Title

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ABSTRACT
Rheem Creek is a three mile long urban stream, located in California's western Contra Costa County. Since 1960, Rheem Creek has been impacted by humans in a number of ways, including channelization for flood control purposes and residential development. Due to the deteriorated state of Rheem Creek, local community groups have partnered with stream restoration organizations to clean-up and rehabilitate the Creek. Little field data exists on the conditions of the Creek itself, or on the geomorphic, hydrologic, water quality and ecological conditions at specific sites. To overcome this barrier, and serve as a resource for local restoration efforts, this study aimed to: 1) Offer an additional qualitative overview of the human impacts on Rheem Creek and 2) Quantify the hydrologic and channel form conditions at the Contra Costa College immediately downstream from a proposed restoration project.

This study reveals that variable conditions exist along Rheem Creek, including the presence of a 100-foot undisturbed riparian corridor, straightened and stagnant waste pools, and stormwater pipes that drain directly into the Creek. Longitudinal and cross-sectional surveys at Contra Costa College show the existence of five distinct reaches within the College grounds, and highlight the need to consider coordinated restoration efforts between the Contra Costa College and restoration groups in order to avoid passing upstream problems to downstream sites; this includes exacerbating the flooding problem on the valley flats. Results from this study serve as a benchmark for planned upstream restoration projects and future monitoring efforts that will measure the impact of the projects over time.

INTRODUCTION

Located 20 miles northeast of San Francisco, California, in western Contra Costa County, Rheem Creek is a three mile long urban stream that has been impacted by residential and industrial development (Figure 1). Within Rheem Creek's 1.7 square mile watershed lie sections of the cities of San Pablo, Richmond, and the unincorporated communities of Rollingwood and North Richmond. On its course to the Bay, the creek begins in the Rolling Hills Cemetery, east of Interstate 80, and then passes through the residential neighborhood of Rollingwood, the Contra Costa Community College (the College), several San Pablo neighborhoods, an industrial area with undeveloped brownfields and ends at an undeveloped bayfront at the mouth of San Pablo Bay south of Point Pinole (Figures 2). Levine (2005) notes that despite its small size, the watershed has four distinct sections distinguished by varying topography, geology, former natural habitats, and present land uses. These four distinct zones are: the Headwaters, the Upper Watershed, the Middle Watershed and the Lower Watershed (Figure 3).

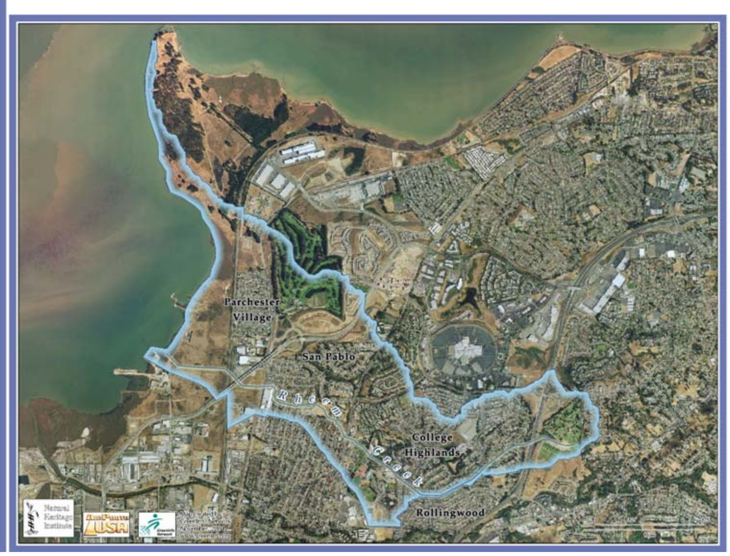

Figure 1 – The San Francisco Bay Region

Figure 2 – Satellite image of Rheem Creek Watershed. Outline delineates watershed boundary .

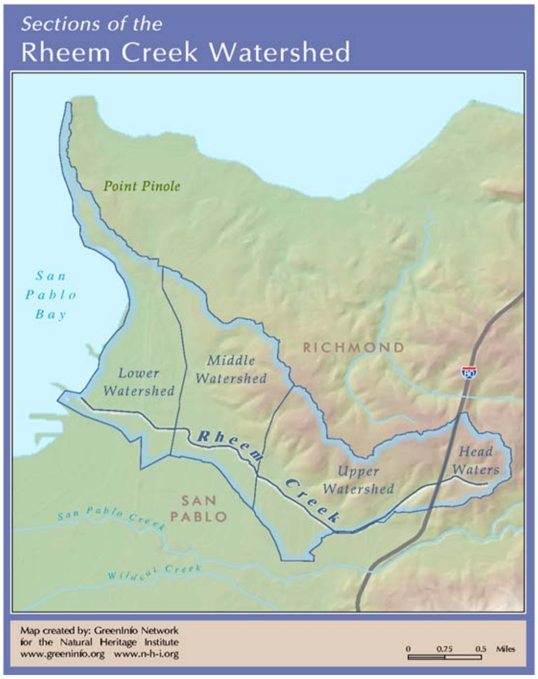

Figure 3 – The four zones of the Rheem Creek Watershed.

The *headwaters* of Rheem Creek are located on the western edge of the East Bay Hills, in El Sobrante. This area is characterized by steep, rolling terrain. The *upper watershed* is bounded by Interstate 80 to the east and San Pablo Avenue to the west. Two residential neighborhoods, the College Highlands subdivision in Richmond and the unincorporated Rollingwood neighborhood, are situated in the gentle hills of this section. The upper watershed also contains Contra Costa College in the City of San Pablo. The *middle watershed*, bounded by San Pablo Avenue to the east and Giant Road to the west, is flatter and more densely developed. It includes neighborhoods in the northwestern part of the city of San Pablo and an industrial area along Giant Road. The *Lower watershed* is the flattest and least developed section of the watershed, bounded by Giant Road to the east and San Pablo Bay to the west. Remnants of tidal flat and tidal marsh habitat, two habitat types that have been severely affected by human development all around the San Francisco Bay area, are found near the mouth of Rheem Creek (Levine 2005).

Due to human influence, Rheem Creek has been altered significantly in the past 50 years. In the 1960s, the Army Corps of Engineers moved and straightened the Creek as a means of flood control. In the headwaters, upper watershed, and middle watershed, parts of the creek were culverted. In the lower watershed the stream channel was straightened and put into a cement channel in the residential areas, and straightened in the tidal flats. Where the channel was straightened in the Rollingwood neighborhood the incidence of flooding is significant (Josh Bradt, personal communication, April 14, 2005). Ironically, flooding is a major problem for houses that abut the Creek in the upper and middle watershed, but is rarely a problem for land adjacent to the concrete box channel in the lower watershed.

As the human population of the watershed has increased, the Creek's water quality has suffered. Since the 1950s, the creek has increasingly been a conduit for pollutants from lawns, driveways, and roads. The few water quality tests that have been conducted within the watershed indicate that runoff into Rheem Creek contains a number of substances, such as zinc, lead, diazinon and mercury, at levels that are harmful to aquatic life (Levine 2005 and CCCFCWCD 1995 and 1996).

Due to the deteriorated state of Rheem Creek, several restoration efforts exist to decrease flooding hazards and to enhance the creek's "natural" conditions. Restoration sites include: 1) The Rollingwood Neighborhood, in the upper watershed 2) Contra Costa Community College, in the upper watershed 3) Wanlass Park, in the middle watershed and 4) Lower Rheem Creek, in the lower watershed. Most of these restoration projects will involve monitoring changes in creek conditions over time, thus making the collection of baseline data a top priority. Until now, however, little data from the field exist to provide a benchmark for restoration efforts.

At the border of the Rollingwood neighborhood and the College, the Urban Creeks Council (UCC) is planning to remove invasive vegetation, and reintroduce native vegetation in an attempt to control flooding (Josh Bradt, personal communication, April 14, 2005). The UCC has also submitted a grant for a conceptual restoration design at the College. Here, the aim is to provide the campus with an overview of the restoration potential for the entire campus, and implement a demonstration restoration project at the border of the college and the Rollingwood neighborhood. Because Rheem Creek has not yet been surveyed in this reach, there exists an important opportunity for collecting baseline data. Such an effort will inform UCC's restoration activities.

