Title
Assessing channel morphology following a floodplain restoration project : Wildcat Creek, Richmond, CA

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FINAL DRAFT

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Abstract

Following settlement in the 1940's along the Wildcat Creek floodplain, reoccurring flooding drew attention to the need for flood control in the area. Four decades later, a flood control and riparian restoration project was completed in 1989; however, the project design proved to be a failure, and lateral migration of the creek caused continued flooding within the community. Approximately twelve years later, an improved channel design and restoration project, including a defined low-flow meandering channel, was completed. Since this time, flooding within the community has not occurred, and the channel geometry has been reasonably stable. We surveyed two cross-sections along the channel floodplain and compared channel geometry to recent and baseline surveys conducted following the original construction. Our results indicate a gradual buildup of sediment on the floodplain since the 2000 restoration project. Within the main channel, however, deepening has occurred, indicating a reversal from sediment accumulation to sediment removal and transport. We draw conclusions about the natural sustainability of the channel and discuss the implications for management and maintenance strategies.

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INTRODUCTION AND PROBLEM STATEMENT

Understanding the geomorphic processes responsible for stream channel development and channel form dynamics is a key component in achieving sustainability and success on restoration projects (Tompkins & Kondolf, 2001). Combining these processes with the knowledge of historic and current land use practices further enhances the planning phase and indicates the appropriate level of restoration for the site. Projects that fail to account for these issues, designing solely from an engineering or ecological approach, set themselves up for failure, as many documented cases confirm this (Kondolf, 1995; Haltiner et al., 1996; Kondolf, 1998; Tompkins & Kondolf, 2001). Repeated restoration and flood control attempts, from 1986 to 2000, along the lower reaches of Wildcat Creek serve as an example of a project that initially failed to establish an accurate relationship between regional flood records, cross sectional areas on the floodplain, and sediment transport and deposition (Riley, 2003). Unexpectedly, invasive "cattail" vegetation covered the majority of the floodplain and resulted in increased sediment deposition and buildup (Riley, 2003), and subsequent flooding of the community (EPA, 1995). A series of modifications followed, including the excavation of defined low-water meandering channels. The first channel, created in 1986, continued to be problematic and subsequent flooding resulted; however, the final design, created in 2000, has proved to be more successful, and to date, no residential flooding has occurred (Owens, Jonathon, personal communication). Time will tell if the channel is naturally sustainable.

As noted in several previous publications (Orr & Owens, 1994; De Neale, 1995; EPA, 1995; Riley, 2001; Boutillier & White, 2002; Boutillier & White, 2003; Riley, 2003), the following history outlines the problem on Wildcat Creek, which began in the 1940's, following residential settlement of the unincorporated floodplain, a known flood hazard area during wet winter months. To address the problems associated with flooding, Contra Costa County began planning for a flood control channel in the 1950's, and began a working relationship with the U.S. Army Corp of Engineers. In the 1960's, the Army Corp of Engineers published a feasibility study with several alternatives, but in the end, none proved economically feasible. In the 1970's, the U.S. Department of Housing and Urban Development sponsored a Model Cities program, which resulted in a more community based land use plan for the North Richmond area; community involvement was high. The Army Corp of Engineers designed another plan, which included protection against the 100-year flood event and several enhancements along the stream corridor designed to benefit the community and wildlife well into the future. After congressional approval in 1976, however, local funding requirements failed to materialize and again the project failed. Contra Costa County then proposed a more affordable plan, calling for a classic trapezoidal channel with rip-rapped banks, but public outcry and increasing environmental regulations kept it from moving forward. Determined to overcome the reoccurring obstacles, efforts by several community groups and Contra Costa County led to the formation of a new inter-agency and inter-disciplinary design team, which completed a plan in 1985. Following approval, construction occurred from 1986 to 1989, and replaced an older trapezoidal channel with a shallow low-flow channel and floodplain, riparian vegetation, a downstream marsh, and an upstream sediment retention basin. Due to concern over disturbing the existing riparian corridor, the shallow channel was centered in the floodplain, outside of the riparian corridor and its shade. This decision eventually proved problematic, as the channel's exposure to solar radiation led to the establishment of invasive "cattail" vegetation across the majority of the floodplain.

In 1996, after winter storms continued to flood the community, it became evident that the existing design was not sustainable. The design team, now formally recognized as a watershed council, discovered that the regional hydraulic geometry data used in the design models were applicable to streams located in the middle reaches of the watershed, opposed to the tidally influenced floodplain streams (Riley, 2003). Whereas the channel design intended to transport sediment, the cattails effectively trapped and built up sediment, changed the channel dynamics, and led to unpredictable lateral migration and flooding. As a result, federal, state, and environmental experts met and concluded that a deeper and more natural channel needed to be excavated through the established riparian corridor. The Army Corp of Engineers authorized modifications to the existing channel, and using methods designed by a well-known hydrologist, Dave Rosgen, a new channel design was developed. To accommodate the overall low gradient (< 0.001) floodplain area, a new one-mile channel (Rosgen E), that was deeper and wider, was carefully excavated through the existing riparian corridor. Initial monitoring indicated the channel was functioning well and holding up to winter storms, but in 1998, while conducting annual cattail removal, the county lowered the floodplain below the elevation of the active channel (Riley, 2003). This change again led to the lateral migration of low flows and caused instability and flooding.

To correct the problems, later in 1998, Contra Costa County and the Waterways Restoration Institute (WRI) secured a grant to assist in the non-federal portion of the design and construction costs under an Army Corp of Engineers Section 1135 project. In 1998 and 1999, the watershed council conducted open planning and design sessions, involving all interested parties and stakeholders; in 2000, the council approved the new design, and construction took place that year from August to December. This time the design model used local gauge records more applicable to tidally influenced streams to create the flow duration curve and accounted for channel sediment transport over time from surveyed cross-sections and profiles. Eventually, using sediment and flow duration curves, the effective bankfull discharge estimate resulted in a new width-to-depth ratio of 4 – 5, which reflected deeper and wider channels and modified meander lengths and amplitude (Riley, 2003).

Construction of the new design took place in 2000 and took 15 days. Tractors modified the channel within the existing riparian area and pushed the soil to the outside bends of the meanders on the floodplain side. As before, the crews used extreme caution so not to damage the existing riparian vegetation. Some areas of the floodplain were still lower than the channel design elevations; therefore, in order to keep low flows from migrating to the floodplain, the channel was lowered below the design elevation, assuming sedimentation deposited from high flows would eventually fill both the channel and floodplain back to their desired elevations and slopes.

