Virtual Restoration and Modeling Environmental Flows in Lower San Leandro Creek

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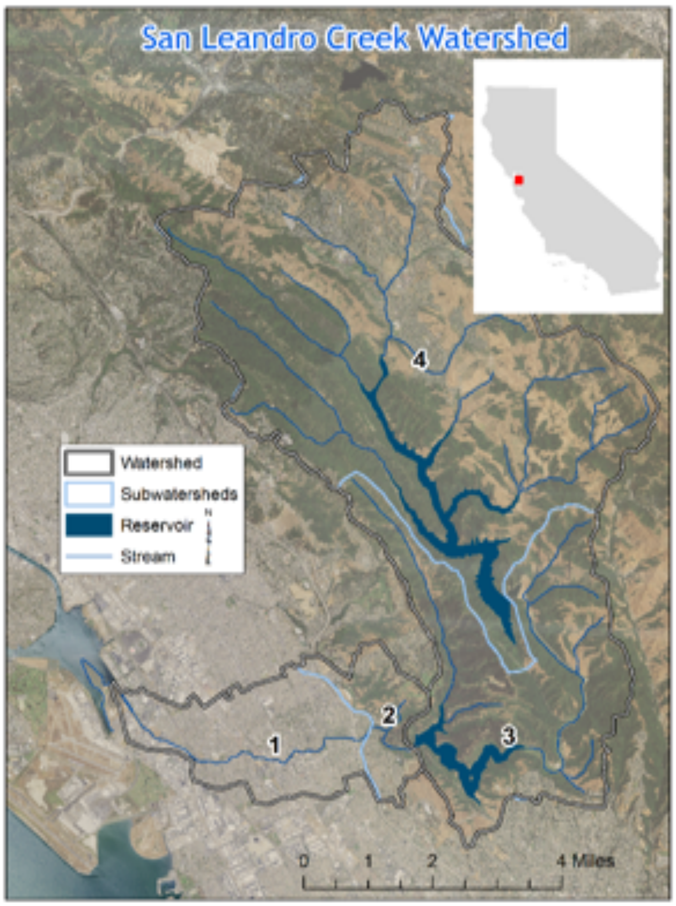
Introduction

The goal of this project is to explore conceptual channel design for enhancing restoration in lower San Leandro Creek Watershed. To this end, I will explore the depth-flow response from theoretical releases from Chabot dam in a potentially modified cross-section in the lower San Leandro Creek watershed known as the Federal Channel. The Federal Channel was built in the late 70s by the Army Corps of Engineers as a concrete box culvert about 2/3 mile in length and ownership was transferred to the Alameda County Flood Control District. Flows are managed by two upstream reservoirs, Upper San Leandro Reservoir (water supply) and Chabot Dam (recreation). A theoretical channel modification is proposed here that has a narrower, deeper channel for concentration of minimum flows and fish passage, with a terraced step-back flood plain for higher flood volumes. Depth response from different flow scenarios were calculated for the original and modified channel by hand using Manning's Equation. Profiles created in HEC-GeoRAS are shown as a comparison of flows along cross-sectional stream profiles. Further development of this HEC-GeoRAS model will help with identification of other restoration opportunities and constraints throughout the lower four mile reach of lower San Leandro Creek between Chabot Dam and San Leandro Bay.

I. Background

A. Site Description

San Leandro Creek is 21.7 miles long and covers 48 square miles. Its source is in the Oakland Hills within the Sibley Regional Preserve, and is joined by five other tributaries as it flows towards the Upper San Leandro Reservoir, built in 1926. A second dam at Lake Chabot reservoir, built in 1875, controls additional flows in lower San Leandro Creek to the Bay. Within the San Leandro Creek Watershed (**Figure 1)** - Section 1 comprises lower San Leandro Creek to the tidal reach near San Leandro Bay. Section 2 is within Chabot Park, which receives base flows from Chabot Dam. Section 3 is the watershed above Chabot Reservoir, excluding Section 4 which is the watershed above Upper San Leandro Reservoir. The reach below Lake Chabot dam to the mouth of the creek at Arrowhead Marsh in Oakland is 4.5 miles long **(Figures 2 & 3**).



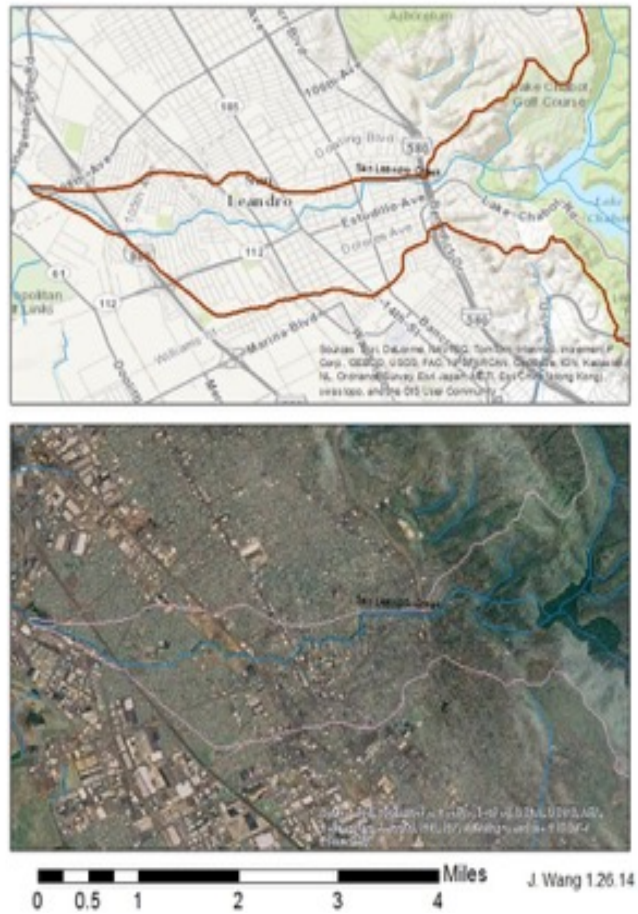


Figure 1. San Leandro Creek Watershed **Figures 2&3. Lower San Leandro Creek Watershed**

Although San Leandro Creek passes through the highly urbanized cities of San Leandro and Oakland, the creek is almost entirely above ground and not within a culvert. The creek is largely within its historic channel, and rainbow trout can still be found in the upper watershed, and steelhead and other species may be found below the dam (NMFS, 2013). The potential for ecological restoration is good, as are opportunities for enhancing creek access and recreation. Summer flows are primarily limited to infrequent releases and spills from Chabot Dam, a reservoir operated by East Bay Municipal Utility District (EBMUD) for recreational purposes.

Summer releases from Chabot Dam are minimal, and winter releases occur during periods of high rainfall in order to maintain flood storage volumes. Baseflows in Chabot Park near the dam support pools in which there are resident fish populations. However, much of the downstream section up to the tidal reaches of San Leandro Creek is dry during the summer, absent maintenance releases from the dam or stormwater flows from urban water uses in the area (**Figure 4** – dry creek bed, 7/7/12). Occasionally, the reservoir is drawn down for maintenance purposes along the Chabot boat docks, which allows flow depth in the creek up to 2 feet deep (**Figure 5** – flowing creek 6/8/12).

Figures 4 & 5. San Leandro Creek without (7/7/2012) and with release flows (6/8/2012) (*J.Wang)*

There are opportunities to restore recreation access for anglers, pedestrians and cyclists along with enhancing flows especially at critical times of the year. One community vision is to connect the extensive trails network of East Bay Regional Parks District from the Shoreline trail to the Ridgeline trail along the San Leandro Creek corridor. Another vision is to create a greenway along quasi north-south as well as east-west corridors that would allow animal and human (non-vehicular) migration along natural and recreational resource routes throughout the entire Bay area (Freeman, et al, 2013).