In order to expand the amount of foundational data on Rheem Creek, our study sought to answer the following questions:

1) Qualitatively, how are humans impacting Rheem Creek in different zones?
2) What are the baseline hydrologic, channel form and water quality conditions at Contra Costa Community College?
3) How can the results from questions 1 and 2 be used to improve restoration efforts, such as the one proposed for the Rollingwood neighborhood?

METHODS

To answer our study questions we documented human influences along the creek, conducted longitudinal profile and cross-section surveys at the College and sampled water quality at 4 characteristic sites along the creek.

Creek Characterization

In mid March, we conducted a creek walk of the Rheem Creek Watershed in order to gain an understanding of Rheem Creek as one continuous river system. We took digital photographs and Global Positioning System (GPS) points as complements to written descriptions.

During our creek walk we looked for the following key attributes:

1. *Channel characteristics*, such as channel width, bank material and bed form;

2. *Geomorphic characteristics*, such as evidence of erosion or incision, terraces;
3. *General vegetation characteristics*, and
4. *Evidence of human use*, such as surrounding land-use, evidence of storm pipes and informal pipes draining into the creek.

Our creek walk began in the headwaters of Rheem Creek at the Rolling Hills Cemetery in San Pablo, and ended at the mouth of the Bay. Due to the Creek's urban obstacles (e.g. culverts, freeways, fences) we were not able to walk continuously, and thus did not examine several stretches of the creek. The five main stretches that we walked included: 1) The headwaters, at the Rolling Hills cemetery, 2) The Rollingwood neighborhood, roughly 400 feet west (downstream) from Fordham Street, in the upper watershed 3) The entire stretch of the creek at the College, in the upper watershed, 4) Wanlass Park and the adjacent neighborhood to the west, in the middle watershed, and 5) Lower Rheem Creek, in the lower watershed (Figure 4).

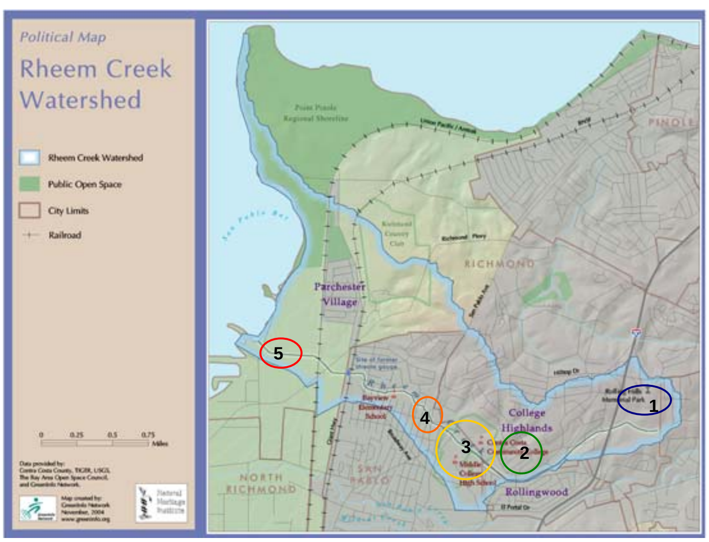

Figure 4 – The five stretches of the Rheem Creek walked for the Creek Characterization.

Longitudinal Profile

In late March, we conducted our survey at the College. The first day of field work was overcast in the early morning. By late morning, showers started. By early afternoon a heavier rain was falling until the evening. The following day, rains continued, with heavy and lighter rains alternating throughout the day. Prior to beginning our profile, we sketched a site map, taking note of riparian vegetation, distances, key landscape features and general channel characteristics.

We started our longitudinal profile at the bottom of the Creek's passage through the campus, and ended roughly 800 feet from this location. Details on our benchmarks and turning points are included in Appendix A. At each station, we surveyed the thalweg, water surface elevation, and bankfull elevation. In addition to general survey points, we noted pool-riffle sequences. We defined riffles as any area of the creek where cobble was more than 1/3 exposed and where water was flowing at a velocity equal to are greater than average speeds for the reach. We defined pools as areas in between the riffles, where water was at a stand-still. We took survey points at the top and bottom of the pools.

Cross-Sectional Survey

We conducted our cross-sectional survey at the 612 foot marker, beginning at the sidewalk level on the right bank, and ending at the fence-line on the left bank. This was a characteristic cross-section that Urban Creeks Council recommended (Josh Bradt, personal communication, March 21, 2005).

To estimate discharge we applied the Manning's equation. Using the Manning's equation we calculated both velocity and discharge at our cross-sections. Here, $v=(cs^{.5}R^{.67})/n$, where v is velocity, c is a constant coefficient, s is the energy slope, approximated by the gradient of the river, and n is a calculated roughness coefficient. Discharge (Q) is calculated as: Q = V*A, where v=velocity and A= cross-sectional area. Using our field-derived velocities we back-calculated Manning's n, to verify our results. We estimated n-values using an iterative process of both n estimations using the Chow (1959) method, as well as photos from the website, where photographs of streams with different n-values are depicted (Culvert BC).

Flood Frequency Analysis

In order to conduct a flood frequency analysis, we analyzed United States Geological Survey (USGS) stream gage data for Rheem Creek, from 1960-1990. We conducted a general flooding analysis for recurrence intervals of two, ten, fifty and one hundred years (Q2, Q10, Q50 and Q100, respectively) for the portion of the creek upstream of the College. To do this, we calculated the fraction of the basin that is upstream of the college using a topographic map and a planimeter. This came out to be 0.84 square miles. As a fraction of the total, this is equivalent to 0.64. We then multiplied original flooding values by this fraction.

Water Quality Testing

At the conclusion of our creek walk, we chose four water quality testing sites: 1) The headwaters, immediately before the Creek enters into a cement channel at the upstream end of the first freeway culvert, 2) the Rollingwood neighborhood at Fordham and Shane streets, 3) Contra Costa College, and 4) the non-tidally influenced lower portion of Rheem Creek. Sites were selected in order to encompass each of Levine's (2005) watershed zones and to correspond with locations where ample qualitative observations had been logged. At each site we tested pH, dissolved oxygen (DO), water temperature, and water conductivity using an YSI Sonde 556 Calibration water quality meter. To test for nitrate levels, we used an Ammonia-Nitrogen colorimetric test kit (of LaMotte Company). Data and analysis on water quality tests is included in the Appendix.

RESULTS

Our three field days allowed us to gather general site characteristics, as well as important data on the longitudinal profile and cross-section at the College. In general, our results highlight a high degree of various types of human impact along the entire length of the creek.

Creek Walk Characterization

Headwaters

Rheem Creek emerges from the Rollingwood Hills in a narrow gulch that bisects the Rolling Hills Memorial Cemetery. The rim of the gulch is bordered by a cemetery access road to the south, burial plots to the east, a wooded buffer zone to the north, and Interstate-80 to the west. Immediately upstream of the area where Rheem Creek first coalesces into a discernable flow, large volumes of soil and fill material have been pushed onto the slope leading down into the gulch. Similarly, a strip of soil with no vegetation alongside the road near the southern rim of the gulch points to potential dumping activity.

Photo 1 – The headwaters of the Rheem Creek in the Rolling Hills Cemetery.

The entire length of the southern slope that leads down to the Creek is unstable. Large sections of the slope are migrating downhill towards the Creek. Several storm water pipes drain into the bottom of the gulch from the upper slopes (Photo 2). For all but the lower 25 feet, the streambed is densely vegetated with blackberries, poison oak, and willows. Native oaks are located on the slopes leading down to the Creek.

Photo 2 – Drainpipe emptying into the Rheem Creek gulch in Rolling Hills Cemetery

Photo 3 – Drainpipe leading from I-80 to Rheem Creek in the Rolling Hills Cemetery.

Photo 4 – Drainpipes entering Rheem Creek as it leaves Rolling Hills Cemetery beneath I-80.

The last 100 feet of bank and adjacent slope, before Rheem Creek enters a cement channel and disappears through a culvert beneath I-80, has been cleared of trees and equipped with 4 storm water drain pipes, which drain directly into the Creek (Photo 3, 4).

<u>Rollingwood</u>

In the Rollingwood neighborhood at Shane and Fordham Streets, Rheem Creek is boxed-in by single family homes, with fences and backyards within 5-15 feet of the stream bank (Photo 5). At its widest, the riparian corridor is 25 feet from left bank to right bank. Our visual observations indicated that water quality was poor. In especially stagnant pools the water had a black, sludge-like appearance, with strong sulfur and sewer odors (Photo 6). Disturbing the sediment layer on the stream bed initiated the release of gases, which continued to bubble to the surface for several minutes. Garbage, including paint cans, spray paint bottles, shampoo and soda cans, was scattered in the stream and along the stream banks (Photo 7). Two dead rats were observed floating in the water (Photo 8). In one 400 foot stretch, we observed at least three homes with informal pipes that empty into the stream (Photo 9). The culvert that stretches beneath Fordham Street was submerged except for the top five inches (Photo 10).