The main objective of our project is to access the current channel morphology, from surveyed cross sections of the channel and floodplain, and compare it to original and prior/past surveys. More specifically, we will compare our surveyed cross sections (83+00 and 88+00) by assessing sediment deposition and removal, and channel incision and erosion that occurred from 2003-2004 winter flows. Based on our results and evaluation, we will comment on the performance and sustainability of the channel and floodplain, as well as the overall success of the latest project design.

METHODS

On April 7, 2004, we made a preliminary visit to the study site to identify potential cross-sections and the elevation pins marking each of their end-points. On April 8, 2004, we returned and surveyed cross sections 88+00 and 83+00. Our methods for this project included an in-depth literature review of other channel and riparian restoration projects and previous survey work carried out on this reach. In the field, we surveyed cross sections and high water marks, and later we calculated field data and interpreted aerial and site photography.

STEP 1: LITERATURE REVIEW

Several term project papers (Boutillier & White, 2002; Boutillier & White 2003; De Neale, 1995) from previous Landscape Architecture classes, as well as government (EPA, 1995; Riley, 2001) and conference publications (Riley, 2003), provided guidance for conducting our surveys and compiling our historical account of the activity on the Wildcat Creek floodplain. We also reviewed several other publications (Kondolf, 1995; Haltiner et al., 1996; Kondolf, 1998; Tompkins & Kondolf, 2001) on stream restoration projects other than that for Wildcat Creek, all of which helped us better understand the issues related to restoration of urban creeks.

STEP 2: CROSS-SECTION SURVEYS, HIGH WATER MARKS, AND CALCULATIONS

On April 8, 2004 we re-surveyed two cross sections along lower Wildcat Creek, located between Third Street and Giaramita Avenue in Richmond, CA. We located cross sections 83+00, 88+00 and 93+00 using area maps (Boutillier and White, 2002) and spray-paint markings from previous surveys conducted by the Contra Costa County Flood Control District. Since the 93+00 cross section had rip-rapped banks that would not likely exhibit the changes in channel morphology we were interested in, we decided to only survey the 83+00 and 88+00 cross sections.

For both cross sections (83+00, 88+00), we were only able to locate the survey pins on the northern side of the creek near the path. The southern ends of the cross sections were densely vegetated with blackberry bushes, inhibiting us from locating the pins. In both cases, however, a narrow clearing through the trees and otherwise dense riparian corridor marked a straight line from the north and south pins, and we conducted our cross-sectional surveys along this line. We surveyed the cross sections using a level and stadia rod, taking measurements along the cross section at intervals reflecting changes in topography, at high water marks, at inflection points, at the right and left edge of the water in the channel (REW & LEW), and at the thalweg of the main channel. For survey points located within the water, we also noted the height of the water above the channel substrate. Initial high water marks were located and recorded along the upper edge of the floodplain, where distinct changes in vegetation, debris, and soil existed.

After recording the two cross sections, but leaving the level in place, we placed the tape measure parallel to a longitudinal profile between the two cross sections. We then walked back and forth in the floodplain and identified additional high water marks from debris caught in small saplings and shrubs. With the level still in place, we surveyed these elevations and later used them to confirm the initial high water estimates from the upper edges of the floodplain.

STEP 3: INTERPRETATION OF SITE AND AERIAL PHOTOGRAPHY

The papers by Bouitillier and White (2002, 2003) included aerial photography of Wildcat Creek in 1984, 1989, and 1996, and we used these images as a time series to track changes in channel morphology and surrounding vegetation.

We also took digital photographs of the reach during our survey. These photos document high water marks, vegetation along the stream channel and flood plain, sedimentation, and the flow of water in the main channel.

RESULTS

CALCULATION OF FLOW VALUES USING THE MANNING EQUATION:

We employed Chow's (Chow, 1959) "Values for Calculating the Roughness Coefficient" to calculate Manning's roughness coefficient (see Appendix A). For each cross section, we derived a flow (Q) value for the defined channel (by itself) and for the entire floodplain (including the defined channel) up to the high water mark.

<u>CROSS SECTION 83+00 (defined channel at bankfull water level)</u>

Q = 157 cfs

<u>CROSS SECTION 83+00 (defined channel + floodplain at high-water mark)</u>

Q = 697 cfs

<u>CROSS SECTION 88+00 (defined channel at bankfull water level)</u>

Q = 187 cfs

<u>CROSS SECTION 88+00 (defined channel + floodplain at high-water mark)</u>

Q = 748 cfs

DESCRIPTION OF SEDIMENTATION AND SCOURING IN LOWER WILDCAT CREEK:

Using cross sections surveyed in 1986, 1999, 2001, 2002, 2003, and 2004 we described how the channel has changed as a result of "natural" and man-made processes in the time period between 1986 and 2004.

YEAR	CROSS-SECTION DESCRIPTION	NOTES / EXPLANATION
1986	Baseline	Main floodplain dredged out
1999	88+00 floodplain has filled in. 83+00 floodplain filled in, small defined channel present	Following completion of new low-flow defined channel in 1998
2001	Modified defined channel	Following new defined channel (deeper, wider, increased meandering)
2002-2003	Buildup of sediment in main channel and floodplain	No intervention
2004	Scouring of main channel	No intervention

Comparing our 2004 cross sections to those taken in 2002 and 2003 (Boutillier and White), we can see that the main channel has been scoured out over the past year (see Figure 2, Figure 4).

DISCUSSION

CHANNEL FORM: We overlaid our surveyed cross sections (83+00 and 88+00) with survey data from several previous studies. First, we compared our cross sections to those taken by the Contra Costa County Floodplain District a month prior to our work (see Figure 1, Figure 4). While our results for cross section 88+00 lined up almost exactly with their results, our results for the 83+00 cross section did not line up. Since no large storm events occurred between the time of the two cross sections (Contra Costa County Floodplain District did not have an exact date for the survey but estimated that theirs had been taken a month prior to when we went out), we think this discrepancy resulted from error, which was inserted in our cross section from not finding the survey pin on the southern side of the creek. Thus, for further comparisons, we used the 2004 cross sections taken by the Contra Costa County Floodplain District.

We compared the 2004 results to those of the "as-built" original channel, from 1986. While the channel has obviously changed dramatically over that 20-year time period, it was important to consider the history of the channel in understanding what amount of change had been induced by natural processes, and what change was causes by human intervention and channel alteration.

