District indicate blue gill and sucker populations make use of isolated pools on Sinbad Creek that persist through the dry months of May-October, and that temperature in some of these pools is suitable for steelhead (Pete Alexander, personal communication, March 2004). Sinbad Creek may dry up in sections during summer, and even during dry periods of spring and fall, but isolated pools may continually provide suitable rearing habitat for juvenile steelhead.

Variations in flow may change the extent to which stream crossings, check dams, and natural features are barriers to steelhead migration. Steelhead in Alameda County migrate upstream during the November through April migration period during 2% to 95% exceedence flows (2% exceedence flows are flows that are exceeded 2% of the time, and 95% exceedence flows are flows that are exceeded 95% of the time) (Love 2001). Based on our survey of Sinbad Creek and

Love’s 2001 regional flow duration curve for the November through April migration period (Appendix B), we calculated the exceedence flow range during which steelhead migrate upstream in Sinbad Creek to be between 0.06 cfs and 65 cfs.

VI. Recommendations for Further Research

We recommend a more detailed analysis of potential barriers to migration on Sinbad Creek, including calculating depth and velocity of flows at culvert crossings, and pool depth and jumping height at check dams, using the 0.06 cfs to 65 cfs exceedence flow range. For example, at 65 cfs, velocities in culverts may be too high to allow fish passage, and at 0.06 cfs, water depth in culverts is likely to be too low. Planners interested in restoring steelhead to Alameda Creek tributaries could potentially conduct a barrier assessment analysis of Sinbad Creek similar to Love’s 2001 study of Stonybrook Creek, and also assess potential measures to restore fish passage at the exceedence flow range at each barrier.

As a final note, some residents along Kilkare Road have suggested that Sinbad Creek’s flow may have decreased since the time it supported steelhead (Pete Alexander, personal communication, March 2004). Because data from Alameda Creek watershed gauges indicate that overall basin discharge has been consistent over the last century (Gunther 2000), if base flow is indeed decreasing on Sinbad Creek, it could be due to the depletion of a perched aquifer that feeds the creek. We recommend conducting groundwater studies, and more detailed surveys of nearby residents to assess their water use and memory of creek flow, to determine whether or not aquifer depletion may be affecting steelhead habitat in Sinbad Creek.

We also recommend multi-year studies of Sinbad Creek's flow regime to produce a better estimate of the creek's mean annual hydrograph, which would help estimate the number of days flows may be suitable for adult in-migration. Further, we recommend fish surveys of the creek during the summer dry season to determine whether or not intermittent pools are suitable for juvenile steelhead.

VII. Conclusions

Gravel size is adequate to support steelhead redd formation in Sinbad Creek, and the creek has good shading as well as the general pattern of pool and riffle habitat preferred by steelhead. Flow may be adequate for migration during periodic winter rains, and perennial pools may provide habitat for juvenile steelhead. Eleven road crossings and six dams in the first 3.5 miles of the creek, however, may potentially prevent steelhead migration during both high and low flows. In order to determine whether interested parties such as the Alameda Creek Fisheries Workgroup should prioritize restoration of fish passage on these barriers, we recommend further studies of Sinbad Creek's flow regime. Such information would help planners determine whether or not to prioritize restoring Sinbad Creek for steelhead habitat, or instead to direct resources towards other parts of the Alameda Creek Watershed.

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Table 1: Assessment of Potential Fish Barriers

Barrier No.	Site Name	Posted Mile*	Cross Section Shape	Material	Dimensions	Pool Below	Description of Conditions
1	Confluence of Sinbad and Arroyo de la Laguna creeks						3/28/04: No water present in stream from confluence with Arroyo de la Laguna, and upstream for approximately 240' (near Bond St. bridge crossing). High water marks show the reach recently received flow, but during low flows, the dry channel would likely be a barrier to fish migration.
2	75 Kilkare Rd.	0.07 - 0.67	Small check dam	Concrete	Check dam spans creek. 19" outfall drop	Maximum pool depth is 3' deep at 3' from the base of the dam.	Pool depth is 1.89 times the drop. Not a likely barrier at low or high flows.
3	586 Kilkare	0.67	Short check dam	Concrete	First dam: drop approx. 1'. Another smaller check dam immediately upstream	Pool depth is 2' at its maximum.	Not a likely barrier at low or high flows.
4		1.10	Small check dam/weir	Concrete	Weir/dam is 2-3" above water surface in middle of stream.	Water depth is 5" in pool below.	Not a likely barrier at high or low flows
5		1.47	Small dam with retaining wall	Concrete	NA	NA	NA
6		1.61	Small waterfall	Natural	NA	NA	Not a likely barrier
7		~1.84	Box culvert under bridge crossing	Concrete	Width: 8'4" at bottom, 10' across top; Length: 37'. Drop approx. 6".	Pool below channel is 11" at middle and 14.5" to 16" at its deepest.	Barrier to migration at low flows (low water depth in channel) and possible barrier at high flows.