Photo 5 – Rheem Creek in Rollingwood Neighborhood

Photo 6 – Stagnant water and unstable bank

Photo 7 – Garbage in Rheem Creek

Photo 8 – Dead rat in Rheem Creek

Photo 9 – Informal drain pipe from a house

Photo 10– Downstream opening of culvert at Fordham St

<u>Contra Costa College</u>

As Rheem Creek flows through the grounds of the College, the water quality and riparian corridor health are much improved from the conditions in the Rollingwood neighborhood. Within the first 150 feet, at the upstream reach of the College, there was minimal suspended sediment in the water, but a faint sewer odor could be discerned, not unlike that which plagued the Creek further upstream (Photo 11). Proceeding downstream from the first culvert on the College campus, the sewer odor was no long detectable and the water took on a grayish-brown color similar to that observed in the headwaters (Photo 12). This portion of the creek also had a relatively large riparian corridor, ranging from 20 to 80 ft in width, with abundant tree cover provided by non-native eucalyptus trees, and shading that was as high as high as 70-85%. Undercut banks were evident throughout the creek.

Photo 11 – Upstream extent of Contra Costa College campus, looking into the Rollingwood neighborhood

Photo 12 – Looking downstream at a debris-constricted culvert at bottom of Reach 1 on Contra Costa College campus

As in the headwaters and Rollingwood neighborhood, there were numerous stormwater drains emptying directly into the Creek. In the upper 550 feet of the College reach, we observed 7 stormwater pipes draining directly into the creek from parking lots, roads, and the valley flat (see Figure 5, in next section). Rheem Creek flows through 3 culverts in the stretch of creek that passes through the College, all of which were partially blocked by branches, woody debris, and trash. Photos 13– 22 capture the aforementioned characteristics. The College reach can be divided into five sub-reaches, which are discussed below.

Photo 13 – Bank erosion in Reach 1

Photo 14 – Creek overflow grate in Reach 2 (waypoint 28)

Photo 15 – Sackrete lined bank looking downstream from top of Reach 3

Photo 16 – Looking upstream from bottom of Reach 3

Photo 17 – Looking across to the valley flat from bottom of Reach 3

Photo 18 – Downstream end of culvert at Castro St. at top of Reach 4

Photo 19 – Looking downstream from top of Reach 4

Photo 20 – Tributary joining Rheem Creek at bottom of Reach 4

Photo 21 – Looking downstream from top of Reach 5

Photo 22 – Culvert at downstream end of Reach 5

Wanlass Park

Downstream of the College, Rheem Creek travels underneath San Pablo Avenue, and surfaces at Wanlass Park. Visually, there was no discernable difference in water quality between the turbid, grayish brown water that flowed through Wanlass Park and the College. A grazed or mowed meadow flanks the right bank of the Creek, while a gravel access road hugs the left bank approximately 8 feet from the stream. Dead grass at the streamside edge of the access road appeared to be killed using herbicides. At the downstream end of Wanlass Park, Rheem Creek enters a concrete channel, which crosses underneath 20th Street and continues through a residential neighborhood in its channeled form. Garbage was strewn along the stream and in the stream channel (Photos 23 – 25)

Photo 23 – Looking upstream toward San Pablo Ave in Wanlass Park

Photo 24 – Looking downstream at the 20th St. culvert

Photo 25 – Looking downstream from 20th St.

Breuner Marsh

After emerging from Giant Road, Rheem Creek flows through Breuner Marsh and enters San Pablo Bay. As it flows through Breuner Marsh, Rheem Creek parallels a dirt access road in a straightened channel with a consistent width of approximately 8 feet. Mixed native and non-native grasses dominate a flat, featureless landscape. The riparian corridor is hundreds of feet on either side (with the exception of the access road along the left bank) with promising potential to restore native vegetation and stream sinuosity. (Photo 26).

Photo 26 – Breuner Marsh looking downstream toward San Pablo Bay (*photo courtesy of the Natural Heritage Institute*)

An overview of the data gathered during the Creek walk is presented in Appendix B: Creek Walk Characterization Data.

Survey Results: Longitudinal Profile and Cross-Section

Moving downstream to upstream at the College reach of Rheem Creek, we identified five distinctive sub-reaches, which we will refer to as Reach 5, 4, 3, 2, and 1 (Figure 5).

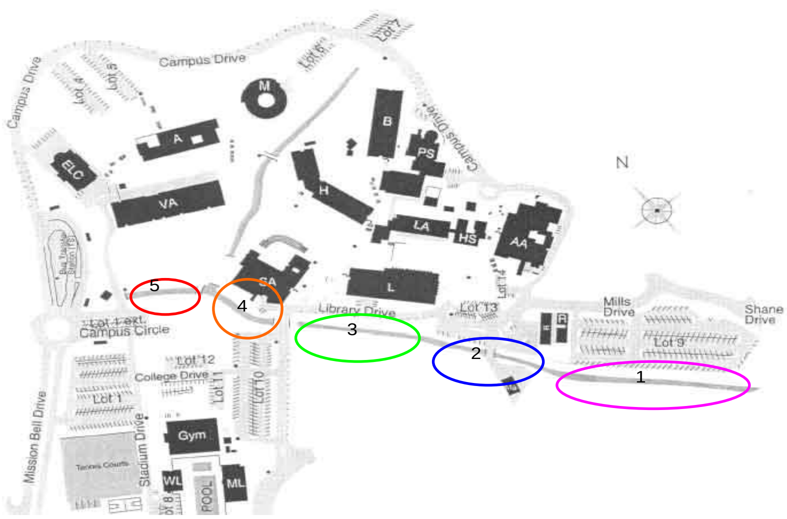

Figure 5 – Site map of Contra Costa College with the 5 sub-reaches that were identified

Our longitudinal profile stretched 816 feet. The site maps (Appendix C) highlight the reaches we surveyed on the College campus.

Key characteristics can be noted for each reach. In Reach 5 these include a gentle riffle characterized by embedded cobble and *diffuse aquatic vegetation, dominated by horsetails*. At 51.4 feet the channel widens to roughly 10 feet and the density of aquatic vegetation increases. There are also two distinct pools. Reach 4 has one pool, which stretches from the pedestrian overpass that extends from a parking lot adjacent to the right bank, to the student union building on the right bank. The stream maintains a consistent width of 3 to 4 feet and the water surface showed little variation from 260 ft to 379 ft. Also significant for Reach 4 was an evenly proportioned pool-riffle-pool-riffle-pool sequence.

Key attributes of Reach 3 are the"sackrete" slabs (concrete slabs that resemble sacks of sand) used to stabilize the right bank, and its fairly consistent width of approximately 5 feet. Our longitudinal profile ended at the top of a sharp bend where the stream channel is constricted to less than 2 feet in diameter and the flow is accelerated as a result of 50 feet of the right bank being lined with concrete. This high energy section of the reach begins 20 feet upstream of a 6 inch diameter stormwater pipe (the second turning point) on the left bank at 802 ft, and ends at 816 ft. These reaches are also described in more detail in Table 1.