We were able to acquire additional cross sections from the Contra Costa County Floodplain District for the years 1999 and 2001. These cross sections helped us to construct a more complete timeline of the morphological changes that occurred in Wildcat Creek. In this report, we include a time series for each cross section (see Figure 3 and Figure 6) to illustrate some of the man-made and natural changes that the channel has experienced since 1986. For example, the 1999 cross sections are interesting in that the downstream cross section (83+00) shows the defined low-flow channel still intact while the upper cross section (88+00) shows no such channel—just a flat floodplain. Since the channel was described as "clogged" at the time of the 1998 excavation (Riley, 2003), the difference in cross section profiles could be attributed to deposition of sediment onto the upper portion of the reach, following a loss of velocity as the water passed under the Giaramita St. bridge. It is important to note that there is not much observable difference between the 2001 and 2004 cross sections (although Boutillier and White's 2002 and 2003 cross sections do show some sedimentation in the interim, which we believe has been removed by 2004 storms).

DEPOSITION: We placed the cross sections that we recorded next to the cross sections taken by Boutillier and White in 2002 and 2003. While their results show sediment buildup on the floodplain and main channel, our data show the channel scoured back down to a lower level (i.e. to the original level of the 1986 survey, and the bottom of 2001 channel). Both the Contra Costa

County Floodplain District data and our survey data, indicate the main channel has cleared out since the 2003 cross section was surveyed, which seems plausible as there was a large storm event in mid-February, 2004. Even though it appears to have scoured, the 2004 cross section seems to be narrower than the original channel shown in the Boutillier/White diagram; thus, the main channel may be scouring out downward but closing in and experiencing some deposition.

FLOW: The Manning's Roughness Coefficient and corresponding flow values we derived are consistent with previous studies for the same reach (Boutillier and White, 2003). However, we realize there is error inherent to using the Manning's equation; even though we attempted to be precise in computing the area of the channel and floodplain, this is a coarse derivation as is the additive method for computing channel roughness. Wildcat Creek was last gauged in 1995, and unfortunately we did not have time to survey the high water marks from the February storms. This would have allowed us to link our cross sections into a survey of the old USGS gage and tie our data into the pre-1995 rating curve.

CONCLUSIONS

Our results corroborated those of previous studies, which concluded that sediment has been building up in Wildcat Creek. In cross-section 88+00, however, we observed a decrease in sedimentation compared to previous studies, indicating the channel recently experienced natural scouring.

Previous studies concluded this restoration project is not sustainable because so much maintenance is required to maintain the channel form and a clear floodplain (for example, cutting cattails every year and dredging). Continued monitoring over a longer time scale is needed, but our survey results show signs that the channel may be scouring after bigger storm events and may be able to maintain itself to a certain extent.

We suggest future restoration or redesign of this reach of Wildcat Creek be considered at a watershed level, primarily because problems with sedimentation and invasive species are a result of the larger-scale watershed conditions. Additionally, the source of upstream sediment also needs to be addressed, opposed to attempts to simply restore a portion of the Creek without planning for the dynamic effects of sedimentation, urbanization, and hydrology throughout the entire watershed.

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Finally, we would like to thank Matt Kondolf and Jeremy Thomas for their support and guidance on this project.

APPENDIX A: MANNING'S EQUATION CALCULATIONS

Defined channel:

VARIABLE	VALUE	NOTES
Material: *Earth*	n0 = 0.020	The channel in the reaches we studied were largely fine earthen material.
Degree of Irregularity: *Minor*	n1 = 0.005	The guidelines for this value suggest picking "minor" for good dredged channels, slightly eroded or scoured slide slopes.
Variation in Channel: *Alternating Occasionally*	n2 = 0.005	Main channel geometry is fairly uniform, but varies in shape from year to year
Effect of Obstructions: *Minor*	n3 = 0.010	Most choices (stumps, logs, boulders) that would yield higher values for this indicator were not present, but some roots and debris support a low-end minor value.
Vegetation: *Medium*	n4 = 0.020	Cattail vegetation grew in a one location in the main channel, but the upstream cross section was void of vegetation
Degree of Meandering: Appreciable	n5 = 1.150	The defined channel had a sinuosity range from 1.2 – 1.7, matching "appreciable".

n = Manning's coefficient
n = (n0 + n1 + n2 + n3 + n4) * n5
n = (0.020 + 0.005 + 0.005 + 0.010 + 0.020) * 1.150
n = 0.069

Floodplain channel:

VARIABLE	VALUE	NOTES
Material: *Earth*	n0 = 0.020	The floodplain was primarily covered with fine sediment that settled out after high flows. The berms on the outside of the channel were also fine dredged material.
Degree of Irregularity: *Moderate*	n1 = 0.010	The floodplain seemed be somewhere in the middle of smooth and jagged (the two extremes), with berms, swales, and mounds of dirt.
Variation in Channel: *Gradual*	n2 = 0.000	The floodplain is fairly uniform in width and depth; only gradually filling over time.
Effect of Obstructions: *Minor*	n3 = 0.015	Other than dirt mounds, the floodplain had very little to no listed obstructions.
Vegetation: *High – Very High*	n4 = 0.050	The majority of the floodplain is covered with cattail vegetation (although it is cut annually before winter flow), grasses, and a dense riparian forest
Degree of Meandering: *Minor*	n5 = 1.000	The floodplain is fairly uniform and straight, with only gradual downstream bends.

n = Manning's coefficient
n = (n0 + n1 + n2 + n3 + n4) * n5
n = (0.020 + 0.010 + 0.000 + 0.015 + 0.050) * 1.000
n = 0.095

CROSS SECTION 83+00 (defined channel at bankfull discharge)

$V = 1.49(S^{0.5} R^{0.67}) / n$
R = hydraulic radius (A/wp) = $87ft^2 / 24ft = 3.625$ ft
S = slope = 0.00125
n = 0.069
A = area = $87ft^2$

$V = 1.49 [(0.00125)^{0.5} (3.62 \text{ ft})^{0.67}] / 0.069$
V = 1.81 ft/s
Q = VA = (1.81 ft/s)(87 ft^2) = **157 cfs**

CROSS SECTION 83+00 (defined channel + floodplain at high-water mark)

$V = 1.49(S^{0.5} R^{0.67}) / n$
R = hydraulic radius (A/wp) = $481ft^2 / 137.75ft = 3.49$ ft
S = slope = 0.0016
n = 0.095
A = area = $481ft^2$

$V = 1.49 [(0.0016)^{0.5} (3.49 \text{ ft})^{0.67}] / 0.095$
V = 1.45 ft/s

Q = VA = (1.45ft/s)(481ft^2) = **697 cfs**

CROSS SECTION 88+00 (defined channel)