Table 1: Assessment of Potential Fish Barriers (Cont.)

Barrier No.	Site Name	Posted Mile	Cross Section Shape	Material	Dimensions	Pool Below	Description of Conditions
8		1.90	Box culvert under bridge crossing	Concrete	Width: 10.5'; Length: ~40'; Water depth: ~0.5 to 2".	Pool below channel is 1' to 22" deep. Pool above culvert is less than 1' deep.	Barrier to migration at low flows (at given flow on 3/28/04, water was only 0.5 to 2" deep). Possible barrier at high flows.
9		2.05	Waterfall	Natural	26" drop; Distance from water across dam: 60".	18" deep	Possible barrier during low flow. Pool is only 0.47 times the outfall drop.
10		2.10	Waterfall	Natural	40" drop	Approx. 1' deep.	Possible barrier during low flow. Pool is 0.3 times the outfall drop.
11		2.28	Culvert under bridge crossing with open bottom	Natural	1' drop	NA	Difficult to determine whether a potential barrier; possible barrier
12		2.30	Box culvert under bridge crossing	Concrete	Width: Approx. 8'; Length: Approx. 40'; Water depth: Approx. 1".	NA	Barrier at low flow; possible barrier at high flow.
13		2.49	Box culvert under bridge crossing	Concrete	Width: Approx. 10'; Length: Approx. 40'; Water depth: Approx. 1'. Drop: 20".	Pool depth: approx. 2'	Barrier at low flow; possible barrier at high flow.

Table 1: Assessment of Potential Fish Barriers (Cont.)

Barrier No.	Site Name	Posted Mile	Cross Section Shape	Material	Dimensions	Pool Below	Description of Conditions
14		~3.0	Check Dam (Incision)	Concrete	Distance from water level to top of concrete is approx. 2.5'. Angled lip/apron at top of concrete extends for approx. 1'.	Pool depth: approx. 2'	Possible barrier at low flows. Pool depth is 0.8 times the outfall drop.
15		~3.1	Stepped stone dam (2 steps)	Concrete	Upper step is approx. 2' high. Lower step approx. the same height. Length of lower step is 6' 8".	1' deep.	Possible barrier at low flows. The pool may not be deep enough for a jump of approximately 4'. Pool is only 0.25 times the outfall drop.
16	Glenora Way	~3.20	Bridge crossing with closed-bottom channel and notch in channel	Concrete	Width: Approx. 10'; Length: Approx. 19'. Water depth in notch: 2"-3".	NA	Possible barrier at low flows, although the notched channel allows for higher depth than the box culverts.
17		3.40	Box culvert under bridge crossing	Concrete	Similar dimensions as barrier at mile marker 2.49.	NA	Possible barrier at low and high flows.

* Mile marker on Kilkare Road; 0 mile is approximately located at Main Street

Table 2. Lower Reach Survey Data, Long Profile

BM1	BS	FS	WD	HWL	ToBL	thal	ToBR	HWR	HW	HI	EL (thal)
BS	1.47									722.12	
0			1.05		6.25	15.58	4.6				706.54
10			0.35			13.97					708.15
20			0.3	10.1	5.51	12.93	3.56	10.91			709.19
30			0.6			12.98					709.14
40			0.45			12.88			9.45		709.24
50			0.55		3.52	12.98	5.59				709.14
60			0.8			12.95					709.17
61			0.3			11.74					710.38
70			0.7		1	11.4	2.05				710.72
80			0.7			11.39					710.73
TP		9.11									
TP	14.73									725.62	710.89
90								13.61			
100			0.2			16.14					709.48
110			0.45			15.43					710.19
120			0.5			15.09					710.53
130			0.4	12.43		14.06		11.86			711.56
140			0.2			13.75					711.87
150				11.47	3.15	13.63	3.06	12.04			711.99
BM (close)		7.16									

NOTES:
BM1 = Benchmark 1
BS = Backshot
FS = Foreshot
WD = Water Depth
HWL = High Water Left Bank
ToBL = Top of Bank Left
thal = Thalweg
ToBR = Top of bank Right
HWR = High Water Right Bank
HW = High Water
HI = Instrument Height
EL (thal) = Elevation at thalweg
TP = Turning Point

Instrument Location A (Top of Bank, Left Bank)
Mile Marker 2.12, Kilkare Road East Side

Table 3. Lower Reach Survey Data, Cross Section

Point No./Description	WD (ft)	FS	Notes	HI	EL
BS to road marker		8.25	FS RB	648.25	
53		2.48	ToRB		645.77
51		5.46			642.79
48		8.92			639.33
45		11.55	REdge		636.7
43		14.81			633.44
41		15.69			632.56
36*		16.15	REW		632.1
25		14.37			633.88
21*	1.2	18.35	pool		629.90
17*		16.79	LEW		631.46
14		15.43	HWLB		632.82
12		12.87			635.38
10		10.90			637.35
8		9.39			638.86
5		7.28	ToBLB		640.97
2		5.02			643.23

NOTES:

