Restoration Recommendations for Fish Species Re-population of Strawberry Creek based on High Flow and Stream Habitat Assessment

Cheryl Lee

Abstract Strawberry Creek is an urbanized creek that is in the process of being restored. However, the final step of re-populating the creek with fish has not been as successful as planned. One proposed theory for the failure of these attempts has been the lack of high flow refuges. To address this possibility flow patterns were observed and diagrammed during times of high flows at various sites along the creek on the U.C. Berkeley campus. High flows are flows caused by rain storms resulting in higher than normal flows. Habitat assessment was also a concern, thus, creek characteristics of depth, width, bank angle, undercut, vegetation overhang, sediment type, bank development, creekside vegetation and flow were measured. Flow was measured at times of normal or base flow as well as at times of high flow. Six different sites of Strawberry Creek on campus were observed and assessed for flow and habitat characteristics based on observations and previously documented criteria to make larger scale restoration recommendations. Flows were found to vary significantly between base and high flow conditions. Additionally, it was found that there are very few high flow refuges in Strawberry Creek. This in addition to mostly unfavorable habitat characteristics leads to a wide range of restoration recommendations. However, implementation of such recommendations are limited due to the highly urbanized nature of the creek. Ideally, restoration should include the reduction of channelized sections and/or banks as well as the planting of more vegetation along the banks. Other recommendations which may not be as feasible would be to create more meanders or variations on ox bow to give fish areas of reduced flow.

Introduction

Strawberry Creek on the University of California, Berkeley campus has been an integral part of the university's long history. The current site of the campus was originally chosen because of the presence of Strawberry Creek (Willey 1887). However, over the years, the creek has been modified and degraded due to the urban impacts and influences of the campus and surrounding areas. These impacts have led to poor water quality, lack of flora and fauna and threatened structures due to bank erosion. Finally, in 1987, these concerns were addressed by the University to create and implement a management plan for Strawberry Creek (Charbonneau 1987). The plan has been implemented in several aspects and has treated many of the problems the creek faced. Restoration efforts have included sewer and sanitary system repairs, bank stabilization, check dam repair and installation, regrading, slope stabilization and revegetation. These efforts have led to improved water quality and the return of several biological communities (Charbonneau and Resh 1992).

The next step in the restoration process is the reintroduction of several fish species. However, these efforts have not experienced their anticipated success (Kondolf, pers. comm). One reason of the lack of success may be the extreme urbanization of the Strawberry Creek watershed. About 40% of the 470 ha watershed is urban, and characterized by extensive areas of impermeable surfaces, such as parking lots, buildings, roads and irrigated lawns. The added impermeable surfaces create more run-off, which leads to increased flows since less water is able to permeate into the ground. These factors combined with culverting, channelization and storm water routing create a hydrologic regime where peak storm flows are higher than pre-urbanization conditions (Charbonneau and Resh 1992, Charbonneau 1987).

Impacts of channelization on habitat for fish and invertebrates include removal or subsequent loss of riparian vegetation, loss of instream cover (snags), altered riffle pool sequence, decreased stream sinuosity, altered substrate composition, increased stream velocity, increased bank erosion and bed scour, increased suspended sediment and increased water temperature (Crandall, et al 1984). These factors lead to the idea that perhaps the winter storm flows flush the fish populations out, thus preventing them from establishing themselves.

High flows or flushing is detrimental to the fish if they are unable to tolerate the increased water velocities. The intolerance of higher flows can lead to the fish being eliminated from the stream (Nunnally 1978). Another possibility is that the fish are flushed downstream by the high flows, but not eliminated from the stream. Yet, both of these consequences are still counter to the goal of fish re-population in the desired stretch. However, the “flushing” might be avoided if there are high flow refuges for the fish populations. Yet, the presence of high flow refuges has yet to be documented for Strawberry Creek, although the issue has been considered for the creek and other restoration efforts (Kondolf, pers. comm.).

Flow refuges not only offer areas or retreat for energetic savings but also offer opportunities for enhanced feeding and migration (Gerstner 1998). It has been shown that areas of high flows have reduced predation on macroinvertebrates (Hart and Merz 1998). The lack of predation or potential food for fish species is another reason why refuges are essential. It has been found that the availability of flow refuges is a critical habitat factor for brown trout and grayling species (Maki-Petays 2000). These refuges have been found to be essential during the winter (Vehanen 2000). Additionally, during times of high flow these species were more susceptible to downstream displacement in channelized streams (Maki-Petays 2000).

Refuges provide a number of benefits for fish. They should provide protection from swift currents, high temperatures and predators (Garcia De Jalon 1996). One way these qualities can be attained is having areas of adequate cover. Cover may be in the form of riparian vegetation, undercut banks, aquatic vegetation and rubble-boulder areas. Debris jams may also form refuges and pools (Reiser and Bjornn 1991). Plunge pools can offer additional refuges due to the increased dissolved oxygen levels and depth (Fitzgerald 1998). Another high flow refuge could result from in-stream large woody debris, which has many other stream altering benefits (Kondolf 2000).

Other consequences of refuge areas should also be considered. While debris jams may form beneficial refuges, they could become sediment traps (Reiser and Bjornn 1991). Another effect of refuges could be increased pool formation or flooding, which is a drawback for a highly developed or urbanized stream floodplain. This drawback is one of the main reasons that channelization of urban streams first took place. It was presumed that channelization would lead to lower flood crests and/or decrease in flood duration (Nunnally 1978). However, it is also probable that higher flows produce more scour and cause more undercutting which can threaten banks and/or nearby structures (Maranzana, pers. comm. and Charbonneau 1987)

Refuges can be recreated in a number of different ways. Simple revegetation projects will produce areas of cover and can positively affect stream flow. Another relatively inexpensive technique of placing logs, boulders, gravel, etc can help to recreate habitat and refuges (Newbury and Gaboury 1993 and Garcia De Jalon 1996). Other structures such as deflectors, check dams and placement of larger debris (wood or boulder) has also been documented as being effective for forming refuges (Gore and Hamilton 1996). However, the recreation or restoration of habitat should only be planned and/or implemented after an assessment of current conditions is performed.

Strawberry Creek was studied to see the impacts of the urbanization on the creek. Specifically, the creek was examined to locate and document any high flow refuges which would be necessary for fish populations to survive in the creek. Additionally creek characteristics were documented and assessed to better characterize and document the creek habitat and refuges.

Methods

Strawberry Creek on the U.C. Berkeley campus (37°52' N; 122°15' W) (Alameda County, California, USA). A total of six sites were assessed: three sites along the South fork, two sites along the North fork and one after the North and South fork come together (Figure 1 and Appendix A).