$V = 1.49(S^{0.5} R^{0.67}) / n$
R = hydraulic radius (A/wp) = $102ft^2 / 27.5ft = 3.71$ ft
S = slope = 0.00125
n = 0.069
A = area = $102ft^2$

$V = 1.49 [(0.00125)^{0.5} (3.71 \text{ ft})^{0.67}] / 0.069$
V = 1.84 ft/s

Q = VA = (1.84 ft/s)(102 ft^2) = **187 cfs**

CROSS SECTION 88+00 (defined channel + floodplain at high-water mark)

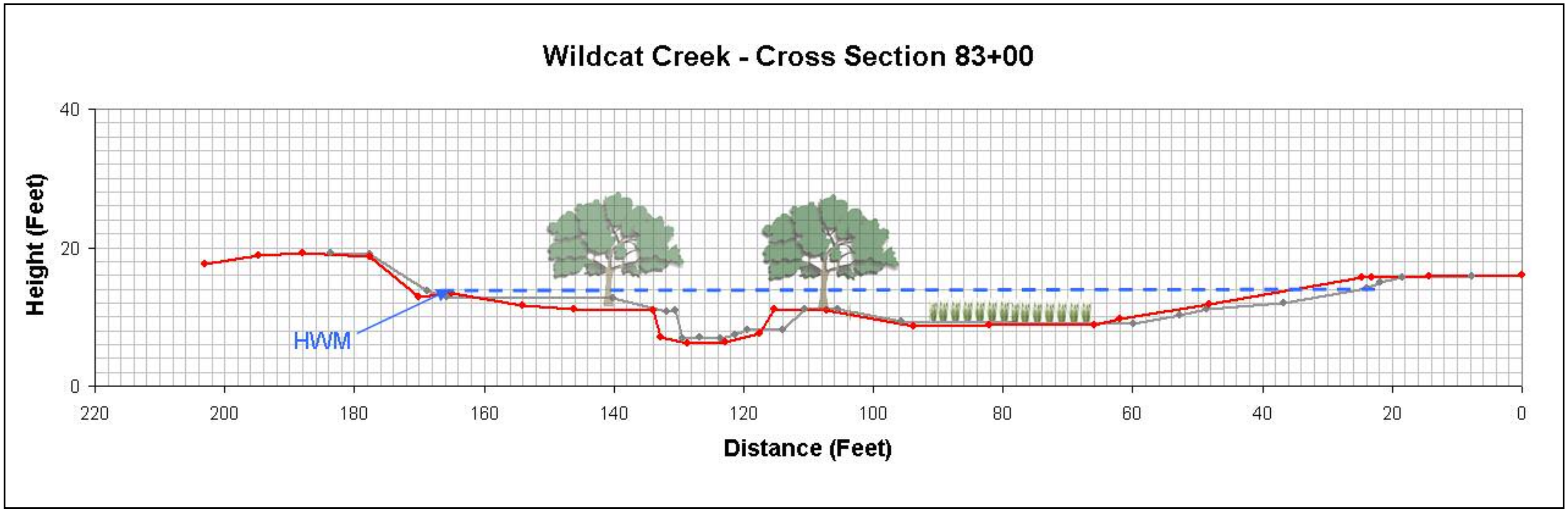
$V = 1.49(S^{0.5} R^{0.67}) / n$
R = hydraulic radius (A/wp) = $528ft^2 / 156.5ft = 3.37$ ft
S = slope = 0.0016
n = 0.095
A = area = $528ft^2$

$V = 1.49 [(0.0016)^{0.5} (3.37 \text{ ft})^{0.67}] / 0.095$
V = 1.42 ft/s

Q = VA = (1.42ft/s)(528ft^2) = **748 cfs**

FIGURE 1: WILDCAT CREEK CROSS SECTION 83+00, LOOKING DOWNSTREAM

COMPARISON OF BATTAGLIA/HOLT 2004 CROSS SECTION AND CONTRA COSTA COUNTY 2004 CROSS SECTION

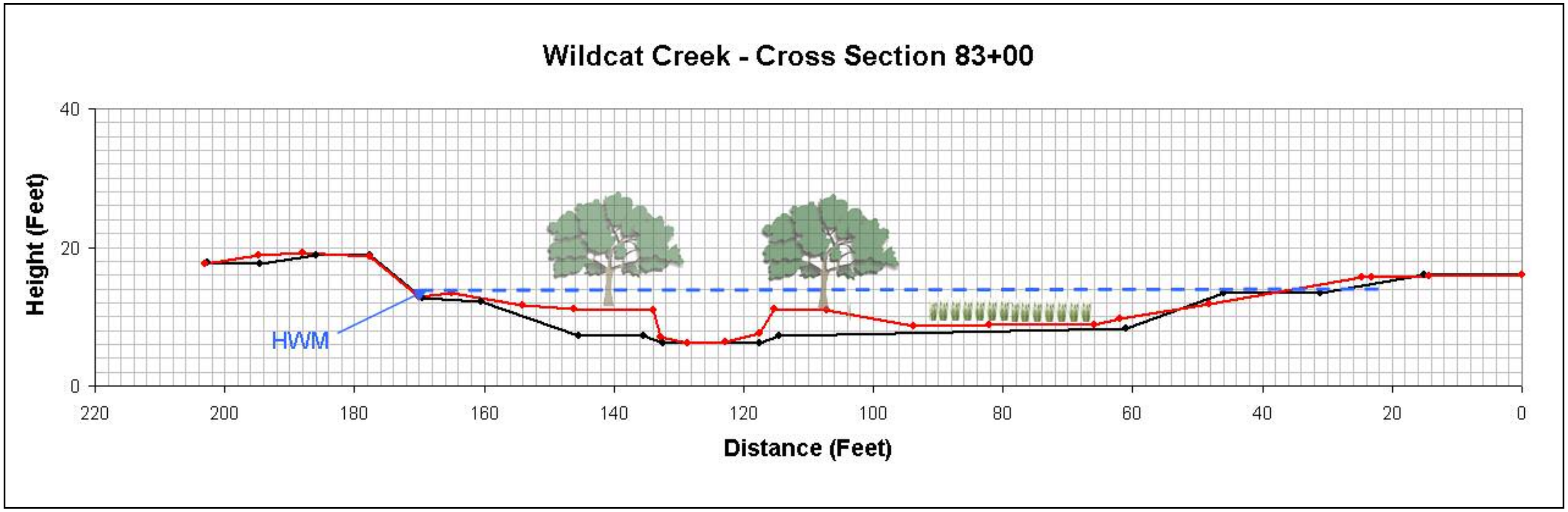


2004 cross section (Battaglia/Holt)

2004 cross section (Contra Costa county)