WD = Water Depth
FS = Foreshot
HI = Instrument Height
EL = Elevation

BS = Backshot
FS RB = Foreshot Right Bank
ToRB = Top of Right Bank
REdge = Right Water's Edge (first)

REW = Right Edge Water (second)
LEW = Left Edge Water
HWLB = High Water Left bank
ToBLB = Top of Bank Left Bank

Location: Mile Marker 2.12, Kilkare Road East Side

Table 4. Upper Reach Pebble Count Results

Size class (mm)	Number of Rocks (incl. embedded)	Number Embedded	Percent of total	Cumulative	Finer than (mm)
360+	1		1	100	512
256	6	3	6	99	360
180	3	2	3	93	256
128	1	1	1	90	180
90	6		6	89	128
64	5		5	83	90
45	10	2	10	78	64
32	9		9	68	45
22.6	5		5	59	32
16	9		9	54	22.6
11.3	10		10	45	16
8	6		6	35	11.3
5.7	9		9	29	8
4	12		12	20	5.7
<4	8		8	8	4
Total Pebble Count n	100				
Total embedded:	8				
All greater than:	45 mm				
% embedded:	8				
d16 =	4 mm				
d50 =	16 mm				
d84=	90 mm				
dg=	18.97 mm				

NOTES:
Kristen McDonald (recorder) and Mary Ann King (counter) (switched half way)
Date: April 3, 2004
Time: 10:00 am

Table 5. Lower Reach Pebble Count Results

Size class (mm)	Number of Rocks (incl. Embedded)	Number Embedded	Percent of total	Cumulative	Finer than (mm)
360+	11	1	11	100	
256	1		1	89	>256
180	8	4	8	88	256
128	6	3	6	80	180
90	4		4	74	128
64	5		5	70	90
45	4		4	65	64
32	8		8	61	45
22.6	9		9	53	32
16	7		7	44	22.6
11.3	7		7	37	16
8	11		11	30	11.3
5.7	7		7	19	8
4	4		4	12	5.7
<4	8		8	8	4
Total Pebble Count n	100				
Total embedded:	8				
All greater than:	128 mm				
% embedded:	8				
d16=	5.7 mm				
d50 =	22.6 mm				
d84=	180 mm				
dg=	32.03 mm				

NOTES:
Christy Herron (recorder) and Mary Ann King (counter)
Date: April 3, 2004
Time: 4:30pm

Table 6. Orange Peel Flow Measurement

Replicate	Time (s)
1	38
2	23
3	16
4	55
5	28
6	24
7	31
8	49
9	26
10	35
Total:	325
Length = 40 feet	
Width = 7.8 feet	
Depth = 2/3 inch = 0.06 feet	
Area = 0.468 feet	
Average time = 32.5	
Average velocity = 1.23 feet/sec	
Q = 0.6 cfs	

NOTES:
Date: April 3, 2004
Time: 5:30pm

Table 7. Flood Frequency Analysis

Return Period	Flow*	Flow (Love, 2001)**	Flow (Rantz, 1971)***	Flow (Waananen Crippen, 1977)****
1.4	130			
2		173	182	106
10		500	760	534
25		1300		
50		2300	1933	1156
100		3000		1485

* 1) flow on 4/4/04 = 0.6 cfs (see table 6)

2) back calculation of manning's n:

$$n = \frac{(1.49\ R^{0.67}\ S^{0.5})A}{Q}$$

A (area) = 3.3 feet (determined by plotting the cross section on graph paper and counting the number of squares in the channel below the water surface).

R (hydraulic radius) = Area/wetted perimeter = 3.3 feet/7feet (also determined by counting squares) = 0.47 feet

S (slope) = 0.05 (see Figure 5 – determined by dividing the difference in elevation over the distance between station 0 and station 150).

$$n = \frac{(1.49 \times 0.47^{0.67} \times 0.05^{0.5})\ 3.3}{0.6\ \text{cfs}}$$

n = 0.124

3) use manning's n to calculate flow <u>at observed high water mark</u>:

A = 44.5 (calculated using same method as above)
R = 1.44 (calculated using same method as above)
S = slope at observed high water marks at station 20 and station 130 = 0.036

$$\mathbf{Qhw = 44.5}\ \frac{(1.49 \times 1.44^{0.67} \times 0.036^{0.5})}{0.124} = 130\ \text{cfs}$$

** **See Appendix A.**

******* $Q_T=KA^aP^b$, where K, a, and b are constants, A is area in square miles, and P is mean annual basin-wide precipitation in inches, A = 6.44 square miles,P=23.2 inches

**** $Q_T=KA^aP^bH$, where H is average of stream elevation measured at 10% and 85% of distance from the gauge to the divide, in thousands of feet, H=0.88

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Figure 2. Site Location Map

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Figure 3. Map of Study Reaches and Locations of Potential Fish Barriers

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Figure 4. Upper Reach Site Sketch

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Figure 5. Lower Reach Site Sketch