B. Aquatic Resources of Lower San Leandro Creek

San Leandro Creek has documented populations of fish species that are dependent on pools and seasonal flows. A California Department of Fish and Game (now called CA Department of Fish and Wildlife, DFW) survey noted the existence of a remnant steelhead trout (*Oncorhynchus mykiss*) run in lower San Leandro Creek (Curtis and Scoppettone 1975). Juvenile *O. mykiss* were observed during the DFW survey as well as during U.S. Environmental Protection Agency and EBMUD Surveys in 1981, 1993, and 2000 (Leidy, 2000). Observations of spawning steelhead and juveniles with smolt characteristics indicate that at least a portion of San Leandro Creek *O. mykiss* exhibit recent anadromy (CEMAR 2014). Several fish with "the appearance of steelhead" were collected in 1997 and fin clips were taken for genetic analysis. Surveys by East Bay Regional Park District (EBRPD) Staff also have found three-spine stickleback, Sacramento sucker and prickly sculpin. Mosquito fish and goldfish also occur in lower San Leandro Creek (URS-GWC 1999).

In addition to the restoration of aquatic resources in lower San Leandro Creek (SLCk), visions of restoring a “blueway” with enhanced aesthetics and recreational opportunities along the San Leandro Creek corridor are being synthesized and communicated by the broadening community of stakeholders – local citizens, conservationists, students, NGOs and running/cycling groups, and agency representatives (**Appendix I. San Leandro Creek Stakeholders**).

Conceptual restoration design and hydraulic modeling can help quantify beneficial flows during the process of setting minimum flows in the lower creek reaches, while maintaining less frequent flood volumes. Relationships of inundated in-stream and floodplain areas at various flow magnitudes are needed in sections 1 and 2 downstream of Chabot Dam. One previous study by EBMUD (2013) indicates that these two sections have a 50% chance of flooding at 154 cfs. Restorative flow criteria can be developed that will benefit the entire watershed without causing harm to localized sections, will benefit stream biota and provide beneficial human utilization of the lower San Leandro Creek watershed.

II. Conceptual Design – *Creating a low flow channel to improve fish passage and aesthetics, while maintaining safety and flood protection*

A. Environmental Flows Literature

There is increasing interest in the conservation and restoration of ecological health and functioning of rivers and their associated wetlands for human use and biodiversity. To achieve this, many organizations have developed methods for defining "environmental flows", i.e. the flow regime required in a river to achieve desired ecological objectives (Acreman, 2004). Many scientists and managers agree that to protect freshwater biodiversity and maintain the essential goods and services provided by rivers, we need to mimic components of natural flow variability, taking into consideration the magnitude, frequency, timing, duration, rate of change and predictability of flow events (Arthington, 2006). However, it is difficult to translate general hydrologic-ecological principles and knowledge into specific management rules for particular river basins (Poff et al. 2003).

Methods designed to quantify minimum ‘‘in-stream flows’’ to sustain fish appeared in the United States in the late 1940s. With increasing concern about the impact of dams and flow regulation on river biota, the scientific field of ‘‘environmental flows’’ has produced more than 200 methods that can be grouped into four categories: hydrological rules, hydraulic rating methods, habitat simulation methods, and holistic methodologies (Dyson et al. 2003, Tharme 2003).

B. Virtual Restoration

Given the highly managed and high degree of urban development in the lower San Leandro Creek watershed, the possibility of setting or establishing minimum flows will be dependent on existing agency management practice as well as social or community drivers of change. The management context and property ownership mosaic make it difficult to implement and therefore impossible to model in the real world. However, if we create a "virtual" restoration conceptual design, we can experiment with different design ideas involving not only channel morphology, but also recreation and aesthetic features.

While any increase in flows would enhance habitat or aesthetics within the lower creek environment, certain stream reaches would need significant flow in order to have sufficient depth to convey water that would support fish passage. Therefore the idea of having a minimum flow channel would provide a smaller cross section through which water depths might be maintained at critical periods, while having an overflow capacity onto a floodplain that would contain higher flows. The specific area of my inquiry is at the location of the "Federal Channel," rectangular concrete box channel constructed in the late '70s by the Army Corps of Engineers, which stretches from the tidal reaches of San Leandro Creek above 98th Avenue about 2/3 mile in length upstream (**Figure 6 & 7**).

Figure 6. Location of Federal Channel in lower San Leandro Creek Watershed

Figure 7. Federal Channel – Site of potential restoration by channel modification

Ideally, both channel form and sinuosity would be improved throughout this and other reaches of San Leandro Creek. Increases in sinuosity would theoretically decrease flow velocities, allow for deposition of sediment, and the formation of pool riffle sequences that would provide habitat for migrants and spawning fish or aquatic species. An idealized floodplain is shown in **Figure 8** that anticipates suitable substrate, adequate flows and sediment supply, as well as adequate space for proper stream function.

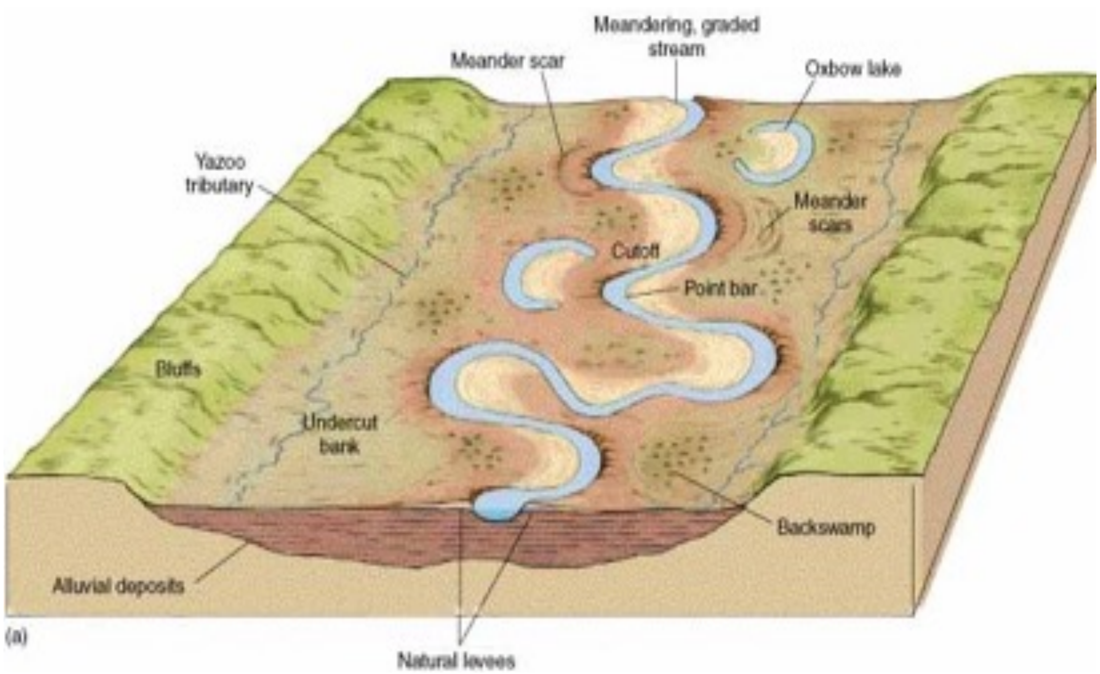


Figure 8. Idealized Schematic of a Sinuous River and Floodplain

A fully meandering and braided channel may not be possible in with the current context of highly urbanized and concretized flood control structures and controlled releases. Residential and industrial land uses predominate and the current channel is largely a straight concrete box with steep sides of 9 feet in depth and 50 feet in width. The current channel design is consistent with the 100-year flood calculation (1% exceedence frequency) from the original US ACOE discharge-frequency plot for San Leandro Creek (ACOE, 1970).

Photos of the Federal Channel and a transition channel are shown in **Figures 9** and **10**. Additional photos can be found in **Appendix IV**.