FIGURE 2: WILDCAT CREEK CROSS SECTION 83+00, LOOKING DOWNSTREAM

COMPARISON OF 2004 CROSS SECTION WITH 2002, 2003 CROSS SECTIONS (BOUTILLIER/WHITE)



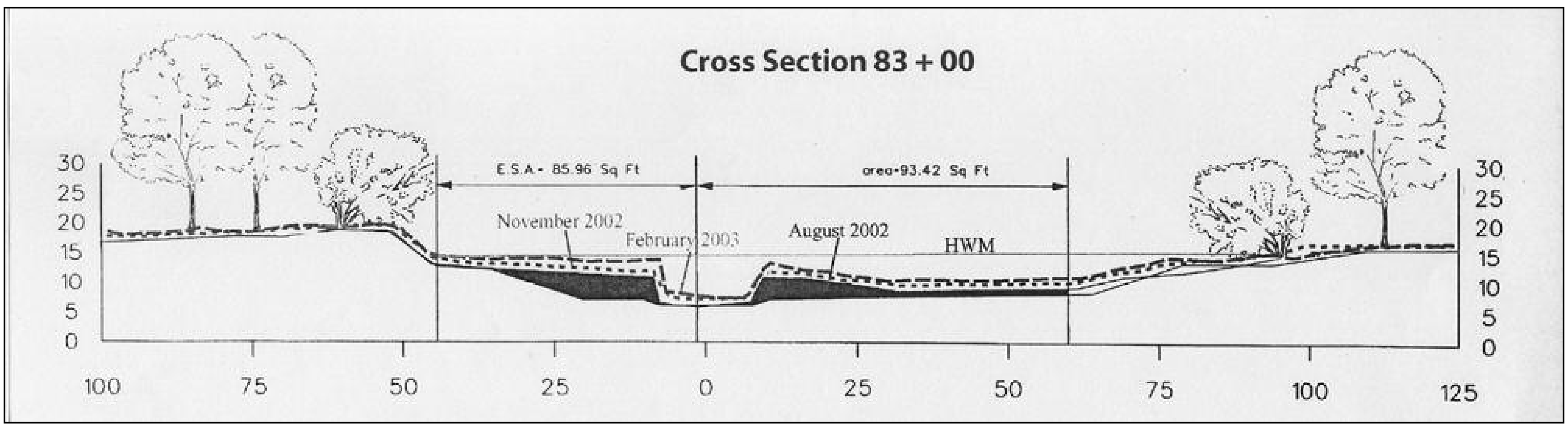
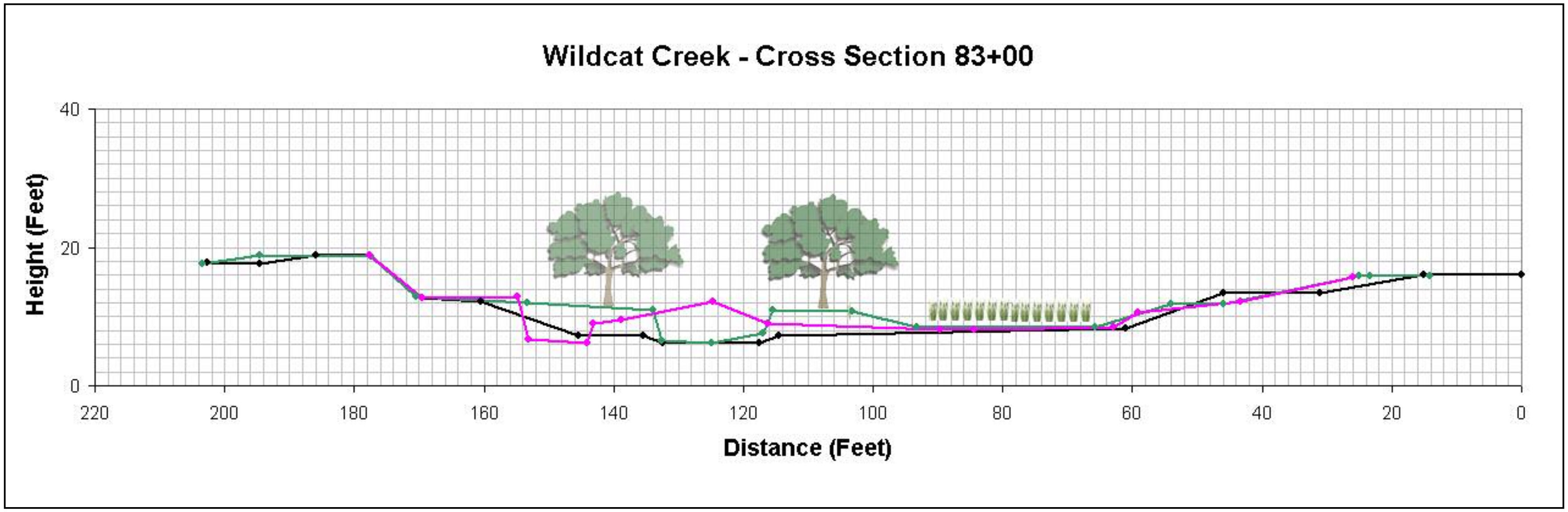