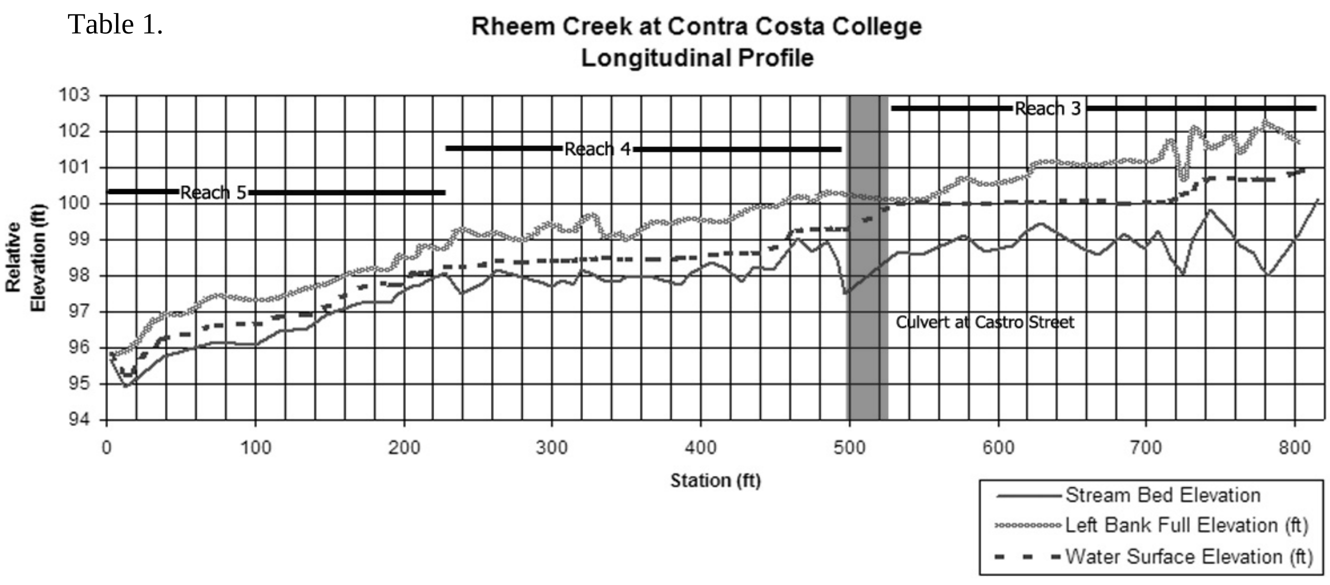

Figure 6 – Longitudinal Profile of Rheem Creek at Contra Costa College

Table 1 - Contra Costa College Reach Descriptions. Water Surface Elevation (WSE), Left Bankfull Elevation (LBF).

Upstream Extent of College

	Top of Reach	***Bottom of Reach***	***Key Characteristics***	***Length (ft)***	***WSE (ft)***	***Avg LBF height (ft)***	***Pool-Riffle*** *Length (ft) and (stations)*	***Vegetation***
Reach 1 *(not surveyed)*	Upstream Extent of College Campus	First Culvert						
Reach 2 *(not surveyed)*	First Culvert	Concrete re-enforced bend adjacent to the College Library						
Reach 3 533-802 feet.	Concrete re-enforced bend adjacent to the College Library.	Culvert at Castro Street by Student Union building	Borders with “sackcrete” slabs to stabilize bank. Channel width constant ~5 feet. Cross section taken at 612 feet.	283	.00329	2.44	None observed	Little in-channel vegetation. Riparian vegetation includes native and invasive grasses, horticulture shrubs on left bank, eucalyptus trees at ~15 intervals on left and right banks, and pines on right bank.
Reach 4 229-497 feet.	Culvert at Castro Street by Student Union building.	Bench on left bank, just downstream of pedestrian overpass	Upstream of tributary, channel width 3-4 feet.	269	.00394	1.46	**Pool 1:** 5 ft (224-249 ft) (stretches beneath pedestrian overpass Pool-riffle-pool-riffle-pool from 379-497 feet.	Left bank covered in English ivy, mix of tall trees. Right bank mixture of grasses, ivy, poison oak and mature trees.
Reach 5 0-228 feet.	Bench on left bank, just downstream of pedestrian overpass.	Culvert at Campus Circle/Mission Bell Drive	First 75 feet is continuous, gentle riffle, embedded cobble. Next 51.4 feet channel widens to ~10 ft.	228	.0108	0.96	**Pool 1:** 19 ft (181-200 ft) **Pool 2:** 8 ft (207-215 ft)	Diffuse aquatic vegetation (dominated by horsetails) in first 75 feet. Next 51.4 feet, density of vegetation increases.

Downstream Extent of College

Cross-Section, Discharge and Flood Frequency

At our cross-section site, the channel width is roughly 4.3 feet (Figure 6). During our rainy-day survey, the average depth of the cross-section was approximately 1.5 feet. A characteristic feature of the channel is the cross section's box-like appearance. Although one can observe a floodplain terrace on both sides of the creek, the valley floodplain is less steep on the left bank. Specifically, the gradient on the left bank is roughly 14%, and on the right bank it is roughly 24%. In terms of vegetation, it is worth noting that on the right bank, within a ten foot buffer of the cross-section, there was only one pine tree and one eucalyptus tree stump. The rest of the ground was exposed soil, with leaf litter. On the left bank, a mixture of grasses and ivy cover most of the area, with shrubs towards the end of the cross-section. Table D-1 and Figure D-1 (Appendix D) capture cross-section notes without vegetation drawing.

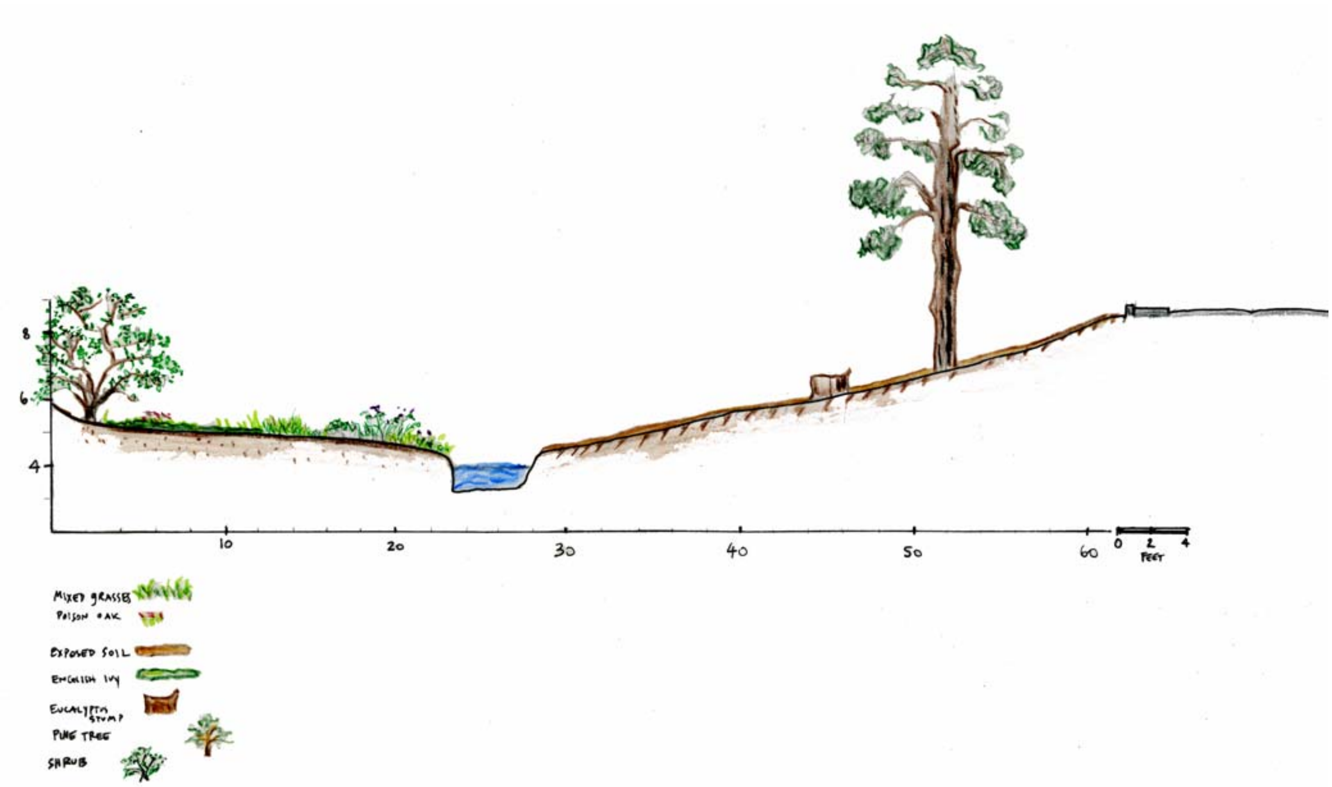

Figure 7 – Cross-section of Rheem Creek at 612 feet, in Reach 3 of Contra Costa College

At our cross-section, we calculated an average velocity of 0.74 ft/sec and a discharge of 1.4 cfs (see Appendix E). Based on the cross-section and the application of the Manning's equation, we estimate that discharge at *rainy-day* flow is approximately 1 cubic feet per second (cfs) with a velocity of 0.35 feet per second (ft/sec). At bankfull, we estimate discharge can reach 3 cfs, and a velocity of 0.43 ft/sec. These estimates were calculated using calculated n-values of 0.071 for both scenarios. Using the field-derived average velocity estimate of 0.74 ft/sec, the back-calculation estimates a discharge of 3 cfs, and an n-value of nearly 0.0 (see Appendix E).