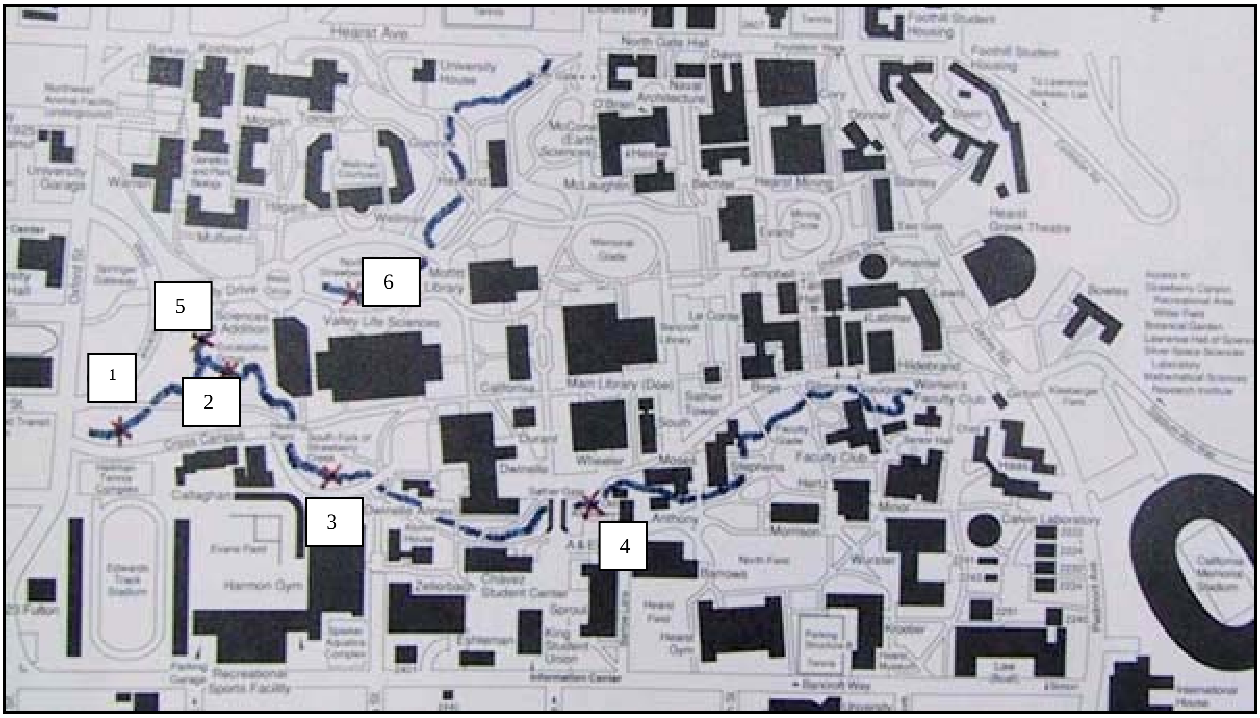

Figure 1: Map of Study Site (sites numbered and denoted with "x")

Prior to sampling, the campus sections of Strawberry Creek were walked to determine ideal sites to assess the creek habitat and make flow measurements. A main factor in choosing and determining ideal sites was based on the appearance of locations with relatively favorable fish habitat. For instance, sites with natural banks were chosen as being more favorable over areas where the channel had been lined with concrete. Sites were also determined based on the possible alteration or planning that might be suggested as a result of this study. Additionally, visual observations were made to see the current status and location of any present fish population locations. The presence of fish was an additional, but less prioritized condition for choosing study locations. Once specific creek sites were chosen base maps were sketched.

Habitats of the creek study sites were documented. Characteristics measured, according to Platts, *et al* 1983, were creek depth, creek width, creek undercut, bank angle, vegetation overhang, creekside cover, substrate type and bank development type. These characteristics were measured at five different transects within each creek stretch. Additionally, depth and width was also measured based on high water marks to determine high flow. Velocity was also measured at base and high flows to determine flows. Lastly, creek currents were diagrammed to document any high flow refuges.

Stream width was measured with a measuring tape. Width is defined as the point where water meets one bank to where water meets the opposing bank at a line perpendicular to water flow. Depth was measured by meter stick at ¼, ½, and ¾ distances across the stream. Depth is defined as the distance from the substrate to the surface of the water. Creek undercut was measured using a meter stick. Undercut is defined as the distance from the bank to where the water flows horizontally beneath it. Bank angle was measured with a meter stick and clinometer. The meter stick was placed along the angle of the bank and then the clinometer was placed along the meter stick and the resulting angle was recorded (Figure 2).

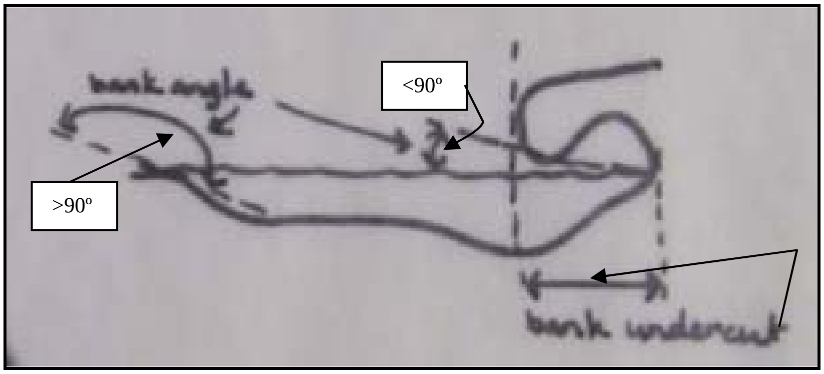

Figure 2: Bank Angle and Undercut

Vegetation overhang measures the horizontal distance of overhang by vegetation within 0.25 meter of the water surface (Figure 3).

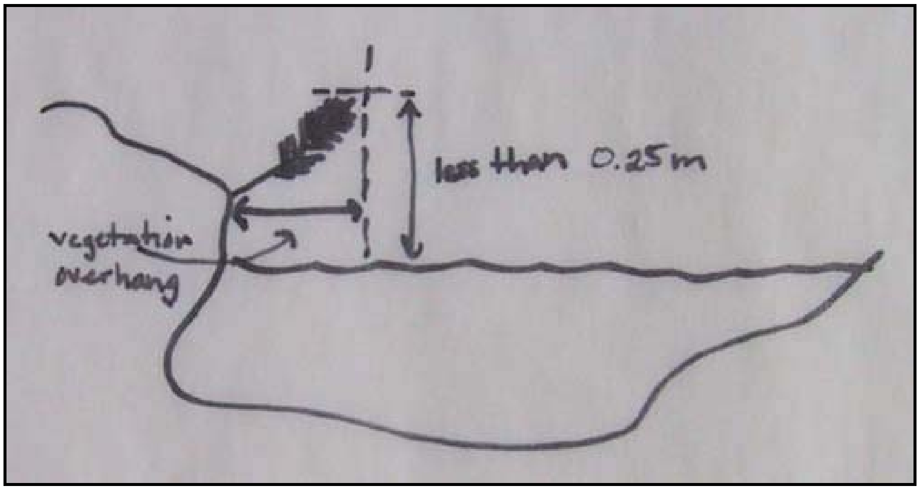

Figure 3: Vegetation Overhang

Creekside cover was classified: dominant vegetation is shrub, dominant vegetation influencing environment is of tree form, the dominant vegetation is grass or forb, and over 50% of creek bank has no vegetation and the dominant material is soil, rock or man-made structures. Substrate type was classified: fine sediment, gravels, cobbles, boulder or rock/concrete surface (fine sediment x<2mm; gravels, 2<x<200mm; cobbles, 200<x<1000mm; boulder, x>1000mm, rock, >4m^2 (Platts, *et al* 1983). Bank development type was also classified: natural, altered (biotechnically), or altered (man-made/urbanization construction).