Figure 9. San Leandro Creek Federal Channel **Figure 10. Transition channel**

While the removal and replacement of existing flood control structures can be expensive, the cost of maintaining and re-permitting modifications for an aging infrastructure is also expensive. Still there exists a number of opportunities to improve or enhance stream features and provide opportunities for restoration within the creek and throughout the watershed. Societal sentiment, especially in the Bay Area, is leaning more and more towards the restoration of aquatic systems, even with urban contexts. Since the existing Federal Channel is over 45 years old and in need of repair and improvements, there is the possibility that parts of this channel could feasibly be replaced and the flow and form in the creek be restored. With estimates for modifying for reinforcing retaining walls in the millions of dollars and permit renewals politically difficult, there is the present opportunity to instead restore and enhance the channel form and function that would enhance social and ecological assets of “blueways” and “greenways” in the lower creek corridor.

C. Design Goals in a Conceptual Modification of the Channel and Floodplain

A conceptual design of a more "natural" channel is proposed for the lower San Leandro Creek at the location of the existing Federal Channel, above 98th Avenue in Oakland, Ca.

Design criteria that were considered include:

- Creating a minimum flow channel to enhance aquatic habitat (fish passage)
- Creating a more gradual step-back floodplain (slow flows, accommodate flood waters)
- Increasing sinuosity of channel within 4000 foot length of Federal Channel (slow flows)
- Create step pools between riffle sequences as habitat enhancement features
- Enhance riparian vegetation that would provide shading and bank structure
- Obtain flows needed to maintain minimum depths of 3 and 6 inches in low flow channel
- Maintain 100-year flood capacity in floodplain corridor

Rather than define the specific flows that would be required to sustain specific biota or fish species, I propose using current reported operational releases or historic flows and determine the flow depths that would result from flow releases of these amounts in a virtual channel envisioned to enhance aquatic habitat, aesthetics, recreation as well as flood management.

I am suggesting that a stream section like this would be an ideal location for a conceptual design that may provide an opportunity for future restoration of the stream into a more "natural" looking channel and floodplain, that would embody characteristics that would be more amenable to enhancement of aesthetics and aquatic habitat, as well as riparian features and floodplain functions.   A theoretical channel that had more of these attributes would have a deeper thalweg and more gradually sloping banks (**Figures 11** and **12**).

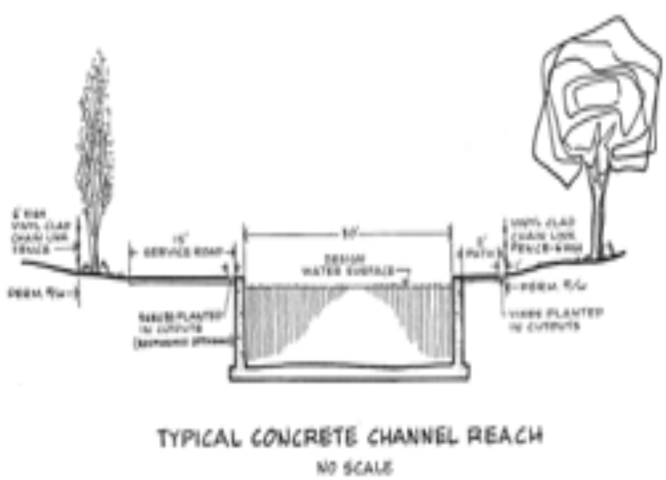


Figure 11. Schematic for Rectangular Channel

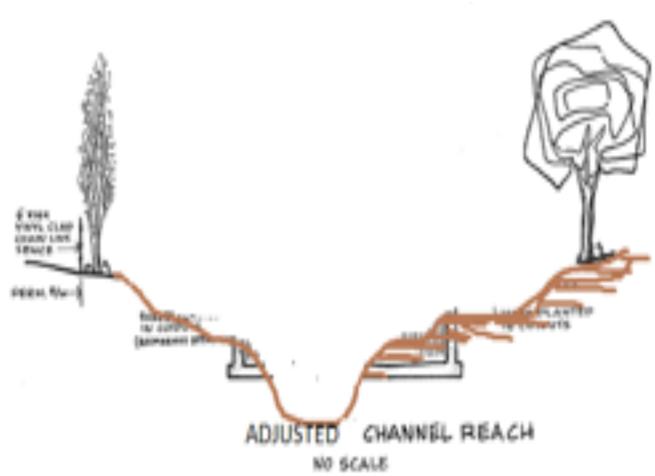


Figure 12. Schematic for Triangular/ Trapezoidal Channel

The feasibility of designing and locating channels in a more sinuous lower creek would be addressed in a realistic design. However since this is a conceptual analysis of a virtual channel, the idea would be to not only alter the channel morphology, but also increase longitudinal sinuosity, which would slow flows, and reduce the slope in individual reaches of the stream. Constraints include acquisition of property along the right of way, or granting of easements through residential or industrial holdings.

An analysis would need to be conducted on ownership, and public meetings could be held regarding whether current land owners would want to grant an easement, sell, or contribute to design alternatives with an integrated stakeholder process for watershed management and restoration.

An illustration of this is depicted between **Figures 13** and **14**.