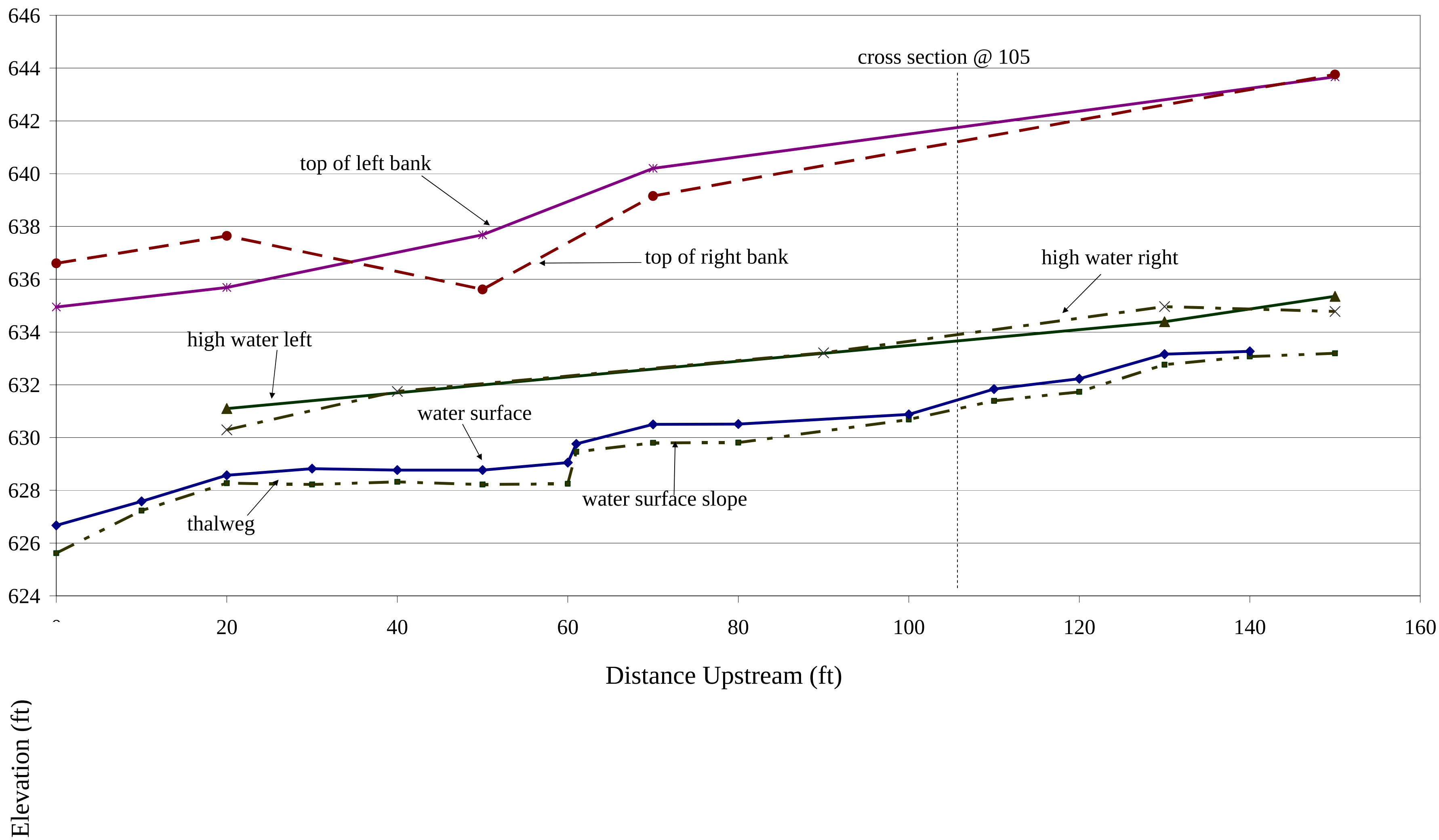

Figure 6. Lower Reach Long Profile

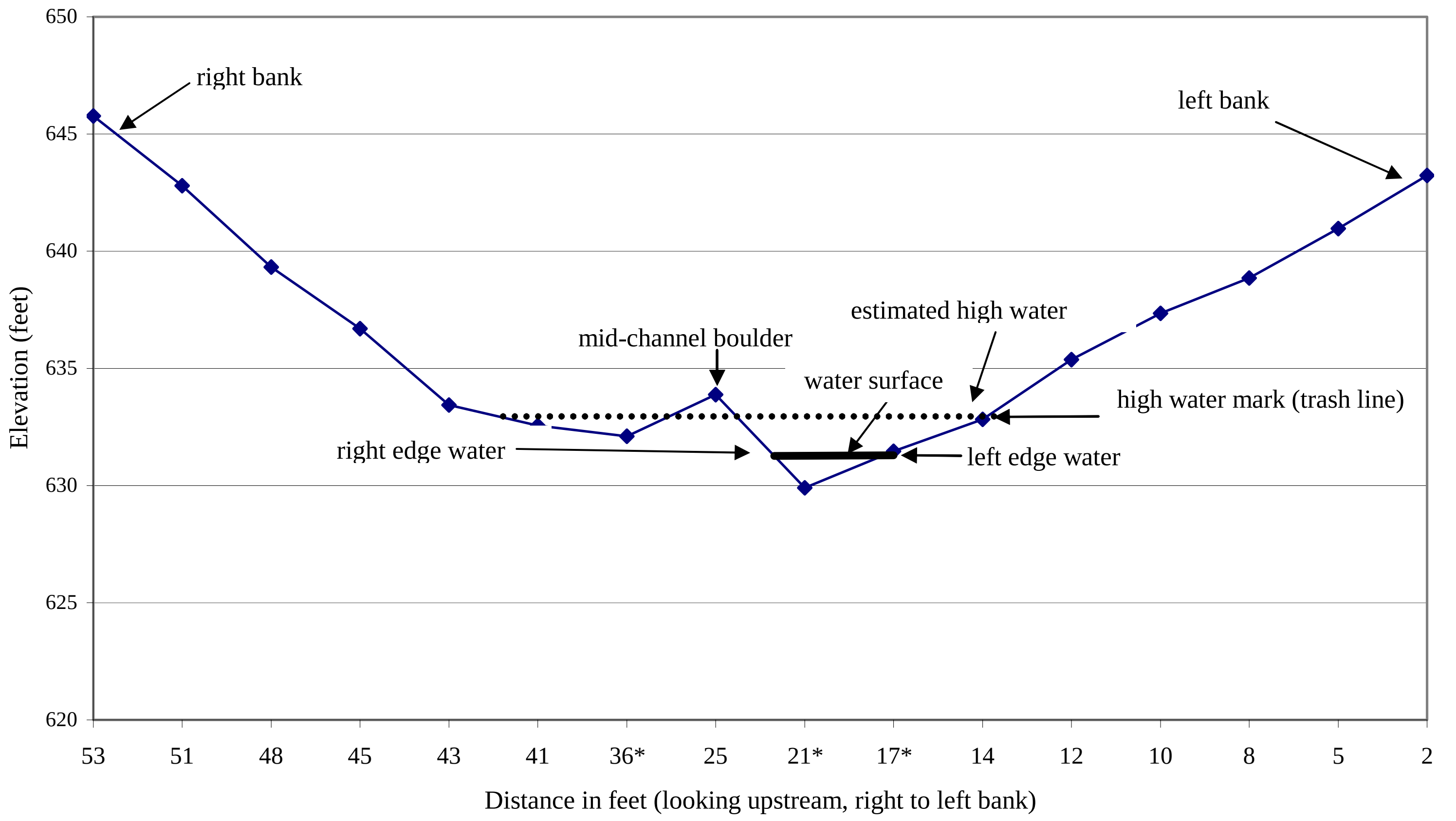

Figure 7. Lower Reach Cross-Section

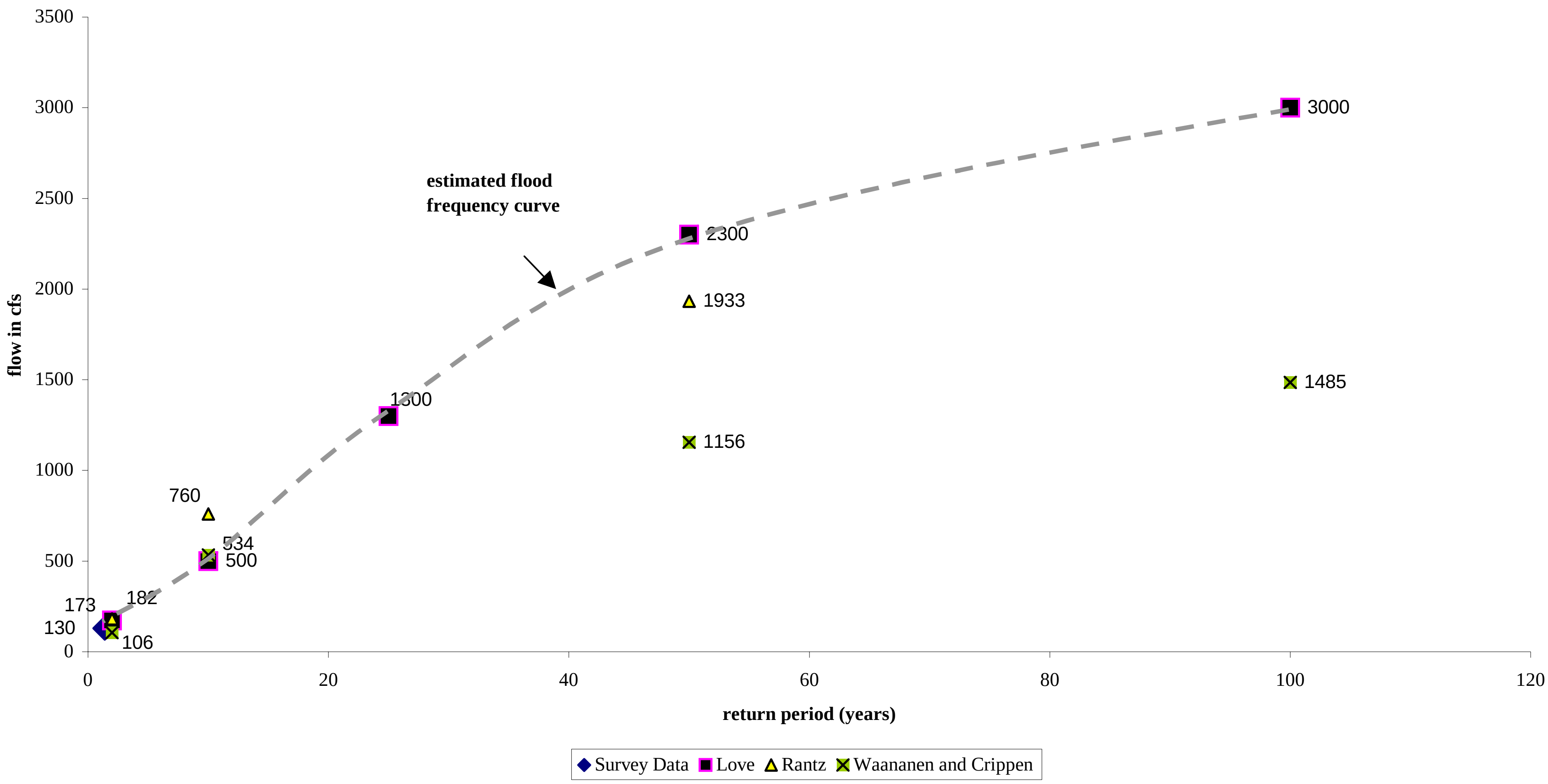

Figure 8. Estimated Flood Frequency Curve

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Figure 9. Upper Reach Photos

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Figure 10. Lower Reach Photos