The creek characteristics were then assessed and classified according to criteria developed by Hunter (1991) Table I.

Creek Characteristic	Excellent	Good-Fair	Poor
Width: depth	5:1	20:1	40:1
Bank undercut	Greater than 0.15 m on 50% of bank	Less than 0.15 on 20-45% of bank	Less than 0.15 on less than 20% of bank
Bank angle	50% of bank less than 90 degrees	30-405% of bank less than 90 degrees	Less than 20% of bank less than 90 degrees
Vegetation overhang	Greater than 0.3 m on 50% of bank	Greater than 0.3 m on 30-45% of bank	Greater than 0.3 m on less than 20% of bank
Creekside cover	Brush/sod	Boulder/rublle, tree, root, brush	Bare soil
Substrate composition	Gravel/rubble boulder	Gravel/rubble and or sand/silt	Sand, silt, boulder
Bank development	Natural	Altered – biotechnically	Altered- man-made

Table I: Creek Character Classification (Hunter 1991)

The float method was used to measure flow. Base flow and high flow were both measured using white mushrooms which were found to float partially submerged and so to give a good indication of water velocity. For base flows the creek stretch was divided into smaller sections based on the transects. Within the sections, mushrooms were timed for one meter of movement. Four trials were taken at each section of the creek stretch. For high flows, mushrooms were timed over the whole creek stretch. Four trials were also taken at each stretch. Velocity measurements were also multiplied by 0.8 to account for the difference in velocities throughout the water column (USEPA 2000). Once the adjusted velocity was known, then flow can be determined using the depth and width or cross-sectional area measurements (USEPA 2000, Nunnally 1978).

To diagram the flows, pieces of orange peels, approximately 3 inches in diameter, were placed in the creek at various distances across the creek and through the creek section. They were then observed for directional movement.

Results

Flow Diagramming Only two high flow refuges were noted in the six sites along Strawberry Creek that were sampled. One refuge was at the South Fork – Valley Life Sciences Building site. A pool has developed along the left side, immediately after a failing check dam. During testing, mushrooms and orange peels were able to repeatedly avoid the rushing water by taking shelter in the pool. The other refuge was located at the North Fork – Valley Life Sciences

Building site. It was the same area that had considerably slower flow even at normal flow times, along the left bank, near the beginning of the site stretch a back eddy, back current, formed creating a high flow refuge. However, at all of the other sites, no refuges were noted. Diagrams of flows are attached in Appendix B.

Flow Comparison Flow was measured at base and high flows for all six sites. There was considerable difference in the flows between base and high flows (Table II).

Site	Base Flow (m^3/s)	High Flow (m^3/s)	Magnitude of increase
1.) Oxford	$0.0141 \pm 8.67 \times 10^{-4}$	1.66 ± 0.12	~118 times
2.) South fork – Eucalyptus Grove	$0.0239 \pm 2.55 \times 10^{-3}$	1.35 ± 0.042	~56 times
3.) South fork – Valley Life Sciences Building / Redwood Grove	$0.0292 \pm 5.06 \times 10^{-3}$	2.02 ± 0.093	~69 times
4.) South fork – Culvert bypass / Sather Gate	$0.0241 \pm 3.59 \times 10^{-3}$	0.95 ± 0.025	~39 times
5.) North fork – Valley Life Sciences Building	$0.00684 \pm 9.72 \times 10^{-4}$	0.401 ±0.012	~59 times
6.) North fork – Eucalyptus Grove	$0.0818 \pm 1.89 \times 10^{-3}$	1.08 ± 0.045	~13 times

Table II: Measured flows of Strawberry Creek at six different sites

Habitat Assessment Ranges for the different characteristics at the different sites varied from excellent to poor conditions as classified by Hunter (1991) (Table III).

Site	Depth (m)	Width (m)	Undercut (m)	Bank Angle (˚)	Vegetation overhang
Oxford	0.030 – 0.200	2.91 – 3.11	0 – 0.08	5 – 240	0
South fork – Eucalyptus Grove	0.010 – 0.500	0.95 – 1.97	0 – 0.45	9 – 153	0 - 0.18
South fork – Valley Life Sciences Building / Redwood Grove	0.01 – 0.145	0.69 – 3.15	0 – 0.4	11 – 139	0 – 0.15
South fork – Culvert bypass / Sather Gate	0.01 – 0.187	1.0 – 1.9	0 – 0.1	10 – 125	0 – 0.83
North fork – Valley Life Sciences Building	0.17 – 0.395	1.20 – 1.56	0 – 0.06	90 – 160	0 – 0.39
North fork – Eucalyptus Grove	0.030 – 0.250	2.71 – 3.04	0 – 0.200	14 – 144	0 – 0.27

Table III: Characteristic ranges at the six sites along Strawberry Creek

Bank development at the six sites varied from being completely natural to partially natural and altered (man-made or urbanized) (Table IV). There were no instances of biotechnical alterations.

Site	Bank development	Creekside cover	Substrate type
Oxford	Natural	>50% no veg.	Gravel
South fork – Eucalyptus Grove	Natural and altered	>50% no veg.	Fine sediment
South fork – Valley Life Sciences Building / Redwood Grove	Natural and altered	Shrub and tree	Fine sediment and gravel
South fork – Culvert bypass / Sather Gate	Natural and altered	Shrub and tree	Gravel, fine sediment, cobble (few)
North fork – Valley Life Sciences Building	Natural and altered	Shrub	Gravel
North fork – Eucalyptus Grove	Natural and altered	Shrub and >50% no veg.	Fine sediment and gravel

Table IV: Bank development and Creekside cover classification at the six Strawberry Creek Sites

Creekside cover at the six sites contained all four types of categories , although >50% no vegetation, shrub and tree dominated the sites (Table III).

The substrate type was classified by size from fine sediment, gravels, cobbles, boulder to rock. The substrate type at the six sites ranged from fine sediment to cobbles, although fine sediment and gravel dominated (Table IV).

Discussion

High flows and habitat were studied, documented and assessed to better understand how to produce successful current and future fish re-populations to Strawberry Creek on the University of California, Berkeley campus. The results were interpreted along with current and future developmental constraints to make recommendations for future restoration and fish repopulation efforts.

High flows were diagramed, in particular, with the purpose of finding and documenting any high flow refuges. Out of the six sites studied, only two refuges were found. While, for some of the more urbanized stretches of Strawberry Creek this may be favorable, it is disappointing since the six sites were chosen initially as being more ideal sites for fish habitat. Additionally, this finding is unfavorable because in naturally occurring creeks there are often several refuges within in documented stretches (Nunally 1978). Thus, the lack of refuges in Strawberry Creek, which is undergoing the process of fish population, may be a forecast for failure.

While high flows are of concern in any creek, they are of particular concern in Strawberry Creek due to the extreme urbanized nature of the creek and the surroundings. The difference in flows found between base and high flow times is evidence of the importance of refuges for any successful fish re-populations. High flows ranged from 13 to 118 times faster than the base flows at the same sites. The fish that have been reintroduced for re-population purposes could be flushed out or eliminated from the creek due to the influence of such high flows (Nunnally 1978).