FIGURE 3: WILDCAT CREEK CROSS SECTION 83+00, LOOKING DOWNSTREAM

COMPARISON OF 1986, 1999, AND 2001 CROSS SECTIONS



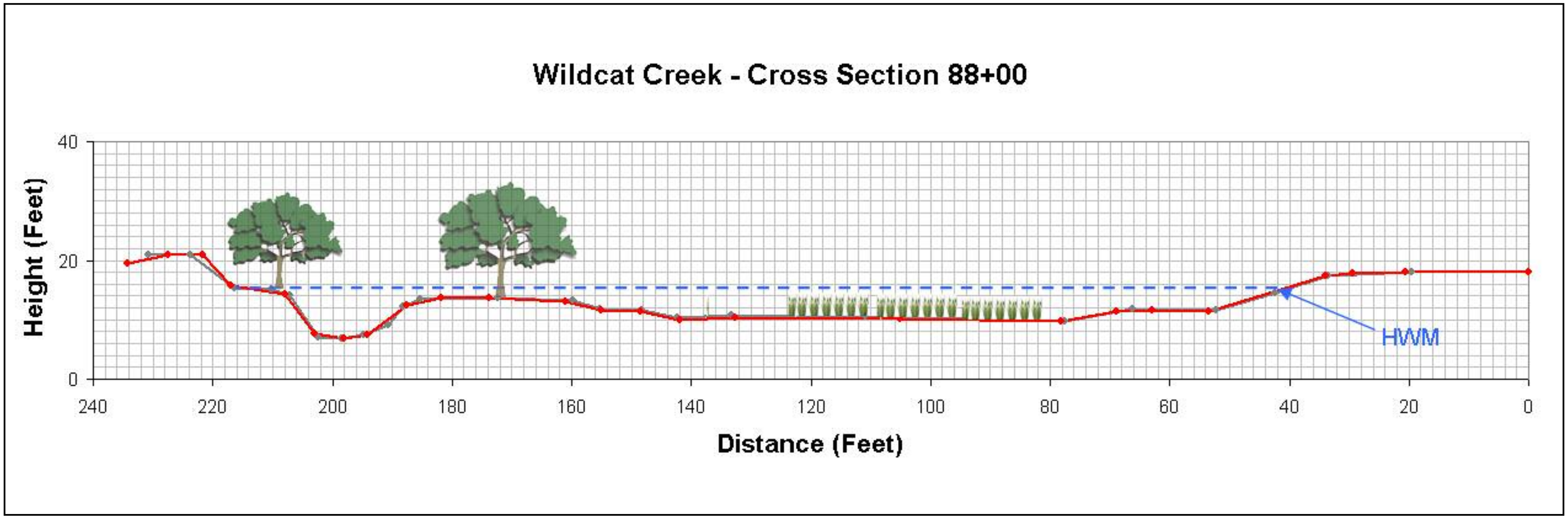
2001 cross section (Contra Costa county)

1999 cross section (Contra Costa county)

1986 cross section (Contra Costa county)

FIGURE 4: WILDCAT CREEK CROSS SECTION 88+00, LOOKING DOWNSTREAM

COMPARISON OF BATTAGLIA/HOLT 2004 CROSS SECTION AND CONTRA COSTA COUNTY 2004 CROSS SECTION



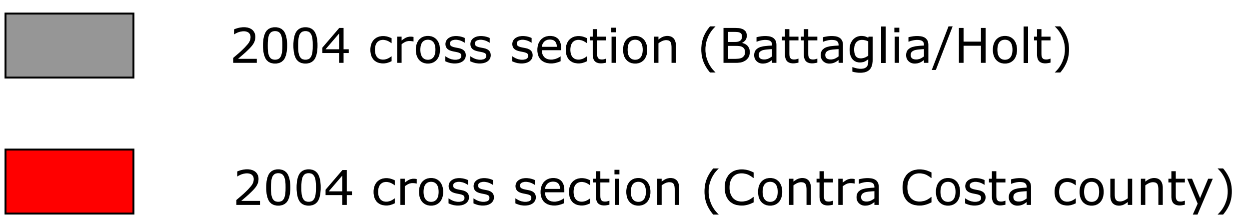
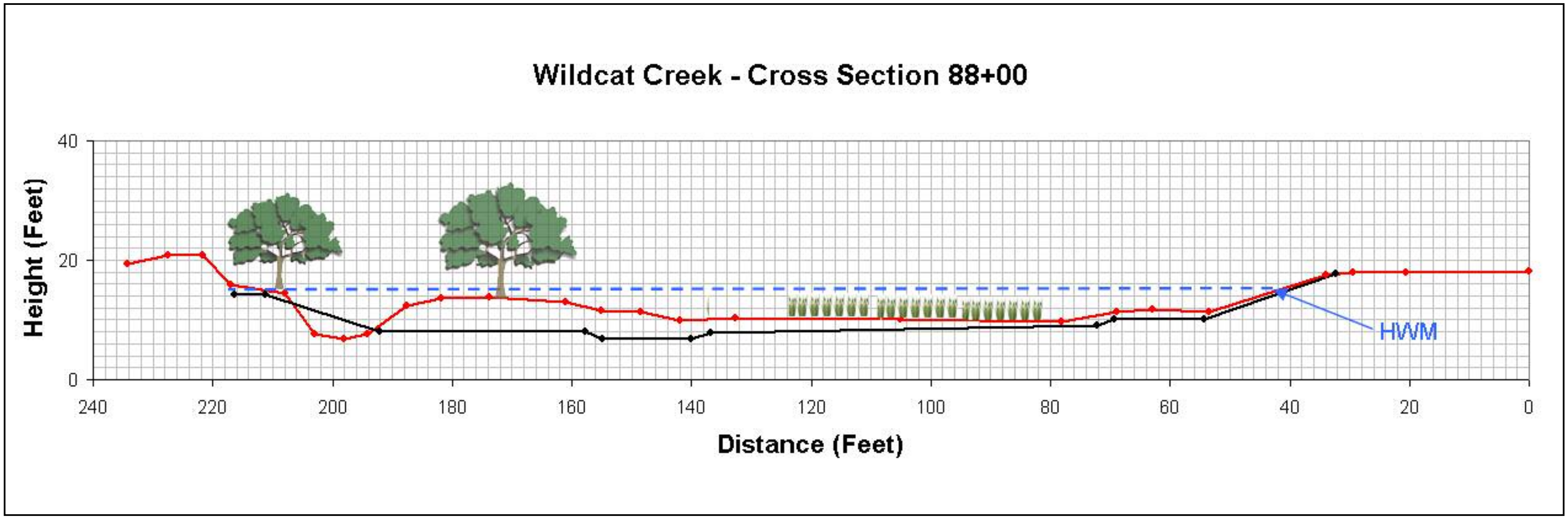


FIGURE 5: WILDCAT CREEK CROSS SECTION 88+00, LOOKING DOWNSTREAM

COMPARISON OF 2004 CROSS SECTION WITH 2002, 2003 CROSS SECTIONS (BOUTILLIER/WHITE)