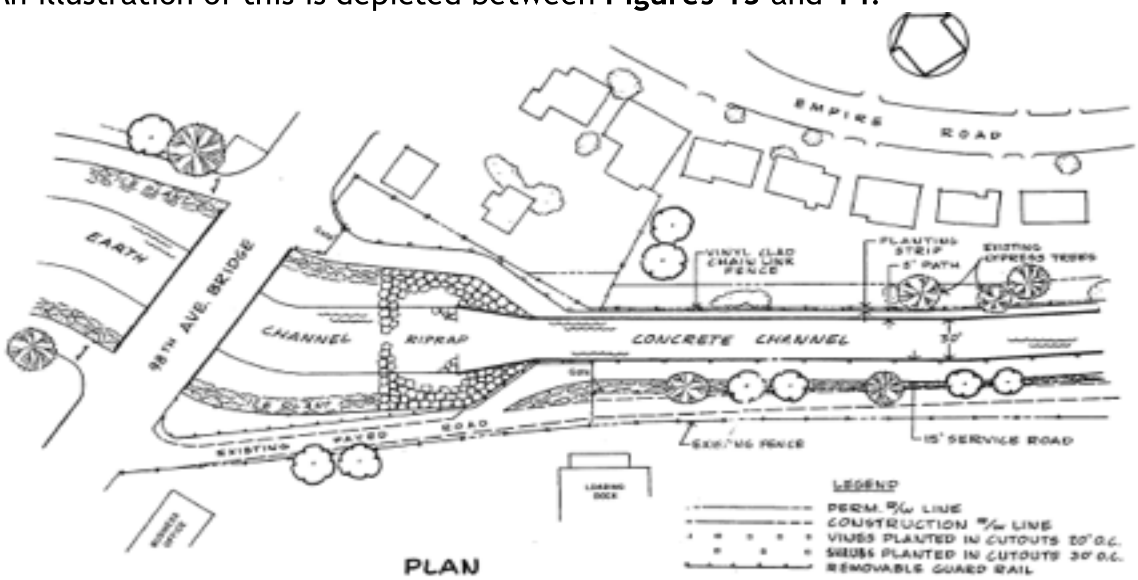


Figure 13. Plan view of original schematic for concrete channel above 98th Ave

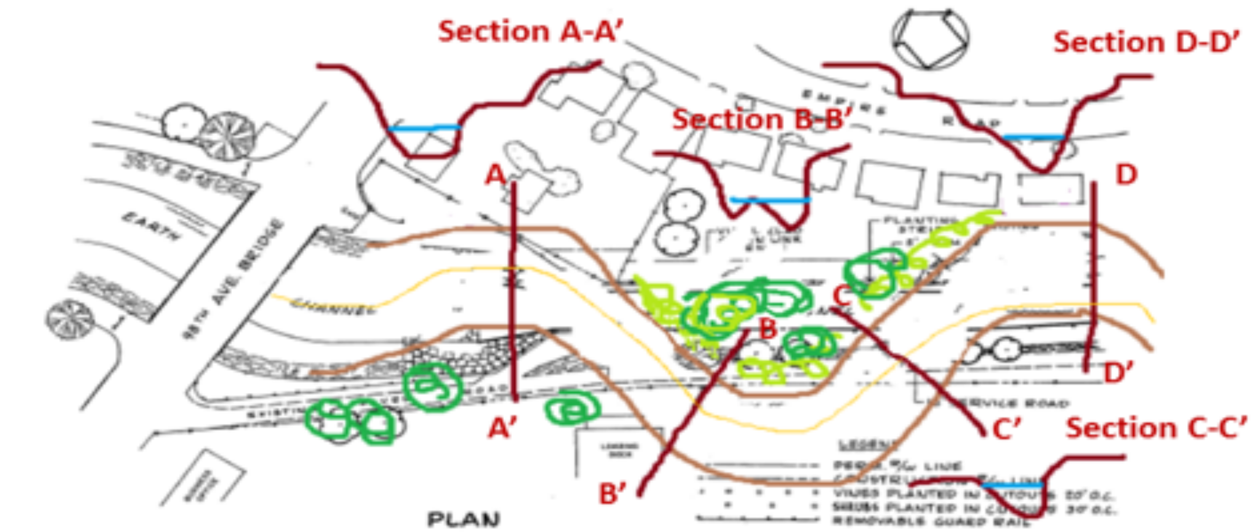


Figure 14. Altered design schematic with greater sinuosity and minimum channels

The existing rectangular channel is 9 feet deep with straight sides and between 34 and 50 feet wide along long straight stretches of stream corridor. This configuration is too flat and wide to allow fish passage, and the lack of bends for pool riffle sequences or refugia is also less than optimal. A different channel shape and sinuosity is proposed for up to a mile of the concrete canals that are currently found above the 98th Avenue Bridge (pictures shown in Appendix III).

III. Methods and Analysis

A. Design Flows:

The Waananen and Crippen regression equations (WRIR 77-21) provide flow rates for recurrence intervals from 2 years to 100 years in the basins of San Leandro Creek (Lower Basins include SL-1 and SL-2). The San Leandro Creek basin has a watershed area of 46.1 square miles, with mean annual precipitation of 23.7 inches, and elevation difference between 85% and 10% of the watershed of 522 feet. The resultant Waananen and Crippen Regression Discharges (without dam conditions) are Q2: 2614 cfs, Q10: 6775 cfs, Q50: 10,906 cfs, and Q100: 12,478 cfs for SL-1 (EBMUD 2013). However, historic flows within lower San Leandro Creek were attenuated by Upper San Leandro Reservoir by 75% in peak flow of the April 1958 flood event (6000 cfs inflow), and 44% of the October 1962 flood event (9800 cfs inflow).

With Chabot dam in place, the peak flow rates published in the effective FEMA Flood Insurance Study (FIS) (FEMA, 2009) account for reservoir storage and match the USACE San Leandro Creek Design Study (USACE 1970). The regulated discharges at the mouth of San Leandro Creek are Q10: 800, Q50: 2000, and Q100: 2800 cfs. The total drainage area downstream of Lake Chabot is 5.2 square miles, or about 1/9th the total watershed area. Due to amount of reservoir storage in the watershed, the lower portion of the watershed peaks well before the rest of the watershed, and there is minimal change in peak flow downstream of Lake Chabot. Based on these analyses and Manning's equation the flood control channel capacity was determined to be approximately 1774 cfs, which corresponds to a 50% annual chance of flood in the without the dam condition. With Lake Chabot Dam in place, a flood of this same annual exceedence probability has a flow rate of approximately 154 cfs (EBMUD 2013).

Maximum recorded daily spillway flows are 487 acre-feet for Upper San Leandro dam and 722 acre-ft for Chabot dam. Maximum total release from Chabot dam for the period of record was 818 acre-ft which is equivalent to a 412 cfs constant flow for the 24-hour period. (Roberts and Cayot, 2011).

EBMUD currently manages releases from Chabot Dam into lower San Leandro Creek. There are no fixed operating rules or procedures no records of changes in operating rules or procedures. There is a general intent to maintain several feet of freeboard between the spillway crest and reservoir water surface through the releases from low level outlets (Roberts and Cayot 2011). Below Chabot Dam, flows are released only to maintain flood storage capacity. Such releases typically occur in winter and vary from 20-120 ft^3/s (Mulchaey, pers. comm.). Dry season discharge bypassing the dam consists of approximately 80 gallons per minute (0.18 ft^3/s) and would have relatively low sediment loads.

For this conceptualization, the focus is on recreating a conceptual design channel with some of the design features elaborated above and to determine depth response at a range of flows including current flows of 0.18 cfs, 20 cfs, 120 cfs, and for 100-year flows (2800cfs) for the existing channel, and "virtual channel." Using these discharge rates, I back-calculated (guess and check) depths that would result in the current rectangular Federal channel, and a future "restored" channel of a couple different configurations.

B. Channel Form:

The current Federal Channel is smooth concrete and has a rectangular cross-section 34 feet wide and straight sides of 9 feet deep in most places.

Rectangular: n=0.02, S=0.0028, d(max) = 9, w/2 = 17

A proposed modification of this channel is proposed which has a thalweg that is 2 feet deeper (11 ft) and banks that have been stepped back in a terraced flood plain that doubles the width of the bank full channel. If we approximate this cross-section as a triangle, the topwidth is 64 feet wide, and the depth at the apex is 11 feet. Roughness should increase with earthen somewhat rocky channel bed and vegetated banks.

Triangular: n=0.035, S=0.0028, d(max) = 11, w/2 = 34

A variation on this is a trapezoidal cross-section of original depth and topwidth of 36 feet, which can be calculated as a triangle of width 32 feet and depth 9 feet, and a rectangular insert of 4x9 ft^2.

Trapezoidal: n=0.035, S=0.0028, d(max) = 9, w/2 = 16, x=4

Figure 15 illustrates proposed channel modifications and dimensions for which flow-depth relationships were developed using Manning's Equation.

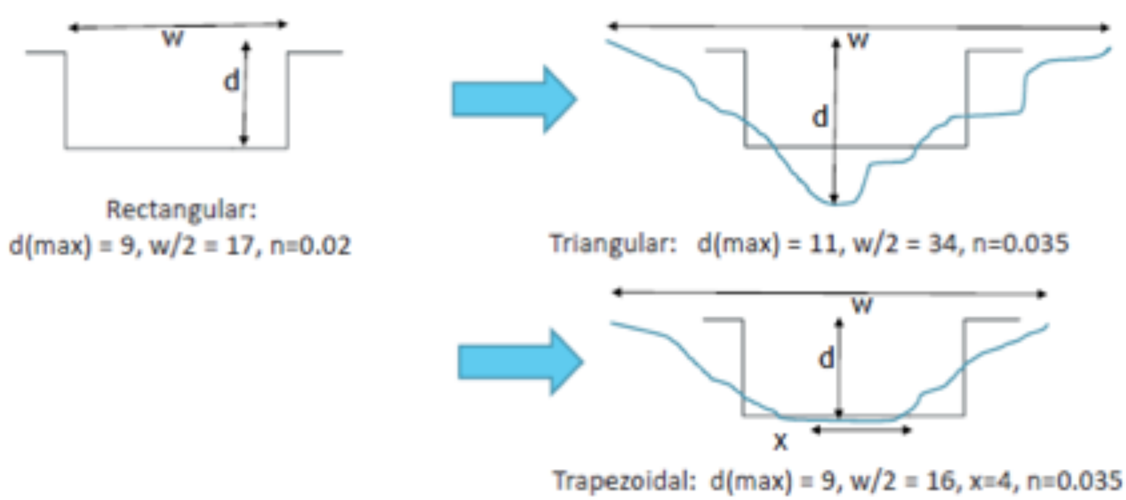


Figure 15. Proposed Channel Modifications and Dimensions

Estimates of roughness were taken from Chow (1959) using n=0.2 for the concrete rectangular channel and n=0.035 for the proposed triangular and trapezoidal channels (**App. III**). The average slope calculated for the extent of the Federal Channel was S=0.0028.