Creek habitat assessment was also found to be undesirable for fish population establishment. Depth was found to range as a whole throughout the creek, but there was little variation within the sites. Whereas in natural creek stretches there are often variations in depth in the form of pools and riffles (Hunter 1991). Pools are deeper, cooler areas of the creek channel where water tends to move slower and riffles are typically faster, shallower, warmer areas (Platts, et al 1983). The variation in depth and movement is key because it affects the water temperature. Additionally, deeper pools are not only areas of cooler water and possible predator and high flow refuges, but they also provide feeding areas (Vehanen 2000). Thus, fish populations would likely be more successful if there were more variation of depth within channel stretches.

Width measurements showed similar results to depth findings. While the total range varied between the sites there was little variation within the sites. The lack of variations are typical characteristics of urbanized creeks (Fitzgerald 1998).

Many urbanized creeks are channelized reducing the natural meanders and variations in the width and depth of streams. Understanding the differences between natural and urbanized creeks should be taken into consideration in planning restoration efforts for the purpose of re-population of fish.

Width and depth are often related to one another and can be also be assessed as a ratio between the two measurements. The favorable ratios reflect the preference for meandering channels with pools and riffles which are closely related to one another. However, the small size of Strawberry Creek makes it difficult to classify in these terms because the conditions described in Hunter (1991) were for streams about twice the size of Strawberry Creek.

Undercut measurements were again similar in nature to the depth and width measurements. There was a small range, but overall undercuts were not present or minimal in the studied sites. At each site undercut was measured ten times, five times on each bank. The number of actual undercuts measured per site ranged from two to six. Additionally, the actual measurement of the undercuts were minimal. So, while undercuts were present, the amount and size of undercuts were minimal. The presence of undercuts are ideal since they provide shelter and feeding areas not only at times of high flows, but also during base conditions (Platts 1983 and Vehanen 2000). Additionally, generally, the greater the size of the undercuts, the more beneficial for fish habitat.

Bank angles are closely related to undercuts. Additionally they are representative of the type of modifications the creek channel has undergone. Bank angle measurements of less than ninety degrees indicate undercut banks (Figure 2). Almost half of the measurements were greater than ninety degrees. Larger bank angles indicate more sloping banks which tend to me more natural and give rise to a better adaptation to higher flows. Eleven of the measurements were ninety degrees, indicating either channelization or downcutting of the creek channel. Ideally, if there are no undercuts present, larger sloping bank angles would be better overall creek habitat for fish (Hunter 1991).

Bank development classification was noted at the six sites to be either natural or altered (man-made or urbanized). While none of the sites were completely altered, it does not mean the whole creek is exempt from this classification. While the sites themselves did range in variation, the extreme of complete channelization was not chosen as a site because it was assumed that such a site would not be suitable habitat nor have any refuges from high flows. All of the sites, except for the Oxford site had mixed bank development. That is, one of the banks was usually altered and the opposite bank was natural. Ideally, at least if the bank were altered, or had to stay altered the alteration could be modified to some type of biotechnical modification (Fitzgerald 1998).

Vegetation overhang is similar to bank undercut in that it shares many favorable characteristics key to fish habitat. It provides feeding areas, shelter from predators and keeps water temperatures lower (Vehanen 2000). As stated earlier, many of the banks were altered on one bank, leading to little vegetation, hence little vegetation overhang. Even with natural bank development, many times there was not any vegetation overhang. At the Oxford site, where both banks were completely natural, there was not any vegetation overhang. Four of the sites only had one to five places of measurable vegetation overhang. The North fork – Eucalyptus grove (Site 5) site was a bit of an exception with seven measurable locations of vegetation overhang, but it only ranged from 0.13 to 0.27 m, which is less than the 0.3 m which is found to be favorable according to Hunter (1991).

Substrate type findings were more favorable. For spawning purposes bed type is a key habitat characteristic. All sites except for the South fork – Eucalyptus grove site had some gravel documented. Gravel is typically known as ideal sites for fish spawning (Knapp 1998). However due to the high flows and consequently high energy currents, sediment type could change seasonally (Knapp 1998).

Creekside cover is related to bank type and bank development. Ideally creekside cover should both protect the banks from erosion and provide shading for the creek (Platts 1983). Even though many of the sites had altered bank development, there were overall favorable shading conditions. Even at the most intense sunlight times, much of the creek was shaded or sheltered keeping water temperatures on the cooler side. The overall shading of the creek is due to the presence of larger trees along the creek. However, these larger trees are likely preventing the growth of smaller more favorable riparian plants that could offer more vegetation overhang and bank stability (Haltiner, pers. comm.).

Of the six sites, none were found to be favorable overall, in terms of creek habitat. Although some sites were found to have one or more "excellent" or "good-fair" characteristics, "poor" characteristics dominated at many of the sites (Table V).

Site	Excellent	Good-Fair	Poor
1	2	1	4
2	1	1	5
3	2	3	2
4	0	5	2
5	2	2	3
6	1	2	4

Table V: Characteristic Rating Tally for the Six Sites

Additionally, the different characteristics have not been prioritized, such as to form an index, so it is not clear if one certain "poor" characteristic would me more important for fish habitat than one less dependent "excellent" characteristic. However, it should also be noted, that Hunter's (1991) classification criteria is only a recommendation and different fish species and creeks may be exceptions. Yet, it appears that since almost half of the characteristics appear to be "poor" that the habitat in general is unfavorable for fish habitat.

Thus, even if refuges for fish were created, there would need to be habitat improvements as well to gain successful fish re-populations. However, perhaps, more importantly, many sites had the potential to be ideal or at least suitable fish habitat. This was in part due to the selection of the sites. Since an overall goal for assessment was to make restoration recommendations, sites were chose that could possibly have restoration potential, meaning that there would be space surrounding the creek to make physical changes.

Flow diagramming was critical in determining if there are any high flow refuges, although due to the method type, it was really only able to test for refuges or currents at the surface of the creek. It is possible that there are more refuges in the deeper depths of the creek. Additionally, due to the short period of time for data collection, and the sparse winter season flows were only diagrammed on two occasions.

Additionally, the rain storm that these flows were collected at was not the heaviest rain of the season. So, even though two refuges were found, at even higher flows, they might not be present, which would be when they are even more important.

Even though there is a small amount of data, the comparison of the two flows is significant ($p<0.005$). Yet, the increase in magnitude, which ranged from 13 to 118 times greater, is the element that should be considered for restoration and re-population purposes.

Due to the substantial number of "poor" habitat conditions and significant difference in base and high flows several restoration projects and suggestions can be made. The pool refuge located at the South fork – Valley Life Sciences Building site is a simple design that could be implemented at several locations along the creek. The pool that is present is actually a consequence of a failing check dam. On the downstream side of the check dam, the bank has begun to cut away creating a pool and shelter from high flows. Another possibility at the beginning of the study was to implement more culvert bypasses like at the South fork – Sather Gate site. However, during the storm when the high flow data was collected the bypass did not seem to be functioning at its intended purpose. Instead of the high energy water flowing through the box culvert, it was all flowing around the meander bypass. So, for the culvert/bypass structure to work, the creek would have to be flowing at an even higher magnitude. Yet, the flow difference between base and high flow was already substantial. A possibility would be to create a similar design, but on a smaller scale. A natural variation is oxbow formations along creeks where water is allowed to meander, yet at times of higher energy flows water can travel in more direct routes. However, a more natural meander may be difficult in many areas of campus due to the limited space and close development of the campus.