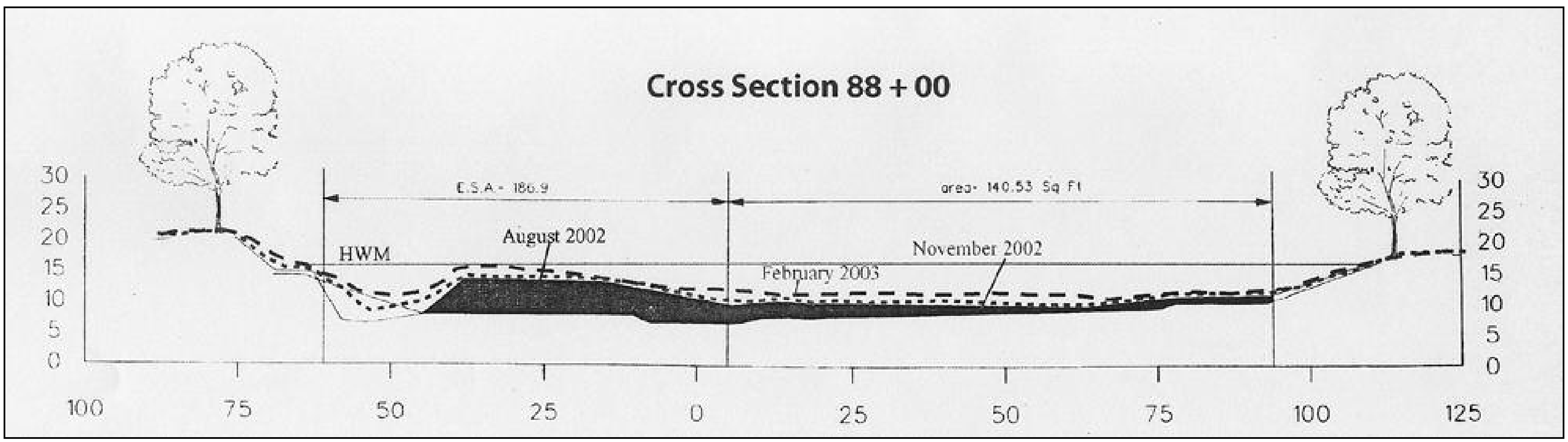
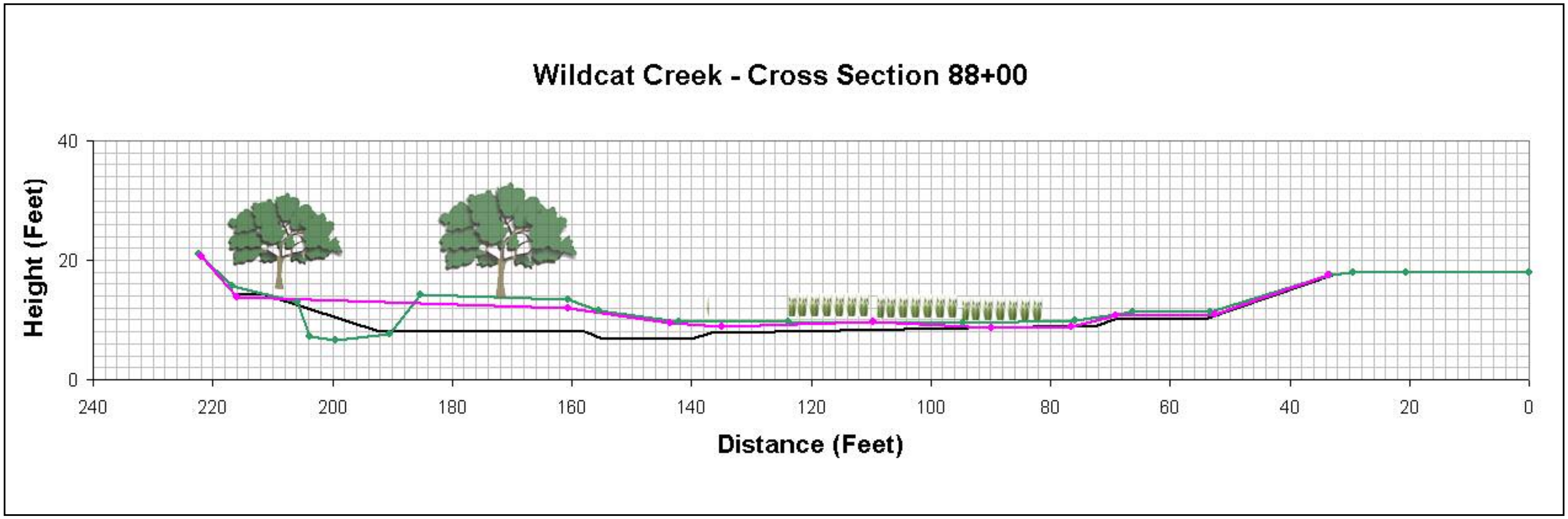


FIGURE 6: WILDCAT CREEK CROSS SECTION 88+00, LOOKING DOWNSTREAM

COMPARISON OF 1986, 1999, AND 2001 CROSS SECTIONS



1986 cross section (Contra Costa county)

1999 cross section (Contra Costa county)

2001 cross section (Contra Costa county)

FIGURE 7: USGS AERIAL PHOTO OF RICHMOND, CA – 1993

1. 3rd Street
2. 83+00
3. 88+00
4. Giaramita Ave.