Multiplying the watershed flood frequency values by our derived fraction of .64, for the portion of the watershed upstream of the College, our flood frequency analysis reveals Q2, Q10, Q100 values of 172, 229, 331 cfs, respectively. Compared to the flooding values for the entire watershed above the gage, these values are roughly 64% of the values for the entire watershed (area above gage).

Water Quality

Data on our water quality tests is included in Appendix F.

DISCUSSION

Creek Characterization

Our creek walk confirmed the presence of distinct zones along the length of Rheem Creek, both in terms of topography, channel form and vegetation, as well as in terms of human impact. The following discussion combines results from the creek walk with surveys taken at the College.

Headwaters

While the riparian vegetation at the headwaters of the creek appears to be predominantly native, the human land-use in the cemetery is likely to be causing erosion and sediment problems, which are likely being passed downstream. Increased runoff from the Cemetery road above the southern slope and removal of trees and vegetation are the most likely causes of slope instability. The downstream effects of this are important to consider, and are discussed below.

Rollingwood Neighborhood in a Comparative Context

The fact that the creek is visually more degraded in residential neighborhoods highlights a key challenge facing residents and stakeholders. As observed from the trash and informal drain pipes, point sources of pollution and contamination to the creek are most directly linked to easily accessible creek areas, such as those found at street crossings in residential neighborhoods. However, given that there are numerous poorly understood and undocumented sources of pollution both upstream and downstream such as stormwater pipes, brownfields in the lowlands, and the dumping of fill material in the headwaters, it would be inappropriate to consider the water quality in residential areas in isolation from other reaches of Rheem Creek.

Our results also highlight the fact that stream conditions in the residential neighborhoods are in sharp contrast to the conditions encountered as Rheem Creek flows through the College and Wanlass Park, where riparian corridors (of predominantly non-native vegetation 40 to 80 feet wide are serving as buffers that mitigate human impacts. Restoration of native riparian species could further improve the water quality and flow conditions at these sights.

The Creek at the College

Our survey at the College highlights the importance of considering the effects of the culverts and streambank modifications on channel conditions. The concrete lined culvert underneath Castro Street has resulted in the formation of a large pool (1.8 feet deep on the day we measured it) on the downstream end and a nick point resulting in a shallow pool on the upstream end of the pool. The culvert and road that separate Reach 3 from Reach 4, and the sackrete bend at 800 ft, appear to be having a significant effect on the flow and channel form of the Creek.

On a related note, the sackrete-lined right bank of Reach 3 appears to accelerate stream flow, resulting in deeper streambed depths and more variation in the streambed elevations. This is in contrast to the conditions of Reach 4 and Reach 5, where a wider floodplain appears to result in much less pronounced streambed elevation changes and shallower streambed depths (See figures G-1 and G-2 in Appendix G). In sum, human constructed gradient and channel width changes in the form of streambank reinforcement and culverts appear to be largely responsible for the hydrologic variance within and between reaches. Another indication that the hydrologic differences between the three reaches are due, in large part, because of the culvert and sackrete bank reinforcement is the difference in water surface elevation slopes. The emerging pool-riffle sequences in all three reaches *could* also be an indication that despite channelization and the presence of numerous stormwater pipes, Rheem Creek is regaining some of its original character.

Our flow estimates are useful indicators for understanding the creek's flow dynamics during a very rainy period. However, the results can not be used to make final conclusions regarding low-flow, or base-flow conditions. A future study is needed to gather data during low flow conditions, as well as during the winter rainy months. Such a comparison would be useful for understanding inter-seasonal variations.

Implications for Restoration Efforts

It is important to consider the above discussion in terms of the UCC's proposed restoration effort. Specifically, our results indicate that the restoration projects planned in the Rollingwood neighborhood and the College could benefit from considering the creek as an entire system. If implemented in isolation, the UCC's plan is well-designed to remove the invasive vegetation that is choking the stream channel, reduce flooding and improve water quality. However, when the upstream and downstream effects are considered, it is apparent that the Rollingwood neighborhood is only one piece of a complex system. The restoration effort should be informed by upstream conditions and potential downstream effects of the restoration project.

For example, it is important to consider the potential negative effects of vegetation removal. Assuming that the piles of dirt being dumped into the gulch in Rollingwood Cemetery and the thick in-stream vegetation slowing the flow of water in Rollingwood are a likely source of the accumulated sediments in Rollingwood, it is important to consider what may happen upon implementation of UCC's restoration project. When the stream channel is cleared in the Rollingwood neighborhood, a significant amount of the sediments and pollution that are currently stagnating in Rollingwood may flow more easily downstream to the College, the middle watershed, and eventually Bruener Marsh. This will have detrimental effects on water quality and could potentially exacerbate flooding in the Valley Flats immediately downstream of the Rollingwood neighborhood. A complete understanding of the effects will not be possible without a more in depth study on the sources of pollution and sediments that are currently aggrading in Rollingwood.

Following the potential increase of sediments in downstream reaches, the College longitudinal and cross-section survey results indicate that increased flow and sediment load would most likely accelerate the rate of sediment aggradation, increase the incidence of debris clogging the culverts, and exacerbate flooding at the school adjacent to the left bank of the creek. While it is difficult to make concrete conclusions from this study without conducting a modeling exercise on the flood height levels resulting from the Rollingwood restoration project, it is clear that the benefits described by the UCC should not necessarily be taken to apply to downstream reaches of the Rheem Creek.

In light of these points, we recommend that restoration plans for Rheem Creek be developed with a basin perspective, starting at the creek's source. If the piles of dirt in the cemetery are a source of the problem, then this needs to be addressed before, or concurrent to restoration efforts downstream that deal with the consequences (deposition, loss of flood capacity) of those piles of dirt.

Sources of Error and Uncertainty

Despite our attempt to quantify water quality, we recognize the limitations of this method. One point-in-time water test cannot be used to draw solid conclusions about the water quality of Rheem Creek. Therefore, perhaps more indicative than our water quality tests, were our visual observations of water quality. A more detailed study that focuses on macroinvertebrates as indicators of water quality, as well as water quality tests over time would offer more conclusive results. In addition, because this study did not quantify water quality effects from brownfields and general non-point sources, a future study would benefit from modeling the various sources of degradation and pollution. It is likely however, that a decrease in litter and stormwater pipes that drain into the creek would improve water quality in the absence of riparian buffers.

Finally, while the method used is adequate, flooding estimates should be taken as approximations to account for any sources of error. Also, due to a limited number of field days, we were not able to complete a longitudinal profile or more than one cross-section survey of Rheem Creek as it runs through the Contra Costa College campus. A future study would benefit by completing the longitudinal profile and surveying additional cross-sections.

CONCLUSION

An immediate result of this study is providing local stakeholders with timely baseline data that will inform Rheem Creek restoration efforts in the Rollingwood Neighborhood and at Contra Costa College, and be a useful benchmark for tracking changes in future years. Our study highlights the necessity to conduct more in depth studies on sediment and pollution transport in Rheem Creek and offers suggestions for Urban Creeks Council's proposed restoration. As noted by the College and the UCC, there exists the potential for a campus-wide stream restoration project. We recommend that such a plan attempt to remove or improve the culverts (specifically, their ability to transport water on high flow days), remove non-native vegetation, and have design efforts take into account the 5 separate reaches identified.

Investigations, such as this one, which provide stakeholders, planners and restoration groups with a more detailed understanding of the hydrology and channel form of area waterways are essential to the larger effort to improve the natural and built environments of the greater San Francisco Bay region.

ACKNOWLEDGEMENTS

We would like to thank the following people: Josh Bradt from Urban Creeks Council, for his time and mentoring on the project. Rich Walkling for his continued advice on the project scope and paper revisions. Aspen Madrone, of the Contra Costa County Citizens Monitoring Program for the use of field equipment and field training. Pam Boyle for her help in the field. Jessie Levine and the Natural Heritage Institute for access to the Watershed Assessment Report, and valuable pictures and GIS coverages of the study area. Matt Kondolf and our peer reviewers, Eric Zhang and Jennifer Hernandez for their insightful comments.