C. Calculation of depth and runoff using Manning's Equation

Flow depth relationships were explored using Manning's Equation, and an iterative estimation process to obtain the desired maximum and minimum discharge rates and depth relationships. Using Manning's Equation, calculated depth from area and velocity: [V=1.49/n*(S^.5)*R^(2/3)]

$$Q = VA = \left(\frac{1.49}{n}\right) AR^{\frac{2}{3}}\sqrt{S} \quad [\text{U.S.}]$$

Where: Q = Flow Rate, (ft^3/s); v = Velocity, (ft/s); A = Flow Area, (ft^2); R = Hydraulic Radius, n = Manning's Roughness Coefficient; (ft); S = Channel Slope (ft/ft)

Relationships were derived for each of the proposed channel cross-sections areas (A) and hydraulic radius (R) in order to estimate water depths from various discharge rates. The relationships used for each cross-section are summarized below [with R=A/P].

Triangle	A=2dw	P=2*(d^2+w^2)^.5
Trapezoid	A=xd+wd	P=(2*(d^2+w^2)^0.5)+x
Rectangle	A=wd	P=2d+w

Slopes were estimated from cross-section stations and set to be 0.0028 throughout the reach of consideration. A summary of the different channel discharge, depth and velocity relationships are shown in **Tables 1** through **3**. More detailed data tables in **Appendix IV**.

Tables 1-3. Calculated discharge, depth & velocity relationships for cross sections

Rectangular Channel (34x9)

Q (cfs)	d (ft)	V(ft/s)
3000.21	5	17.65
234.59	1.00	6.90
121.84	0.67	5.35
20.85	**0.23**	**2.67**
0.359	0.02	0.53

n=.011

Triangular Channel (68x11)

Q (cfs)	d (ft)	V (ft/s)
2539.4	11.00	6.79
120.19	1.73	2.04
20.59	0.60	1.01
4.79	**0.25**	**0.56**
0.019	0.009	0.06

n=.035

Trapezoidal Channel (36x9)

Q (cfs)	d (ft)	V (ft/s)
2909.17	9.00	8.98
802.82	4.00	5.58
125.33	1.3	2.68
8.05	**0.25**	**0.89**
0.026	0.01	0.09

n=.035

A triangular or trapezoidal or other minimum flow channel will require less discharge volume than a wide rectangular channel as currently exists. Having more of a "natural" channel and floodplain (as characterized by earthen or vegetated bed and banks) will lessen velocities, while maintaining needed minimum depths that may be required by aquatic life, or have the appearance of a flowing stream or creek.

For instance, if we presume fish to need a minimum of 3" of water in order to pass (d=0.25 ft), the rectangular channel would need four times as much flow (21 cfs) as the triangular channel would need (5 cfs) in order to maintain the same depth.

D. Hydraulic Modeling

There are a number of tools and programs that would help us identify restoration opportunities in San Leandro Creek watershed, and to simulate what the response may be in a "virtual restoration" from which develop more detailed designs that are consistent with broader stakeholder visions of how to manage this watershed. Building on this approach, we can lay out a conceptual design for the entire lower creek reaches, and model the hydraulics of the system in HEC-RAS[1] or include the ecological parameters using the HEC-Ecosystem Functions Model (HEC-EFM[2]) to help determine ecosystem responses to changes in the flow regime of a river or connected wetland.

Using GIS tools one can also integrate restoration concepts with terrain models, spatial constraints (e.g. ownership, utility lines), and cross sections can be cut directly from the Digital Elevation Model (DEM, or terrain model). Using HEC-GeoRAS one should be able to work between the terrain and virtual cross-sections to simulate flow depths and velocities throughout the entire reach. A number of HEC-RAS model profiles and cross-sections are shown in **Appendix V** for illustration and comparison. The designs may be adjusted and run again to verify hydraulic response and to assist in planning of biophysical parameters as well as social implications.

[1] HEC-RAS: Hydrologic Engineering Centers River Analysis System developed by the Army Corps of Engineers (AOE)

[2] HEC-EFM: Hydrologic Engineering Centers Ecosystem Functions Model developed by the AOE

IV. Conclusions and Discussion

A conceptual design of a more "natural" channel has been presented for the lower San Leandro Creek at the location of the existing Federal Channel, just above 98th Avenue in Oakland, California. Flow-depth relationships were calculated for the existing Federal Channel under current conditions, and in a modified "virtual restoration" of the channel to estimate depth and velocities associated with different discharges. These discharges are directly related to releases from Chabot Reservoir in order to maintain environmental flows within a minimum channel in lower San Leandro Creek.

Design parameters include changes in channel morphology, sinuosity, substrate and cover that would increase roughness, lessen flows while maintaining adequate depth for aquatic biota, particularly during critical periods of time.

The proposed channel will be able to convey flood volumes of 2500 cfs or higher, although the chances of such flows are quite unlikely given the large amount of storage volume provided by Upper San Leandro Reservoir and Chabot Reservoir.

More critical are low or environmental flows in a minimum channel that would have sufficient depth to allow for fish passage or have the aesthetics of a flowing creek. Current releases from Chabot Dam are inadequate in summer, but may be supplemented with minimal impact to the recreational functions that the reservoir provides. Downstream reaches below Chabot provide opportunities for restoration of channel morphology and floodplain function that would benefit social and ecological values in the watershed.

Having a minimum flow channel or modified cross sections with the design characteristics presented, would result in the creek being able to more consistently have adequate depth that could be sustained by flows that are a quarter of that required for the Federal Channel - between 5 to 20 cfs. Additional adjustments of cross-sectional areas, increasing sinuosity, depositional areas as well as ponds are encouraged along with increases in reliable flows within the creek. Spatial analysis and hydraulic modeling is a good option for exploring more restoration opportunity areas and test the parameters that affect or result from this "virtual" restoration of Lower San Leandro Creek.

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Appendix I
San Leandro Creek Watershed Stakeholders

Agency
- East Bay Municipal Utility District (EBMUD)
- East Bay Regional Park District (EBRPD)
- Alameda County Flood Control and Water Conservation District (ACFCWCD)
- Contra Costa County Flood Control and Water Conservation District (CCCFCWCD)
- California Department of Transportation (CalTrans)
- Bay Area Rapid Transit (BART)

Community and Non-Profit
- Friends of San Leandro Creek
- Merritt College: Environmental Management and Technology Program (ENVMT)
- Bicycle/Pedestrian groups
- Private land holders
- Neighborhood organizations
- University of California at Berkeley

City and Local/Regional Government
- San Leandro
- Oakland
- Orinda
- Moraga
- Association of Bay Area Governments
- City parks and recreation
- Schools

Appendix II.