FIGURE 8: MAP OF THE WILDCAT CREEK WATERSHED

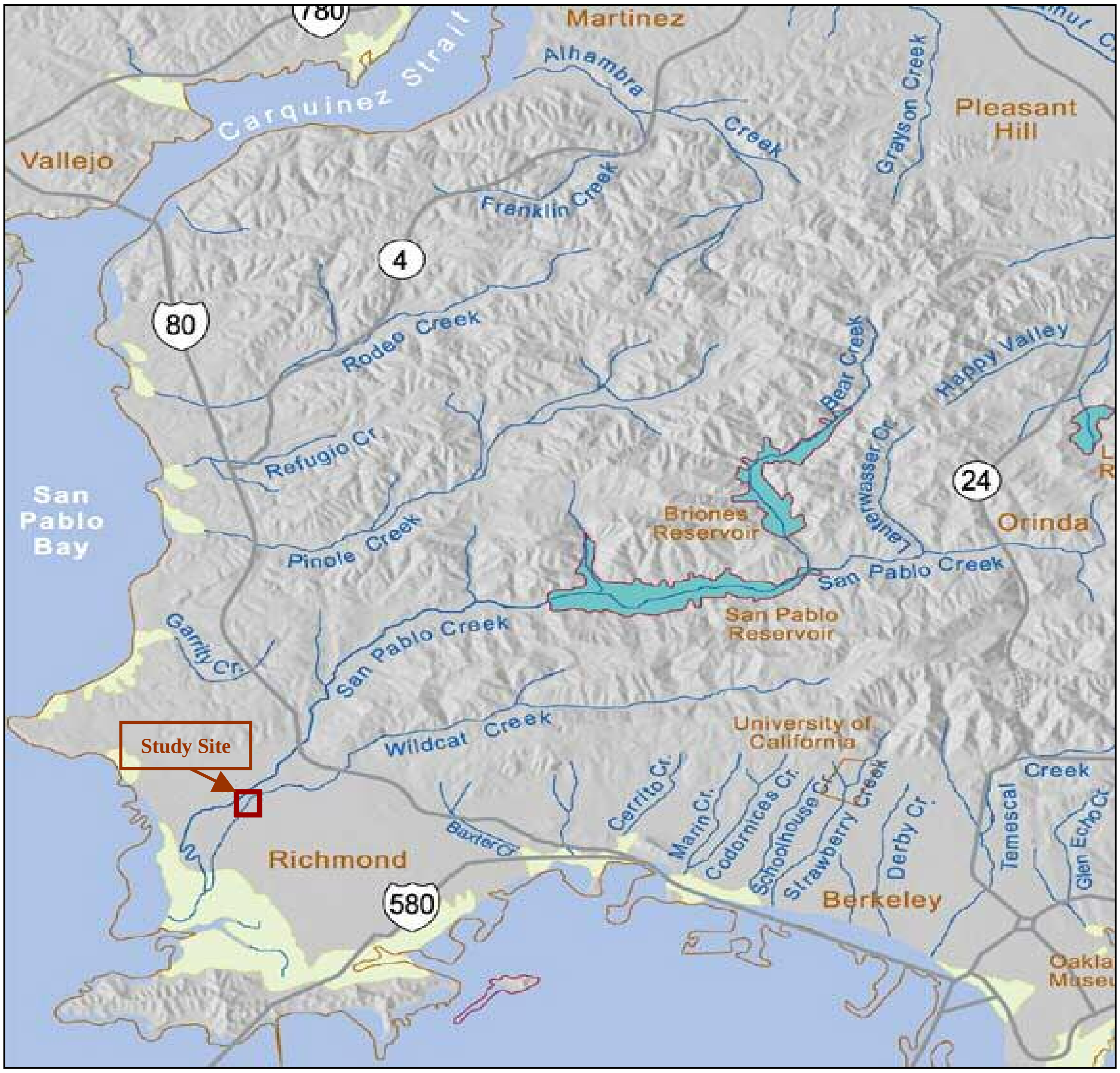


FIGURE 9: USGS TOPO MAP OF RICHMOND, CA – 1998

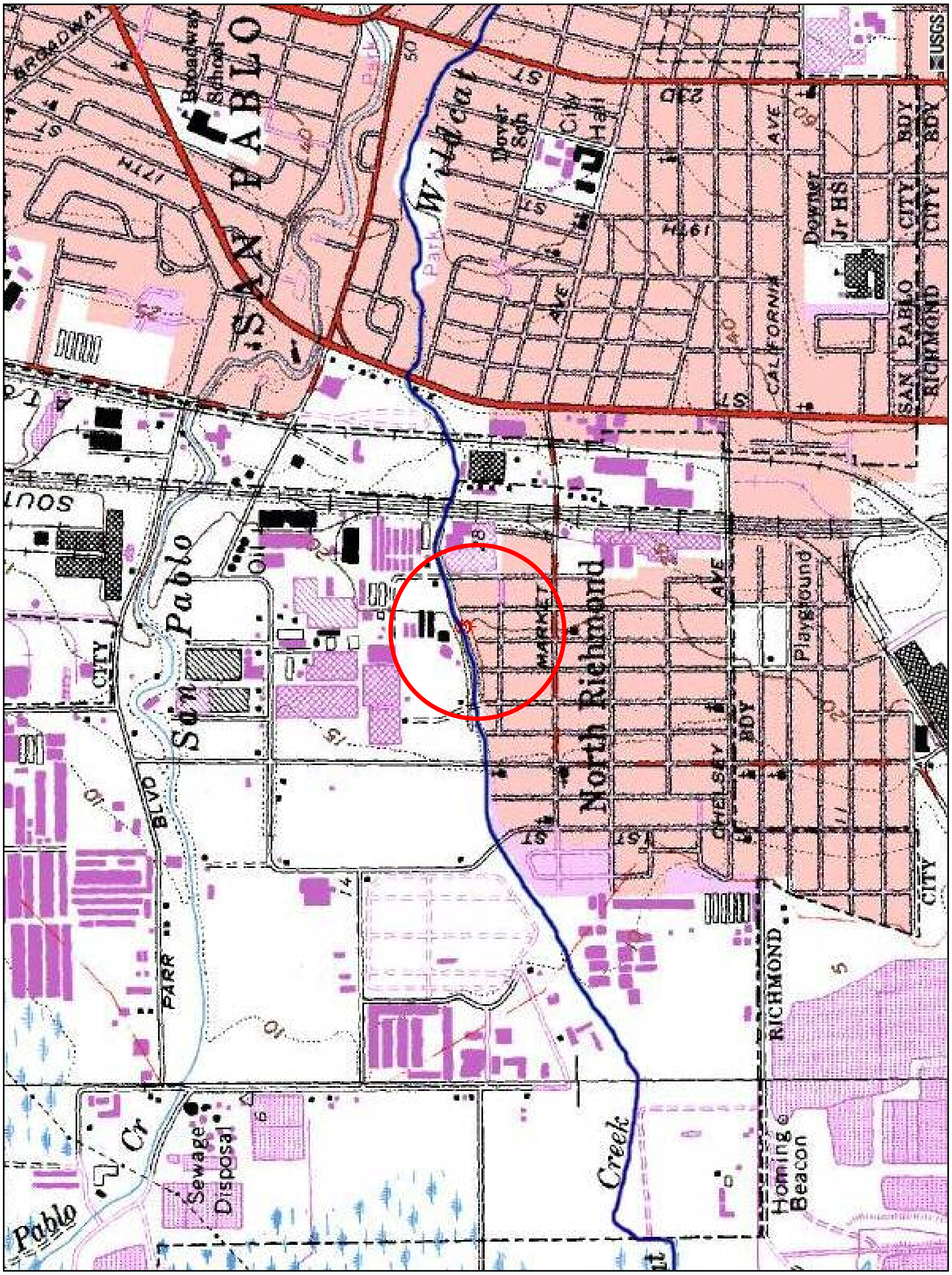


FIGURE 10: CROSS SECTION 83 + 00

View of floodplain looking upstream. Giaramita Ave. can be seen in the distance.

View of floodplain looking downstream. The Third St. bridge can be seen in the distance.

Downstream view of the main (low-flow) channel.

FIGURE 11: CROSS SECTION 88 + 00

View of floodplain looking upstream. Giaramita Ave. can be seen in the distance.

View of floodplain looking downstream. The Third St. bridge can be seen in the distance.

View of vegetation along the bank of the main (low-flow) channel.

FIGURE 12: HIGH WATER MARKS

Debris caught in branch, along floodplain.

Debris built up along the edge of the floodplain.

Debris caught in tree, near top bank of low-flow channel.