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APPENDIX A - *Longitudinal Profile Data - Contra Costa College*

Table A-1

Micah - tripod

Carolina - rod

Legend

SB - stream bed

RBF - right bank full

BM - bench mark

TP - turning point

WS - water surface

Top Riff - top of riffle

Bot Riff - bottom of riffle

3/21/2005 1:00pm - 5:00pm overcast, light rain increasing to heavy rain
frogs croaking

weather on previous days:

(read tape value)	STA	FS SB	FS LBF	BS	HI	EL (SB)	EL (LBF)	WS	SB - WS	EL (WS)	NOTES		
	BM1					100					upper right hand corner of culvert openning looking downstream		
				1.2	101.2	101.2							
	3	5.52	5.36			95.68	95.84	0.1	5.42	95.78			
	13	6.3	5.29			94.9	95.91	0.33	5.97	95.23			
	17	6.16	5.15			95.04	96.05	0.3	5.86	95.34	Bot Riff	2/3 of width is aquatic vegetation	
	38.4	5.45	4.28			95.75	96.92	0.49	4.96	96.24	Top Riff		
	51.5	5.29	4.27			95.91	96.93	0.47	4.82	96.38		*channel widens*	*one continuous riffle*
	73.4	5.04	3.75			96.16	97.45	0.45	4.59	96.61	Bot Pool		
	100.4	5.12	3.86			96.08	97.34	0.59	4.53	96.67	Top Pool		
	116	4.75	3.77			96.45	97.43	0.41	4.34	96.86	Bot Riff		
	135	4.67	3.54			96.53	97.66	0.4	4.27	96.93			
	148	4.3	3.42			96.9	97.78	0.22	4.08	97.12	Bot Riff		
	171	3.94	3.04			97.26	98.16	0.39	3.55	97.65	Top Riff	African and English Ivy	
	191.4	3.93	3.01			97.27	98.19	0.51	3.42	97.78	Mid Pool		Pool 181 - 200
	196	3.68	2.64			97.52	98.56	0.23	3.45	97.75	Bot Riff		
	206	3.5	2.68			97.7	98.52	0.36	3.14	98.06	Top Riff	Pool 207 - 215	
	211	3.45	2.39			97.75	98.81	0.34	3.11	98.09	Mid Pool		
	216.5	3.33	2.35			97.87	98.85	0.22	3.11	98.09	Bot Riff		
	228	3.1	2.41			98.1	98.79	0.14	2.96	98.24	Top Riff		
	238	3.7	1.89			97.5	99.31	0.75	2.95	98.25		Pool 224 - 249	
	253	3.4	2.08			97.8	99.12	0.49	2.91	98.29			
	TP1	2.61				98.59							
				7.24	105.83	105.83					tripod station 2		
	263	7.68	6.63			98.15	99.2	0.25	7.43	98.4	Pam on Rod		
	279.6	7.87	6.82			97.96	99.01	0.43	7.44	98.39			
	291.5	8	6.53			97.83	99.3	0.6	7.4	98.43			
	300	8.11	6.39			97.72	99.44	0.71	7.4	98.43			
	307	7.96	6.52			97.87	99.31	0.53	7.43	98.4			
	314.9	8.1	6.6			97.73	99.23	0.69	7.41	98.42			
	319.4	7.65	6.35			98.18	99.48	0.28	7.37	98.46			
	327	7.79	6.16			98.04	99.67	0.42	7.37	98.46			
	334.2	7.94	6.72			97.89	99.11	0.61	7.33	98.5			
	344.7	8.01	6.68			97.82	99.15	0.64	7.37	98.46			
	350	7.82	6.82			98.01	99.01	0.43	7.39	98.44			
	368.6	7.88	6.34			97.95	99.49	0.49	7.39	98.44			

Continued on next Page

(read tape value)	STA	SB	LBF	BS	HI	EL (SB)	EL (LBF)	WS	SB - WS	EL (WS)	NOTES		
	382	8.05	6.37			97.78	99.46	0.69	7.36	98.47			
	386.3	8.1	6.3			97.73	99.53	0.75	7.35	98.48	Mid Pool	Riffle 403 - 412	
	393.8	7.74	6.25			98.09	99.58	0.4	7.34	98.49	Top Pool		
	407.8	7.46	6.3			98.37	99.53	0.23	7.23	98.6	Mid Riff		
	417	7.62	6.31			98.21	99.52	0.42	7.2	98.63			
	427.6	8.01	6.1			97.82	99.73	0.82	7.19	98.64	Mid Pool		
	436.1	7.6	5.9			98.23	99.93	0.4	7.2	98.63	Top Pool		
	448.4	7.66	5.92			98.17	99.91	0.56	7.1	98.73	Bot Riff		Pool 469.4 - 480.4
16	465.4	6.79	5.64			99.04	100.19	0.2	6.59	99.24	Top Riff, Bot Pool		
26	475.4	7.17	5.74			98.66	100.09	0.62	6.55	99.28			
36	485.4	6.86	5.49			98.97	100.34	0.32	6.54	99.29			
42.5	491.9	7.39	5.53			98.44	100.3	0.88	6.51	99.32			
47.7	497.1	8.33	none			97.5	#VALUE!	1.8	6.53	99.3	in front of base of right culvert openning looking upstream		
	TP1	7.24				98.59							
				4.05	102.64	102.64							
	BM1			2.68		99.96							

3-22-05, 10:20am - 1:30pm, light to heavy rain, heavy rain throughout the previous night

Micah - tripod, Carolina - rod

lower right corner of the culvert arm extension looking downstream from the tripod

(read tape value)	STA	FS SB	FS LBF	BS	HI	EL (SB)	EL (LBF)	WS	SB - WS	EL (WS)	NOTES		
	BM2			2.87	106.115	103.245							
4.3	533.3	7.45	none			98.665	#VALUE!	1.32	6.13	99.985			
4.3	533.3	7.75	none			98.365	#VALUE!		7.75	98.365	height of culvert		
4.3	533.3	3.43	none			102.685	#VALUE!		3.43	102.685	height of culvert openning		
20	549	7.53	6.01			98.585	100.105	1.44	6.09	100.025			
48	577	6.99	5.42			99.125	100.695	0.86	6.13	99.985			
62	591	7.45	5.56			98.665	100.555	1.35	6.1	100.015			
81	610	7.28	5.43			98.835	100.685	1.19	6.09	100.025	odd water depth value (0.19) Adjusted to 1.19		
90.4	619.4	6.86	5.33			99.255	100.785	0.79	6.07	100.045	stream narrows		
100	629	6.65	4.96			99.465	101.155	0.56	6.09	100.025	bot of wide section	slope at x- section (from 533-717):	
129	658	7.36	5.03			98.755	101.085	1.32	6.04	100.075	X sec location	0.048992923	
139	668	7.54	5.05			98.575	101.065	1.49	6.05	100.065			
156	685	6.93	4.91			99.185	101.205	0.83	6.1	100.015			
169.3	698.3	7.38	4.94			98.735	101.175	1.3	6.08	100.035			
179.5	708.5	6.85	4.85			99.265	101.265	0.78	6.07	100.045			
188	717	7.64	4.39			98.475	101.725	1.6	6.04	100.075			
196	725	8.07	5.45			98.045	100.665	2.21	5.86	100.255			
202	731	7.09	4.09			99.025	102.025	1.4	5.69	100.425	Bot Riff		
214	743	6.28	4.58			99.835	101.535	0.86	5.42	100.695	Top Riff		

Continued on Next Page

		FS	FS										
(read tape value)	**STA**	**SB**	**LBF**	**BS**	**HI**	**EL (SB)**	**EL (LBF)**	**WS**	**SB - WS**	**EL (WS)**	**NOTES**		
227.5	756.5	6.91	4.25			99.205	101.865	1.5	5.41	100.705			
233.5	762.5	7.27	4.7			98.845	101.415	1.83	5.44	100.675			
243	772	7.48	4.1			98.635	102.015	2.02	5.46	100.655			
248.5	777.5	7.91	4.03			98.205	102.085	2.49	5.42	100.695			
253.5	782.5	8.11	3.88			98.005	102.235	2.66	5.45	100.665	6 in diameter culvert at Leftt Bank		
	TP2	3.47				102.645							
				10.48	113.125								
273	802	13.98	11.41			99.145	101.715	1.73	12.25	100.875	Bot of Hydraulic jump		
287	816	13.01	none			100.115	#VALUE!	1	12.01	101.115	Top of Hydraulic		
358	887	14.02	11.02			99.105	102.105	0.52	13.5	99.625	Not included in long profile graph		
	TP2			10.46		102.665							
				4.3	106.965								
	BM2			3.75		103.215							