Mannings Equation calculations for three types of channel cross sections

Rectangular Channel A=wd P=2d+w

	n	S	R	V (ft/ sec)	d (ft)	w/2 (ft)	x		A (ft^2)	P	Q (cfs)
MAX	0.011	0.0028	5.88	23.36	9.00	17	0	rectangular	306.00	52.00	7148.90
	0.011	0.0028	3.86	17.65	**5.00**	17	0	rectangular	170.00	44.00	**3000.21**
	0.011	0.0028	0.94	6.90	1.00	17	0	rectangular	34.00	36.00	234.59
	0.011	0.0028	0.64	5.35	**0.67**	17	0	rectangular	22.78	35.34	**121.84**
	0.011	0.0028	0.23	2.67	**0.23**	17	0	rectangular	7.82	34.46	**20.85**
	0.011	0.0028	0.02	0.53	0.020	17	0	rectangular	0.68	34.04	0.359

Triangular Channel (Double topwidth) A=2dw P=2*(d^2+w^2)^.5

	n	S	R	V (ft/ sec)	d (ft)	w/2 (ft)	x		A (ft^2)	P	Q (cfs)
MAX	0.035	0.0028	5.23	6.79	11.00	34	0	triangle	374	71.47	**2539.41**
	0.035	0.0028	4.35	6.00	9.00	34	0	triangle	306	70.34	1836.92
	0.035	0.0028	1.00	2.25	2.00	34	0	triangle	68	68.12	153.01
	0.035	0.0028	0.86	2.04	**1.73**	34	0	triangle	58.82	68.09	**120.19**
	0.035	0.0028	0.50	1.42	1.00	34	0	triangle	34	68.03	48.24
	0.035	0.0028	0.30	1.01	**0.60**	34	0	triangle	20.4	68.01	**20.59**
	0.035	0.0028	0.12	0.56	0.25	34	0	triangle	8.5	68.00	4.79
	0.035	0.0028	0.02	0.15	0.04	34	0	triangle	1.19	68.00	0.18
	0.035	0.0028	0.00	0.06	**0.009**	34	0	triangle	0.306	68.00	**0.019**

Trapezoidal Channel (x is interior rectangular width) A=xd+wd P=(2*(d^2+w^2)^0.5)+x

	n	S	R	V (ft/ sec)	d (ft)	w/2 (ft)	x		A (ft^2)	P	Q (cfs)
MAX	0.035	0.0028	7.96	8.98	9.00	16	4	trapezoid	324.00	40.72	**2909.17**
	0.035	0.0028	3.89	5.58	4.00	16	4	trapezoid	144.00	36.98	802.82
	0.035	0.0028	1.30	2.68	1.30	16	4	trapezoid	46.80	36.11	125.33
	0.035	0.0028	0.25	0.89	0.25	16	4	trapezoid	9.00	36.00	8.05
	0.035	0.0028	0.01	0.09	0.008	16	4	trapezoid	0.29	36.00	0.03

Appendix III.

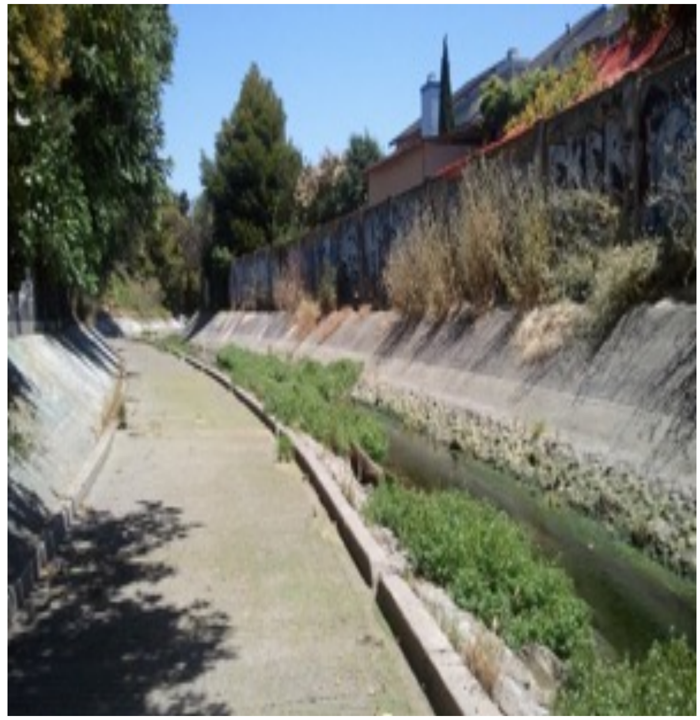
Manning's n for Channels (Chow, 1959). *Taken from* http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm

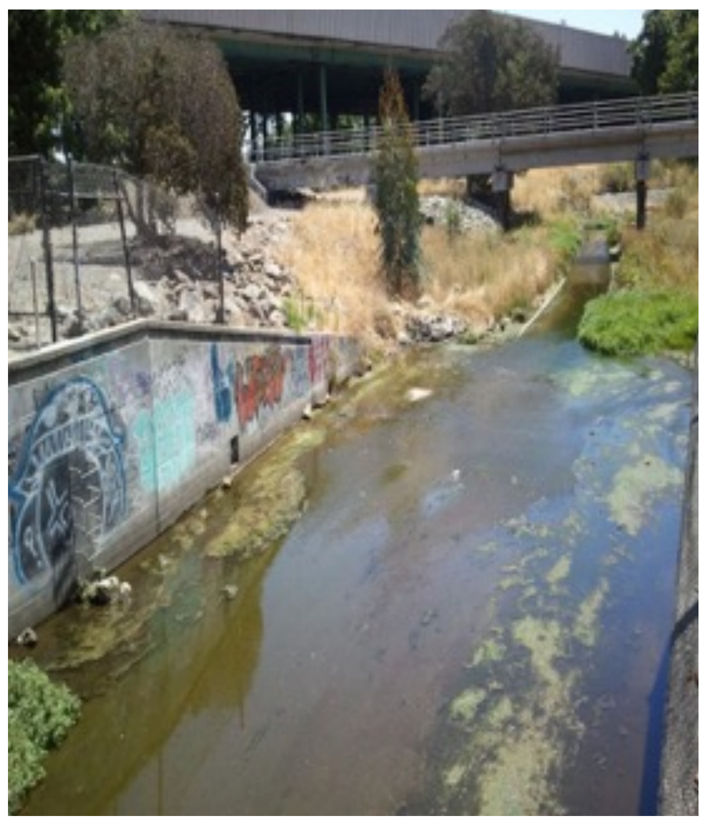
Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050
c. Brush			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. medium to dense brush, in summer	0.070	0.100	0.160

d. Trees			
1. dense willows, summer, straight	0.110	0.150	0.200
2. cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. same as 4. with flood stage reaching branches	0.100	0.120	0.160
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.020
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.030
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.030
2. grass, some weeds	0.025	0.030	0.033
3. dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. earth bottom and rubble sides	0.028	0.030	0.035
5. stony bottom and weedy banks	0.025	0.035	0.040
6. cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.040
2. jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.050	0.080	0.120
2. clean bottom, brush on sides	0.040	0.050	0.080
3. same as above, highest stage of flow	0.045	0.070	0.110
4. dense brush, high stage	0.080	0.100	0.140

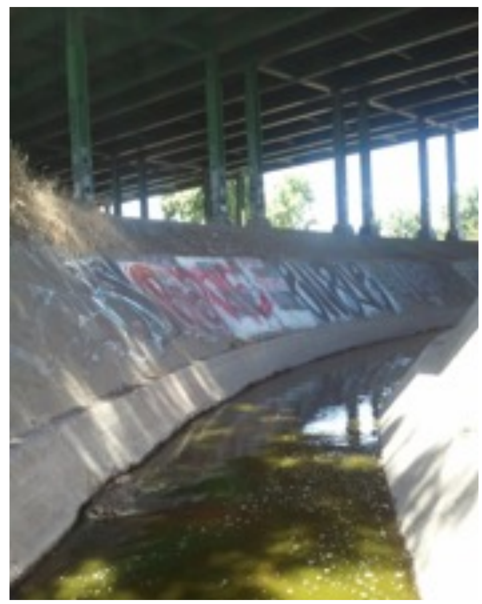
5. Lined or Constructed Channels			
a. Cement			
1. neat surface	0.010	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Concrete			
1. trowel finish	0.011	0.013	0.015
2. float finish	0.013	0.015	0.016
3. finished, with gravel on bottom	0.015	0.017	0.020
4. unfinished	0.014	0.017	0.020
5. gunite, good section	0.016	0.019	0.023
6. gunite, wavy section	0.018	0.022	0.025
7. on good excavated rock	0.017	0.020	
8. on irregular excavated rock	0.022	0.027	
d. Concrete bottom float finish with sides of:			
1. dressed stone in mortar	0.015	0.017	0.020
2. random stone in mortar	0.017	0.020	0.024
3. cement rubble masonry, plastered	0.016	0.020	0.024
4. cement rubble masonry	0.020	0.025	0.030
5. dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.020	0.025
2. random stone mortar	0.020	0.023	0.026
3. dry rubble or riprap	0.023	0.033	0.036