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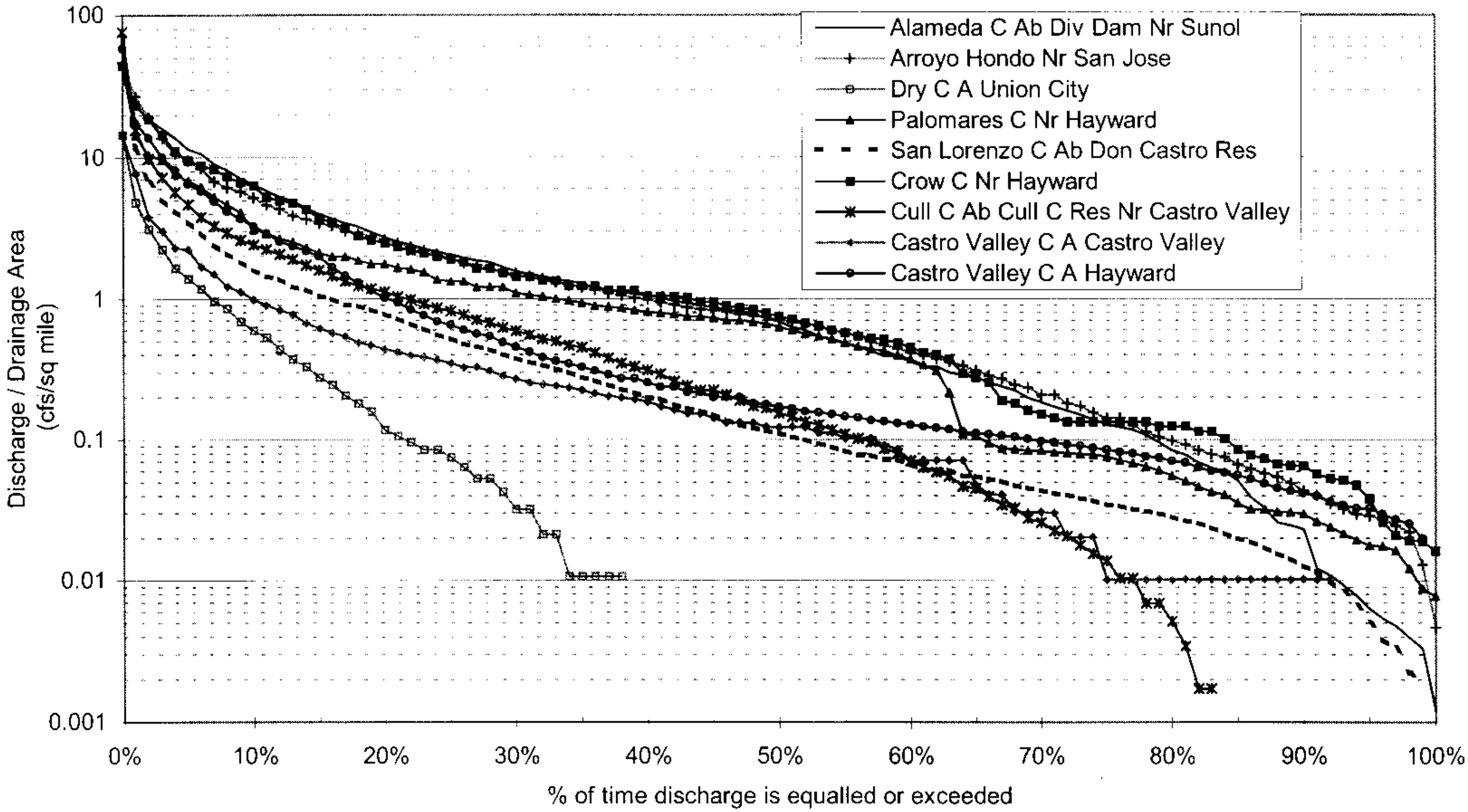
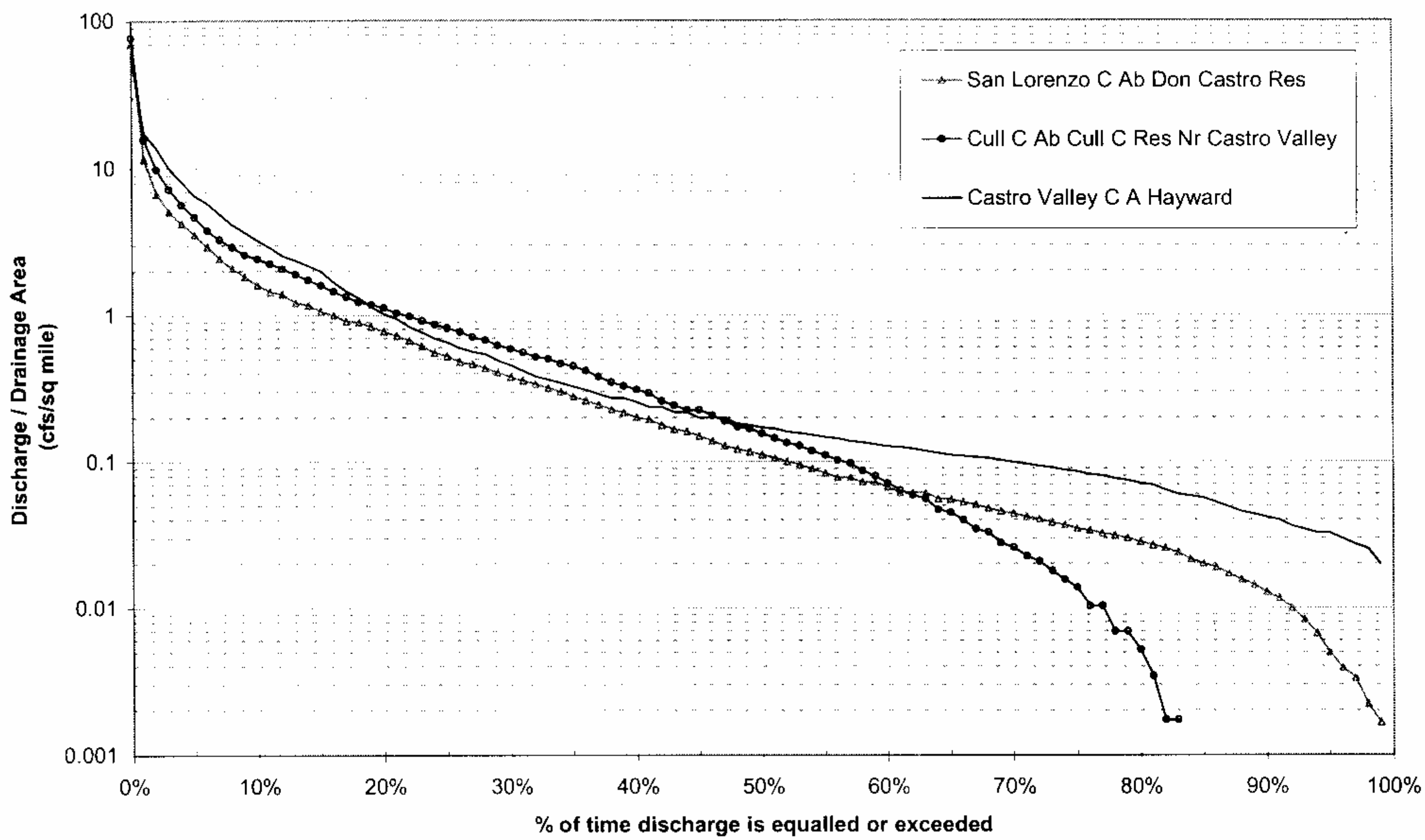
Figure 11. Photos of Potential Fish Barriers

Appendix A: Flow Duration Curves, Alameda County and San Lorenzo Creek Watershed (from Love 2001)



NOTES:
Source is Figure B-4 Appendix B-6 in Love 2001.
Flow duration curves constructed using flow data from November through April, the assumed period of steelhead and rainbow trout upstream migration. Some of the gauge stations have only two years of recorded flows.