Other refuge creating designs include the installation of deflectors and/or riprap. Deflectors are ideal in creating pools and slower flowing areas. However, these benefits can also cause problems on the highly urbanized creek such as becoming debris collectors, thus leading to unfavorable habitat and possibly increase the risk of flooding (Hunter 1991). Since many modifications have been made on the creek to reduce flooding hazards, the addition of deflectors may be counter productive to these earlier modifications. Additionally, they have been found over the years to be less favorable, since they have a tendency to cause bank erosion (Hunter 1991). Riprap is usually submerged branches and similar items secured in locations to provide fish habitat. However, it has similar drawbacks to the deflectors in that it can collect debris and slow water movement (Hunter, 1991).

Other smaller designs or projects could be installation of log sills or the modification or repairing of the failing check dams. Log sills work to slow water flow down as well as create pools on the downhill side. Additionally, placed at angles along the creek they can provide meander-like conditions where sediment can build up and/or refuges can form (Hunter, 1991).

Overall, Strawberry Creek could undergo multiple changes to improve fish habitat and form high flow refuges. Yet, in considering which improvements should be made first, it would be ideal to conduct more studies on Strawberry Creek since after the end of this study fish populations actually have been sighted in the creek. Population counts and distributions could be made at several sites to characterize and/or locate more refuges, since perhaps there are more refuges or that there are other properties or characteristics of refuges that have not been identified. Additionally, population counts could be done over different seasons and compared to natural fluctuations in undisturbed creeks. Or, along the same study lines, Strawberry Creek and unaltered creeks could be compared for fish population sizes, the population distributions and habitat preferences to gain more knowledge on how to improve the possibility of fish species re-population in Strawberry Creek.

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APPENDIX A – SITE PICTURES

Site 1: Main Branch - Oxford

Looking up stream

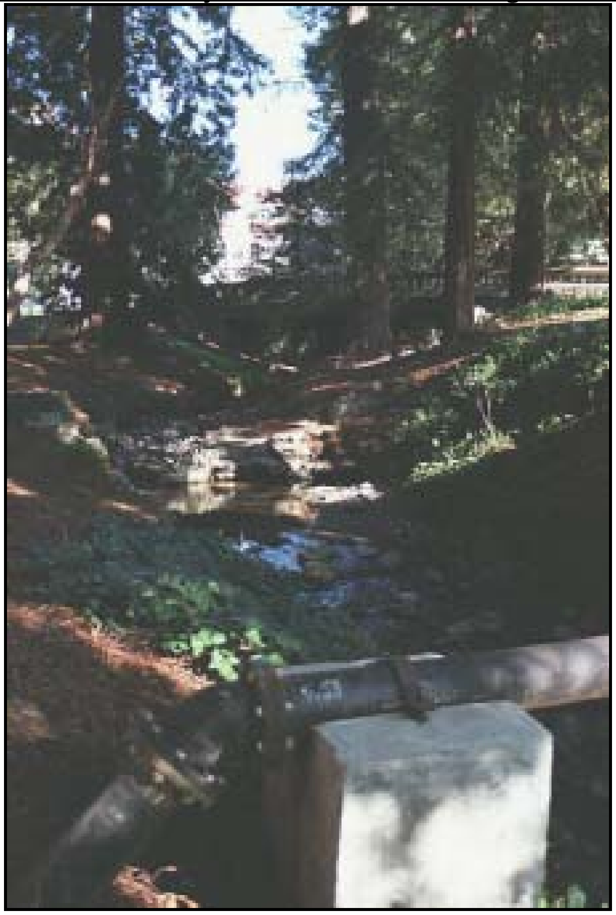
Looking downstream

Site 2: South Fork – Eucalyptus Grove

Looking up stream

Looking downstream

Site 3: South Fork – Valley Life Sciences Building, Redwood Grove



Looking upstream

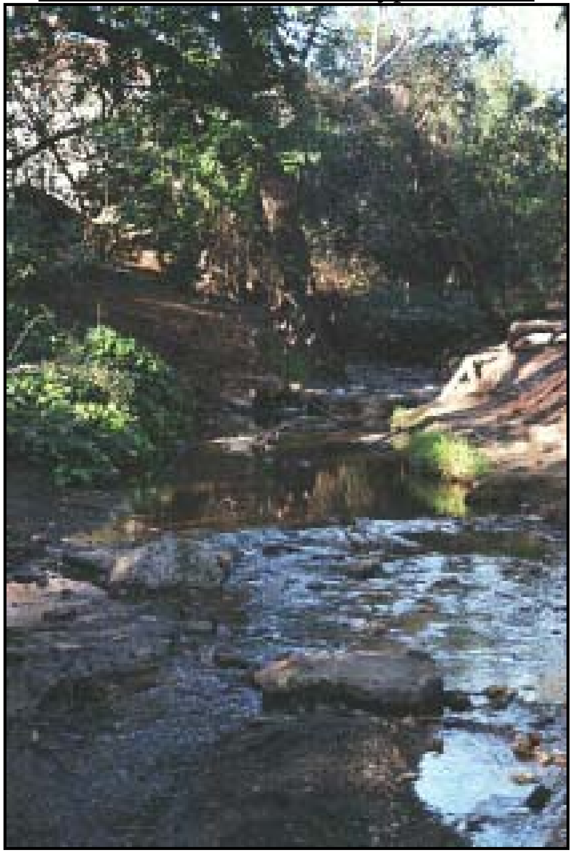
Looking downstream

Site 4: South Fork – Sather Gate, Box Culvert Bypass

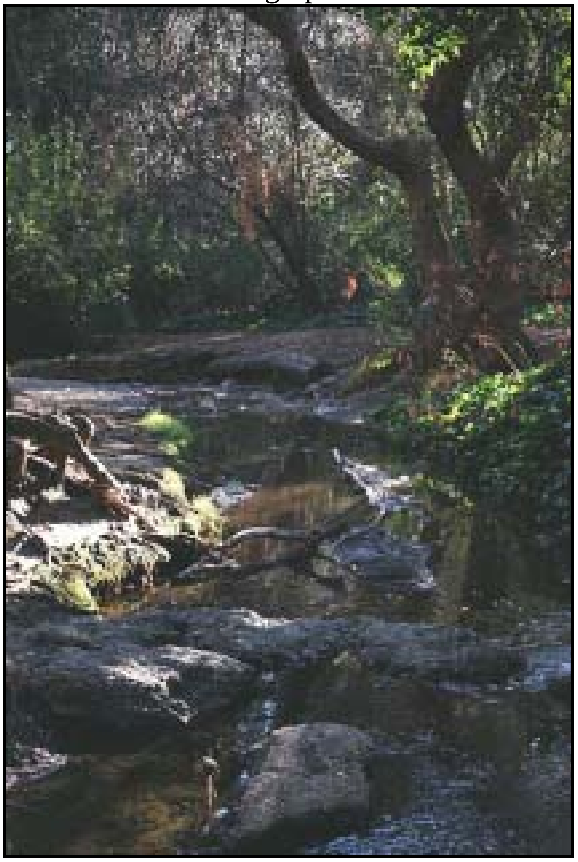
Looking upstream

Looking downstream, on the left is the bypass channel, on the right is the box culvert