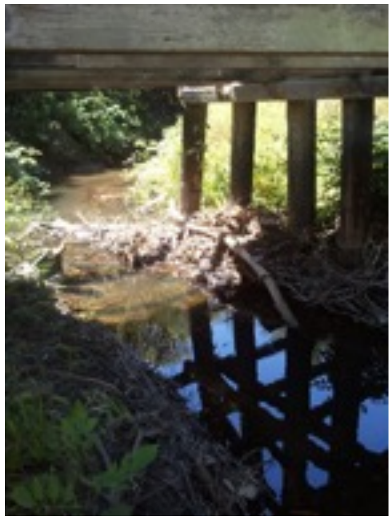
Appendix IV. Photos

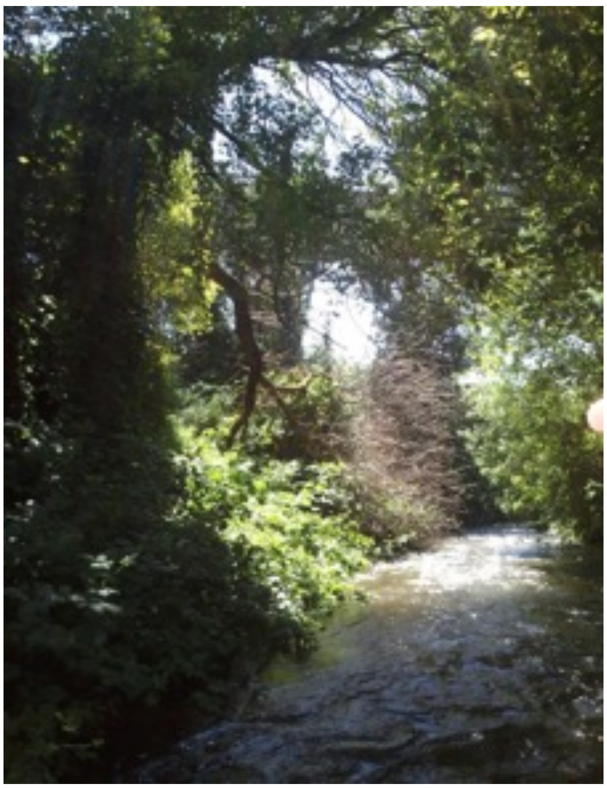




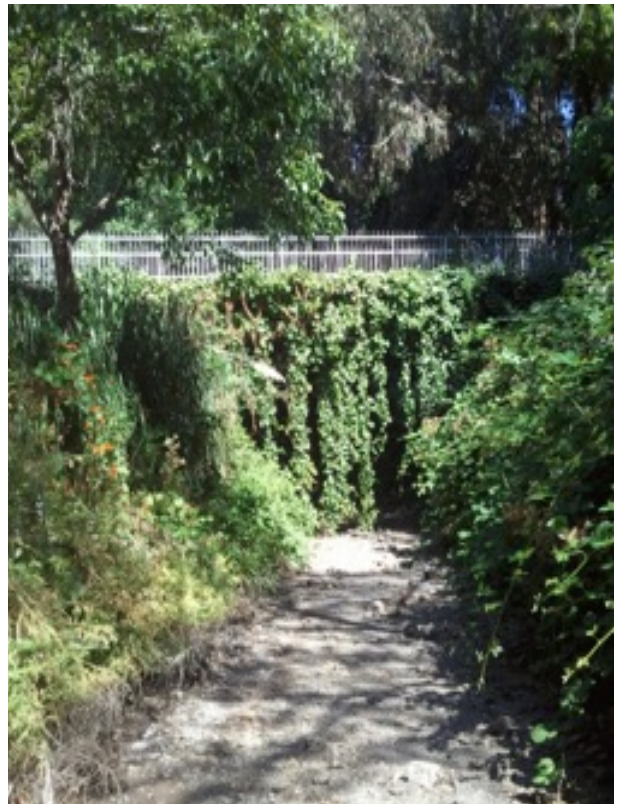


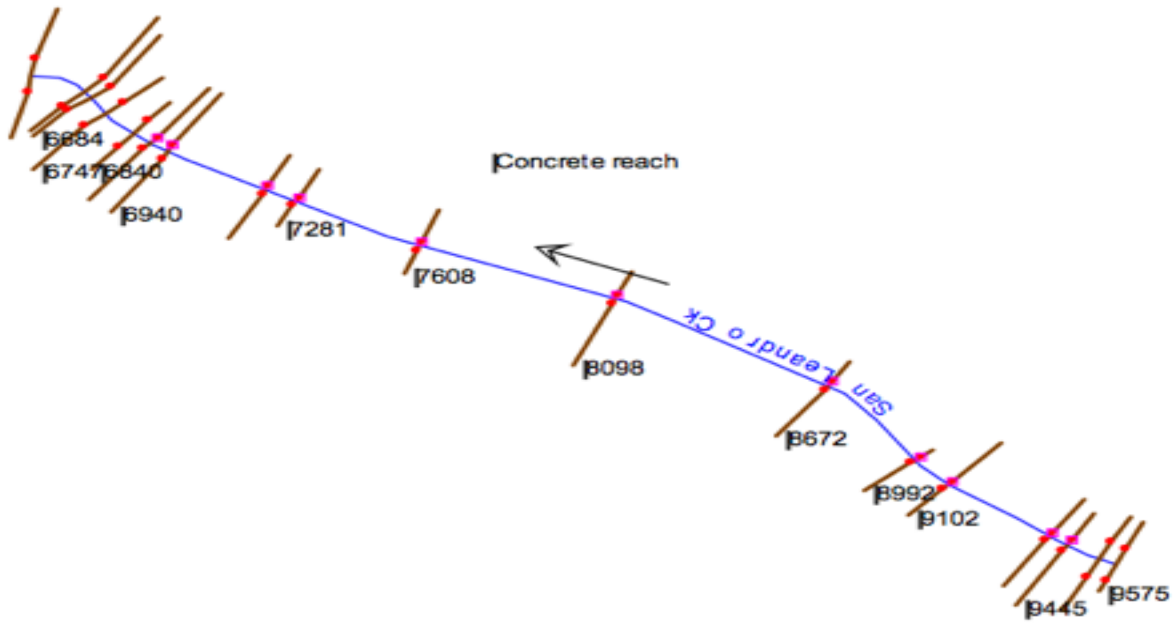








Appendix V. HEC Model Profiles and Cross-Sections in Lower San Leandro Creek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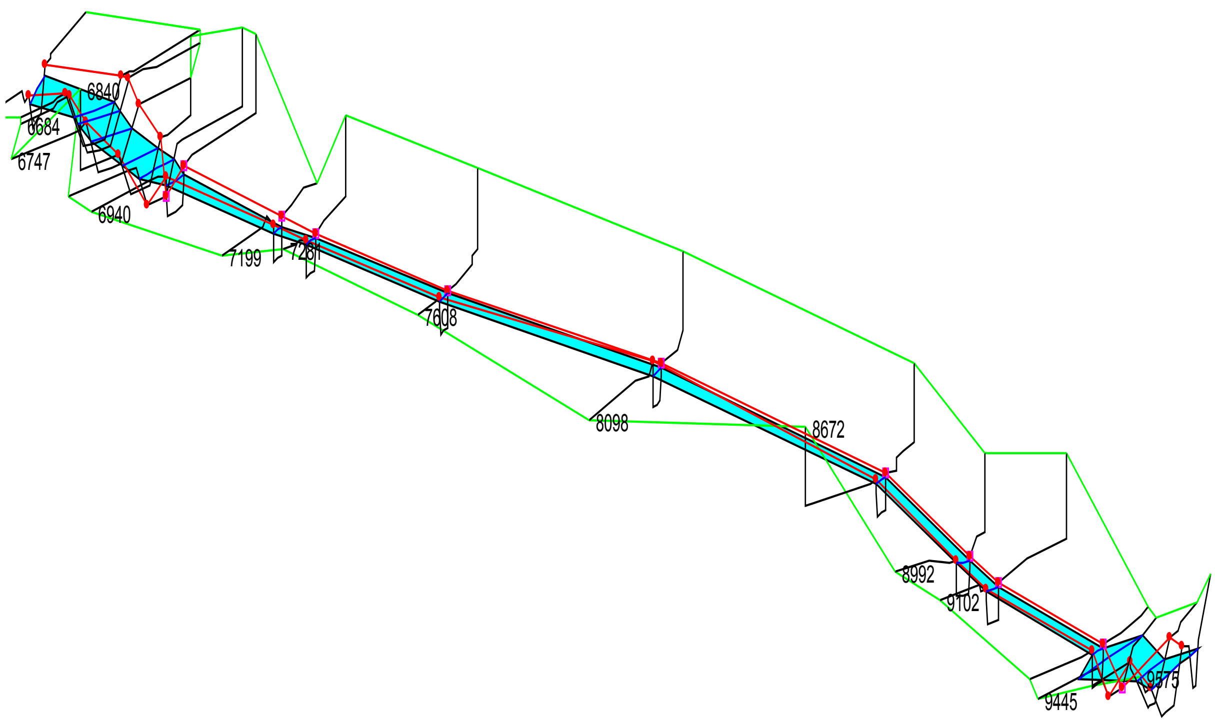
6747
6840
6940
7281
7608
8098
8672
8992
9102