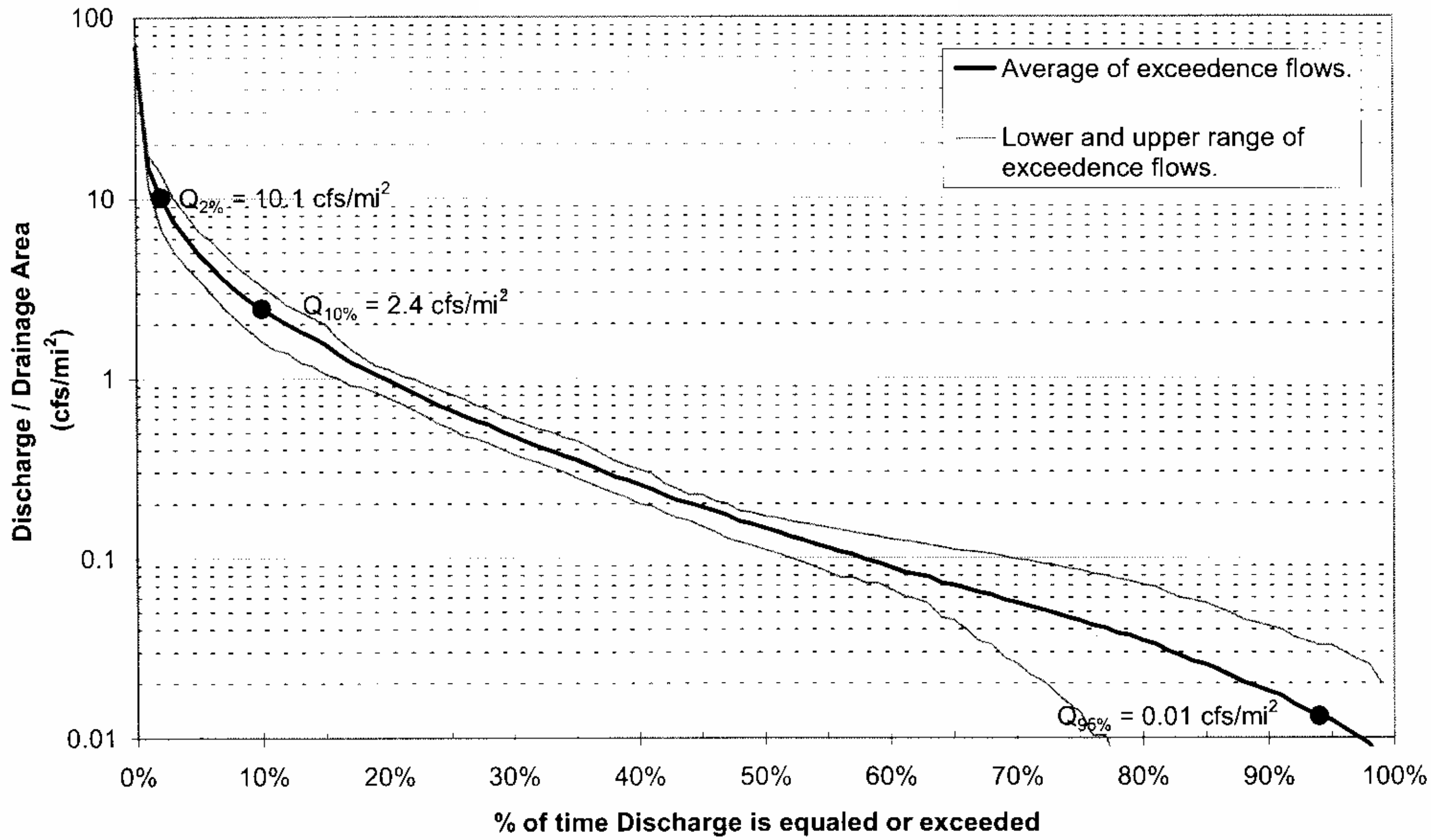
Figure A-1: Flow Duration Curves for November through April, Streams Within Alameda County



NOTES:
Source is Figure B-5 Appendix B-6 in Love 2001.
Flow duration curves constructed using daily average flows from November through April for the three gage sites with the longest record (Dry Creek appears to have regulated flow at times and was excluded).

Figure A-2: Flow Duration Curves for November through April from Long-Term Gauge Sites in the San Lorenzo Creek Watershed

Appendix B: Regional Flow Duration Curve for the Period of Salmon Migration (from Love 2001)



NOTES:
Source is Figure B-5 Appendix B-6 in Love 2001.
Flow duration curves constructed using daily average flows from November through April for the three gauge sites with the longest record (Dry Creek appears to have regulated flow at times and was excluded).

Figure B: Regional Flow Duration Curve for the Period of Salmon Migration (November through April), Southwestern Alameda County