Site 5: North Fork – Eucalyptus Grove



Looking upstream



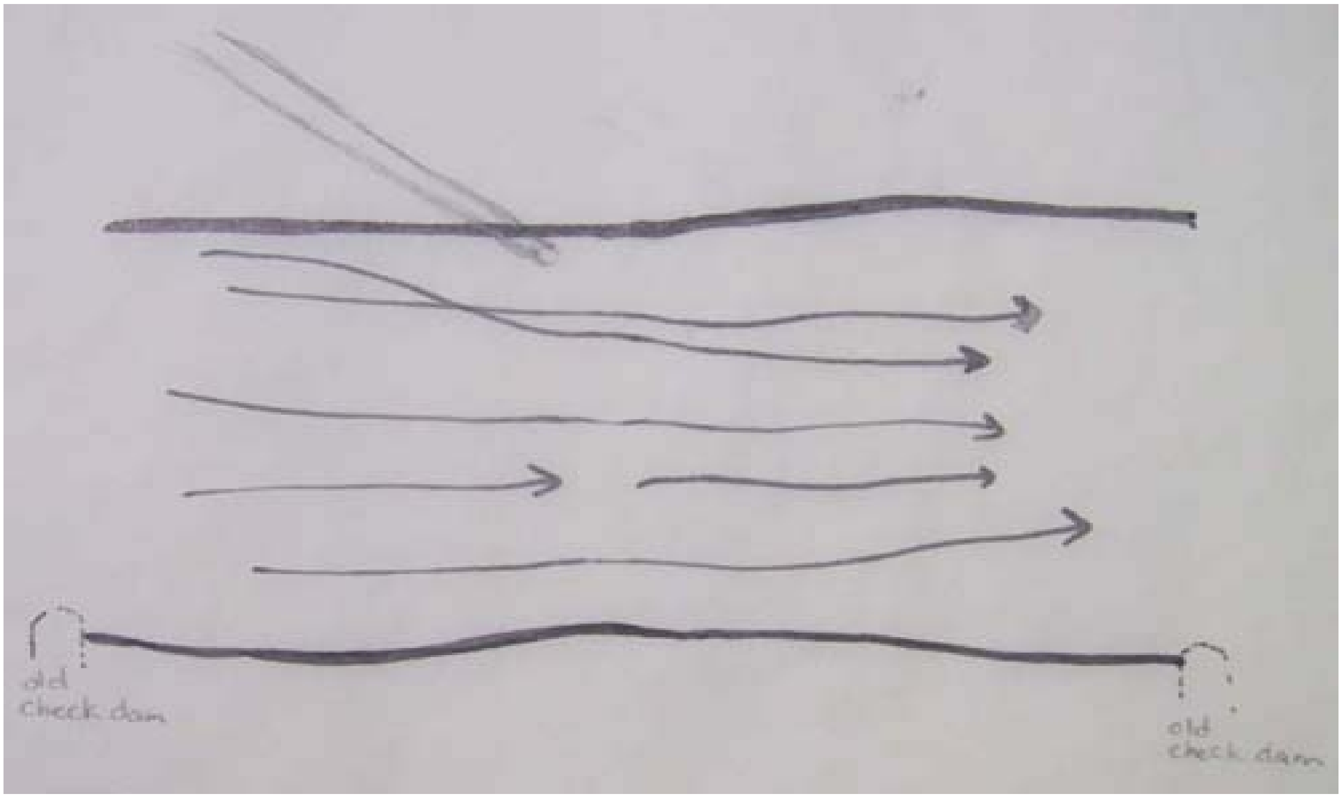
Looking downstream

Site 6: North Fork – Valley Life Sciences Building

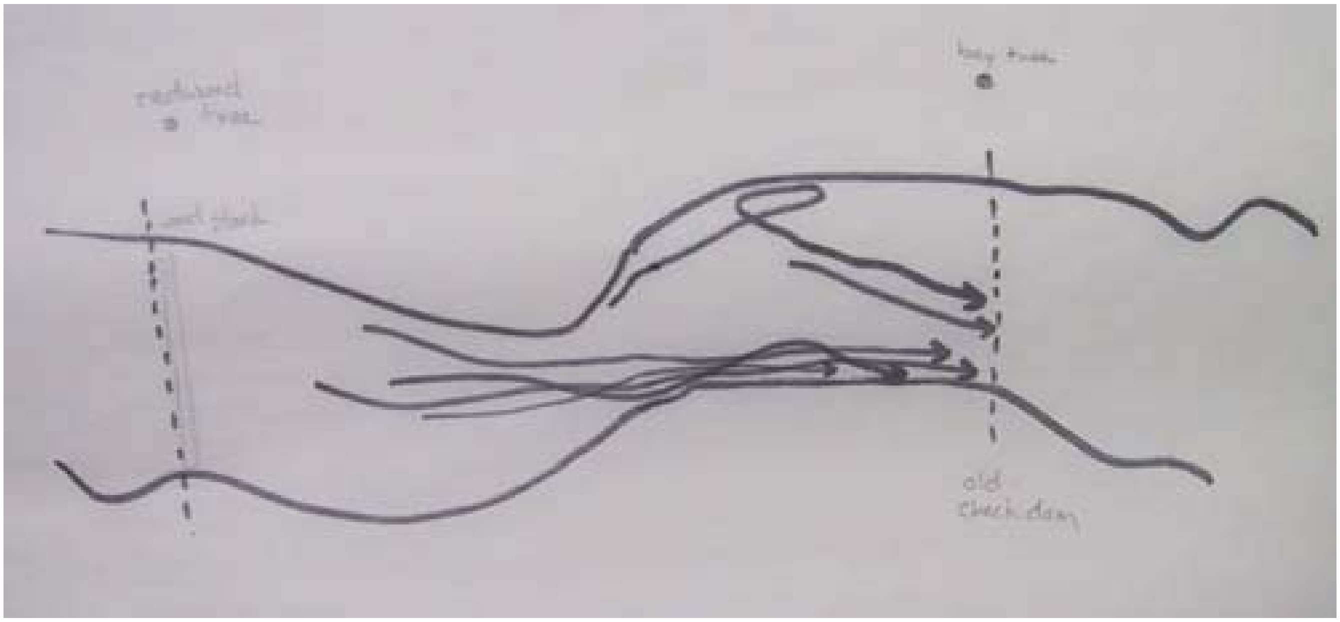
Looking upstream

Looking downstream

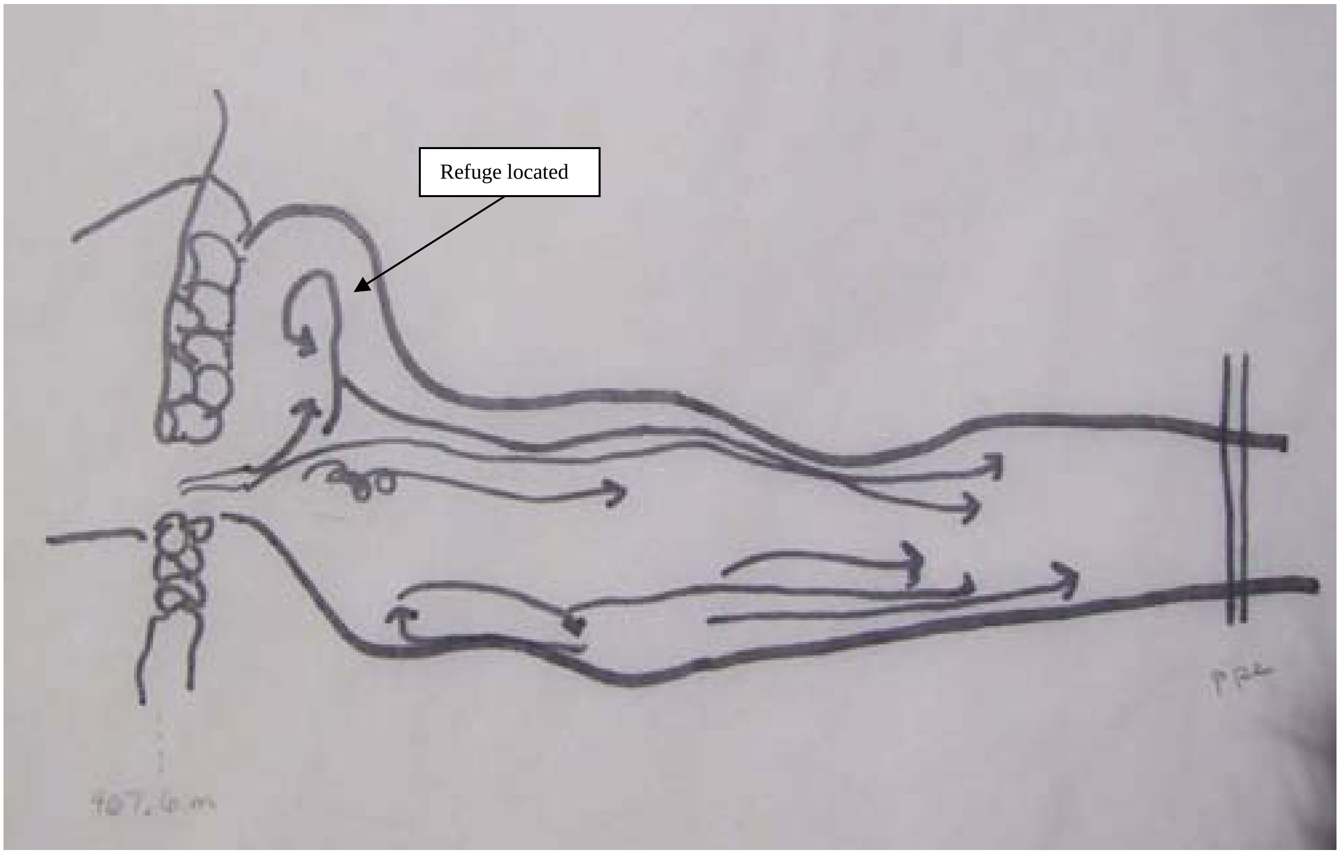
APPENDIX B – FLOW DIAGRAMS