9445
9575
Concrete reach
San Leandro Ck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7281
7608
8098
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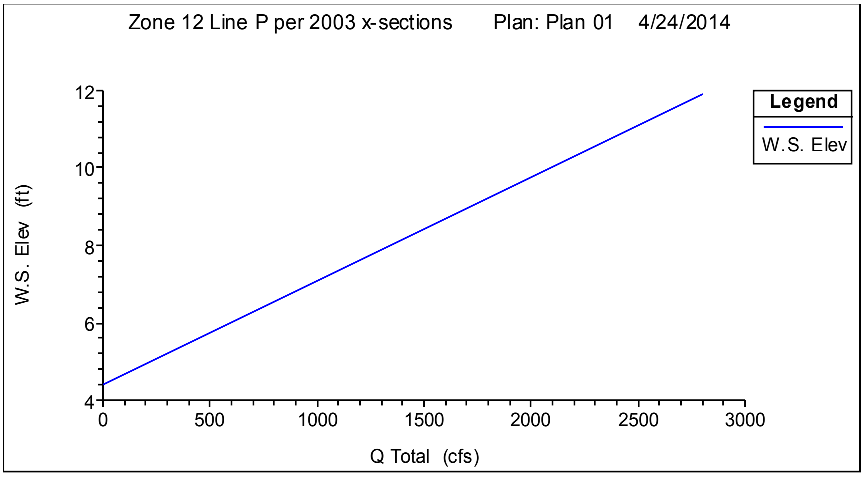
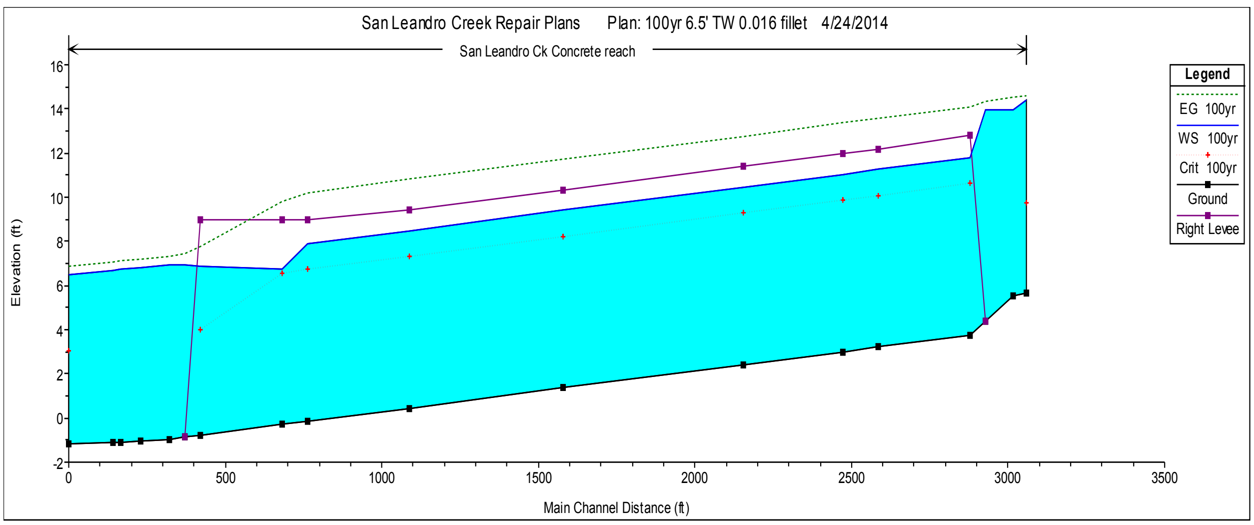
8992
9102
9445
9575

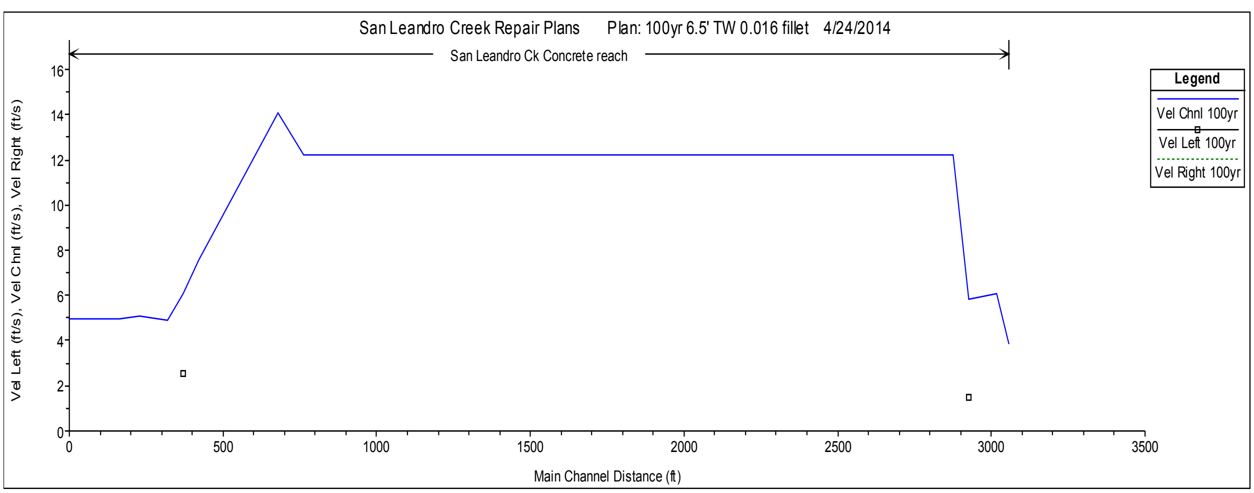
Rating Curve



Longitudinal Flow Profile



Velocity Profile



Channel Cross sections at Select River Stations