APPENDIX B – *Creek Characterization*

Table B-1

	Headwaters			Upper Watershed					Middle Watershed
Location Name	**Cemetery Top**	**Cemetery Mid**	**Cemetery Bot**	**Rolling Wood (Shane and Fordham)**	**CC College Reach 1 -2**	**CC College Reach 3**	**CC College Reach 4**	**CC College Reach 5**	**Wanless Park**
Position			10 S 559785 4202965	10 S 558615 4202295	10 S 558262 4202499	10 S 558157 4202596	10 S 558048 4202699	10 S 557977 4202741	10 S 557658 4202954
Elevation (ft)			196	85	75	63	56	52	11
Channel Width at Water Level	1-2 ft	5-8 ft	4 ft	3-4.5 ft	3-5 ft	1-4 ft	2-5 ft	4-6 ft	4-6 ft
Channel Depth from Top of Bank	<0.5 ft	0.5-1.0 ft	1 ft	5-6 ft	4 ft	4 ft	2-4 ft	1-2 ft	2-4 ft
Bed Material	clay and sand	clay and sand	clay and sand, <10% cobble	clay, sand, embedded cobble	mostly sand, clay, ~35% cobble	sand, cobble	sand, 4-12in diameter cobble	clay, sand, impacted cobble	cobble and sand
Channel Description	no surface water	marshy, pools of water	earthen channel merging into concrete	stagnant, vegetation clogged, straightened	straightened, earthen channel	straightened earthen channel	marginally sinuous, earthen channel	straightened earthen channel	marginally sinuous, earthen channel
Evidence of Erosion	no	right bank sloughing	chain link fence preventing erosion on right bank	-	sharp bank incision at bends	incising on left bank, surface erosion on right bank	sharp bank incision at bank edge	-	-
Understory Vegetation Species	poison oak, blackberry, grasses	poison oak, blackberry,	shrubby willows, bare understory	reeds, cattails, grasses on stream bank and in stream channel	invasive grasses and groundcover	invasive grasses, ivy, (*Hedera helix* and *Delairea odorata*)	invasive grasses and groundcover, ivy, (*Hedera helix* and *Delairea odorata*),	invasive grasses, ivy, (*Hedera helix* and *Delairea odorata*), horsetails, cattails, aquatic vegetation	invasive and native grasses, aquatic vegetation in stream channel
Riparian Corridor Width	400 ft	400 ft	400 ft	15-25 ft	15 ft	20 - 40 ft	60-80 ft	60 ft	8 ft left bank, 10 - 200 ft right bank
Trees Species		willow, valley oak		-	Eucalyptus (*Eucalyptus globulus*)	Eucalyptus (*Eucalyptus globulus*) + pine	Eucalyptus (*Eucalyptus globulus*) +	Eucalyptus (*Eucalyptus globulus*) + cottonwood	none
Tree Cover	15%	40%	90%	0%	10%	20%	25%	5%	0%
Tree Height	30 ft	30 ft		-	100 ft	100 ft	100 ft	100 ft	-
Percent Shading	40%	80%	70%	0	10%	30%	65%	10%	0
Wildlife/Animals		dead deer	deer scat	2 dead rats, house cats, dogs	squirrel, house cats	bumble bee		-	mallard ducks
Human Impact	sediments eroding from East slope	-	chain link fence, culvert under I-80, garbage,	wood retaining wall, abundant garbage in stream and on streambank,	garbage on stream bank			garbage on stream bank	gravel service road with evidence of herbicide use, grazed pasture,
Pipes	pipe draining the South slope	-	pipes draining the South and North slopes	numerous pipes draining single family residences' backyards	stormwater pipes draining school district and college vehicle garage	stormwater pipe draining college parking lot, stormwater grate draining school district, 2 stormwater pipes draining school district	stormwater pipe from College drive next student union		-
Water Description	clear	cloudy with fine sediment	cloudy with fine sediment	black, sulfur and sewer smell, gas bubbles	minimal suspended sediment, faint sewer odor	turbid, grayish-brown, traces of oil on surface, acrid chemical smell	turbid, grayish-brown	turbid, grayish-brown	turbid, grayish-brown

Table B-2 - Waypoint Descriptions

Waypoint	Position	Elevation (ft)	Distance from Headwaters (meters)	Description
20	10 S 559891 4202922	83	122	Streambed
21	10 S 559785 4202965	196	231	concrete channel at upstream end of I-80 culvert
22	10 S 559795 4202924	216	202	top of slope
23	10 S 559976 4202835	229	0	side of cemetery road (top of slope)
24	10 S 558615 4202295	85	1464	culvert on Fordam Street (near Shane)
25	10 S 558262 4202499	75	1734	upstream limit of CC College property
26	10 S 558275 4202468	54	500	stormwater pipe in creek
27	10 S 558238 4202527	60	1765	stormwater pipe draining parking lot
28	10 S 558212 4202553	45	1786	creek overflow grate on left bank
29	10 S 558157 4202596	49	1835	stormwater pipe on left bank
30	10 S 558085 4202646	63	1900	top of reach 4 of CC College, on bridge/culvert
31	10 S 558048 4202699	56	1933	tributary on right bank
32	10 S 557977 4202741	52	2001	downstream end of reach 5, CCC, on top of culvert
33	10 S 557593 4203071	6	2395	downstream end of Wanless Park, two drain pipes
34	10 S 557658 4202954	11	2321	upstream end of Wanless park
35	10 S 556941 4203322	27	3074	11th street culvert/bridge