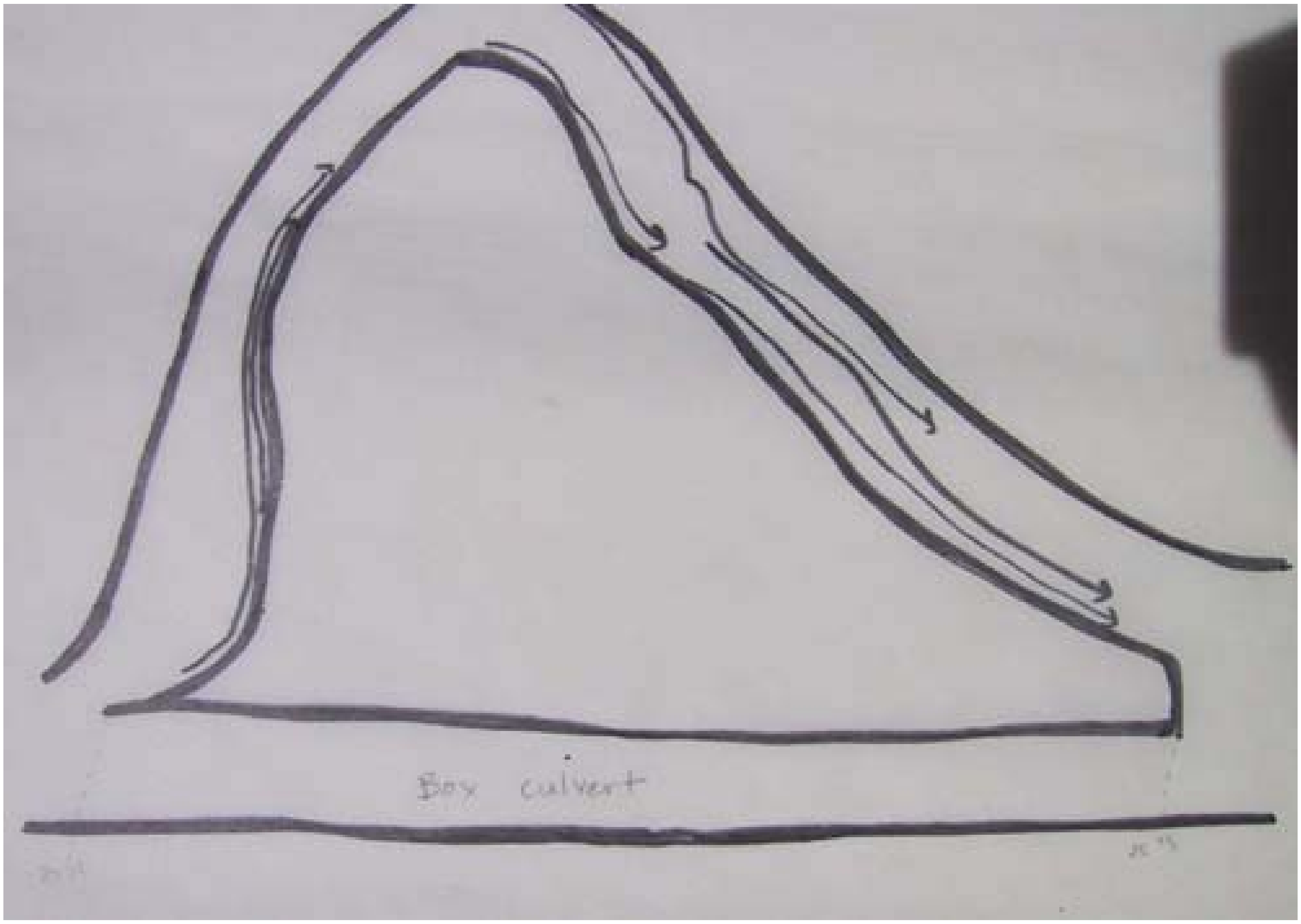
Site 1: Main Branch – Oxford



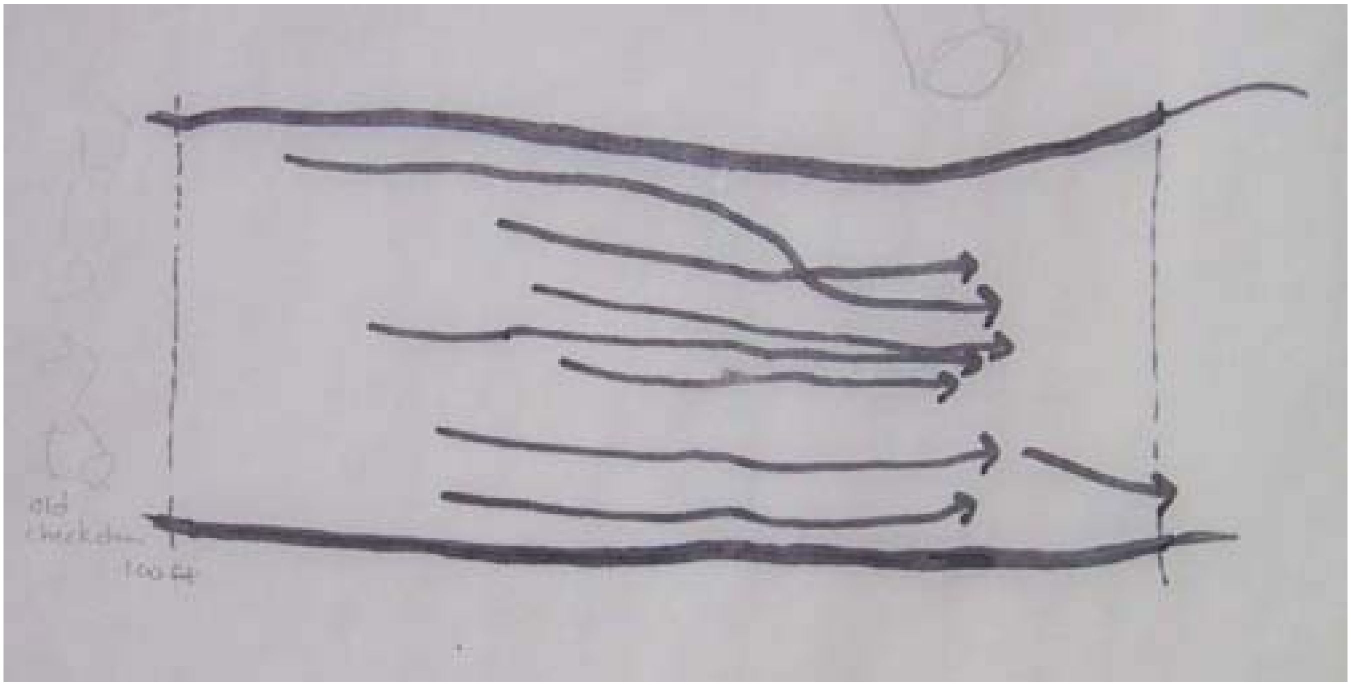
Site 2: South Fork – Eucalyptus Grove



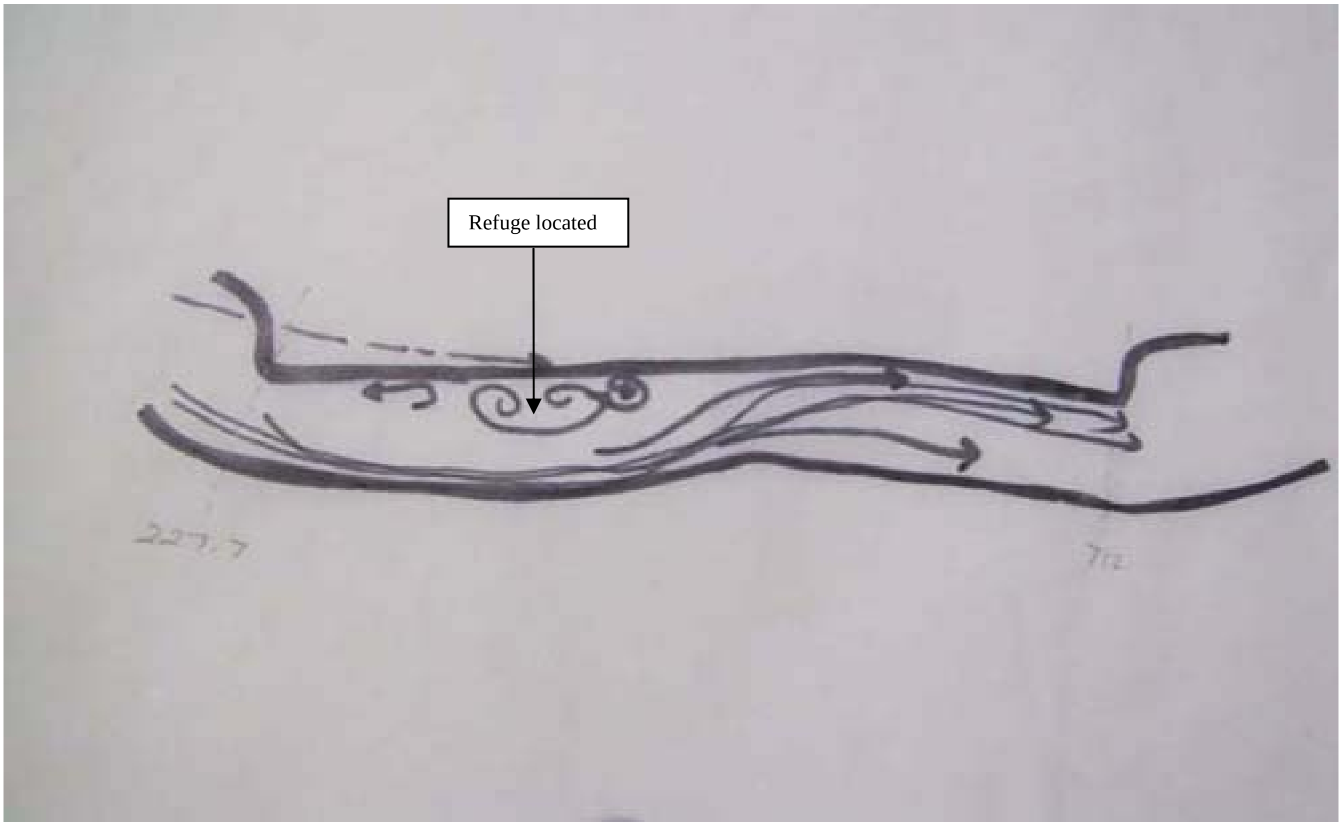
Site 3: South Fork – Valley Life Sciences Building; Redwood Grove (check dam location 407.6 m from city culvert)



Site 4: South Fork – Sather Gate; Box culvert bypass (from 2,739 to 2573 m up from city culvert)



Site 5: North Fork – Eucalyptus Grove (check dam at 30.5 m up from confluence of north and south forks



Site 6: North Fork – Valley Life Sciences Building (rock wall along left bank from 217m to 227.7 m from confluence)