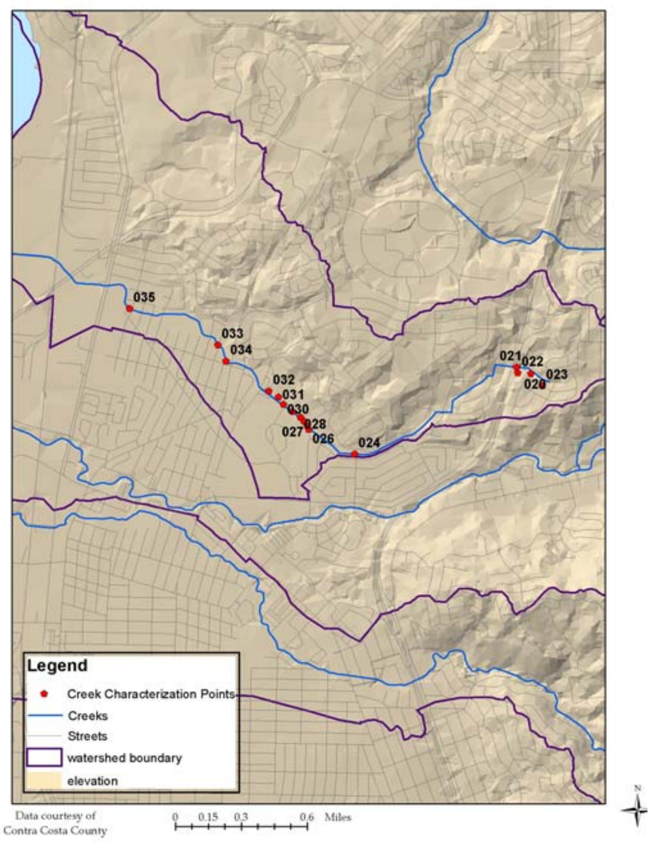


Figure B-1 – Creek Characterization Points

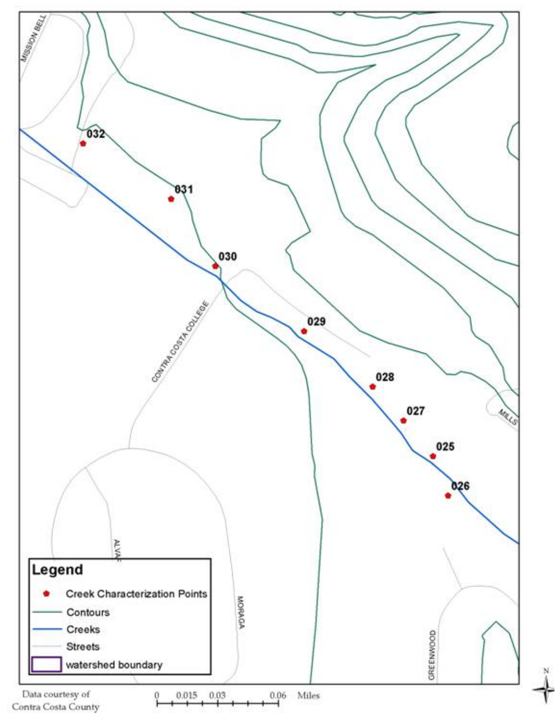


Figure B-2 – Creek Characterization Points at Contra Costa College

APPENDIX C – *Site Maps, Contra Costa College*

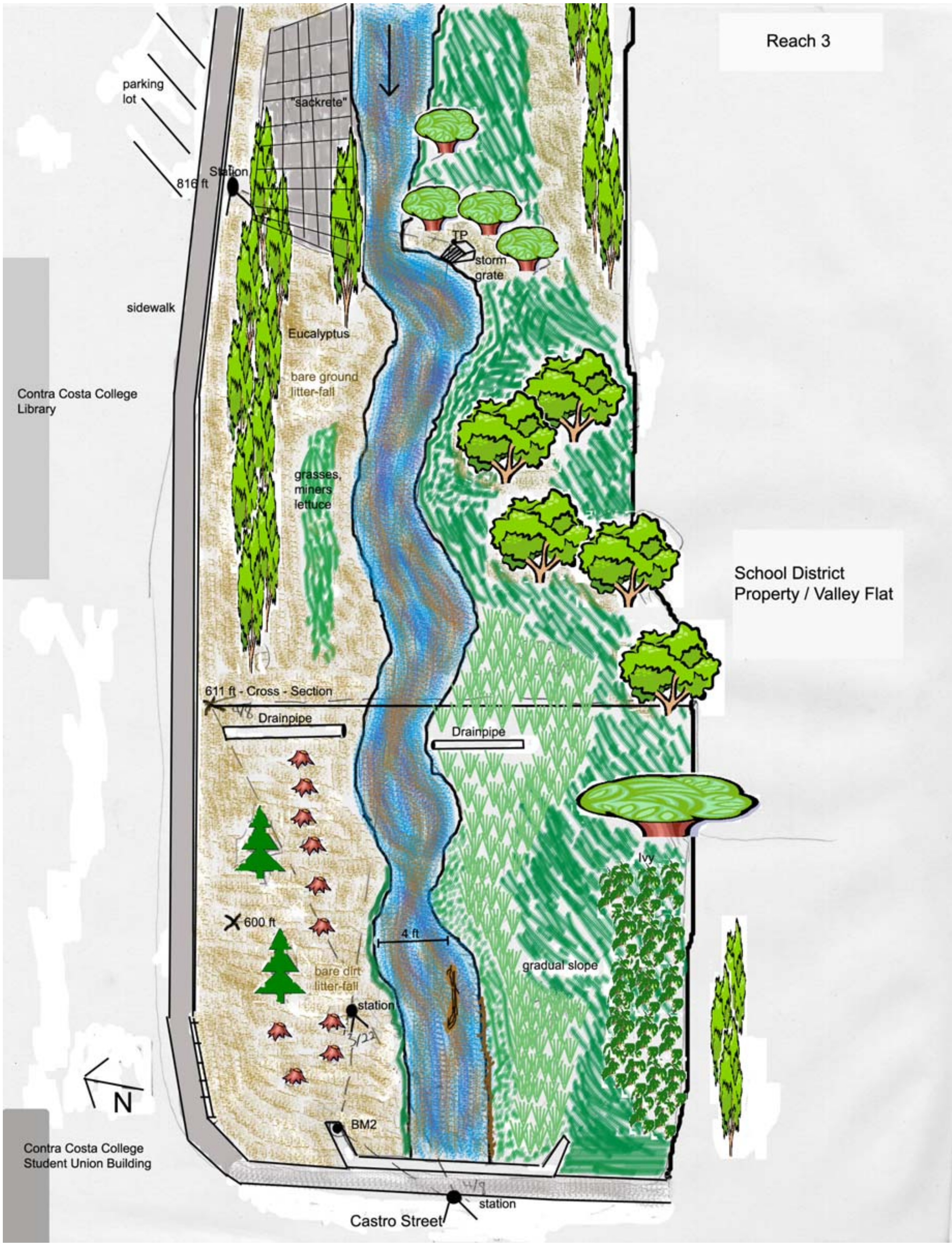


Figure C-1 – Reach 3 of Contra Costa College

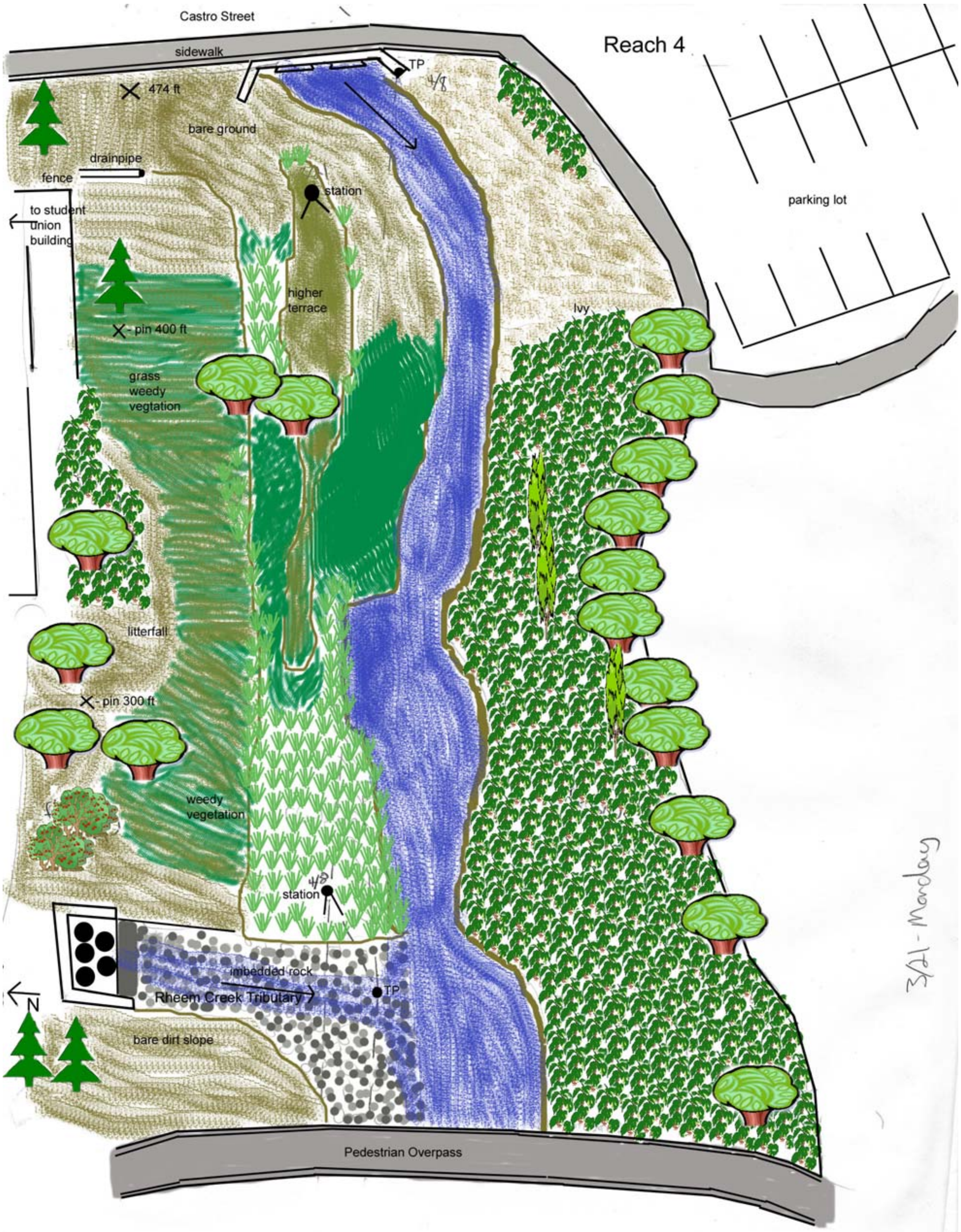


Figure C-2 – Reach 4 of Contra Costa College

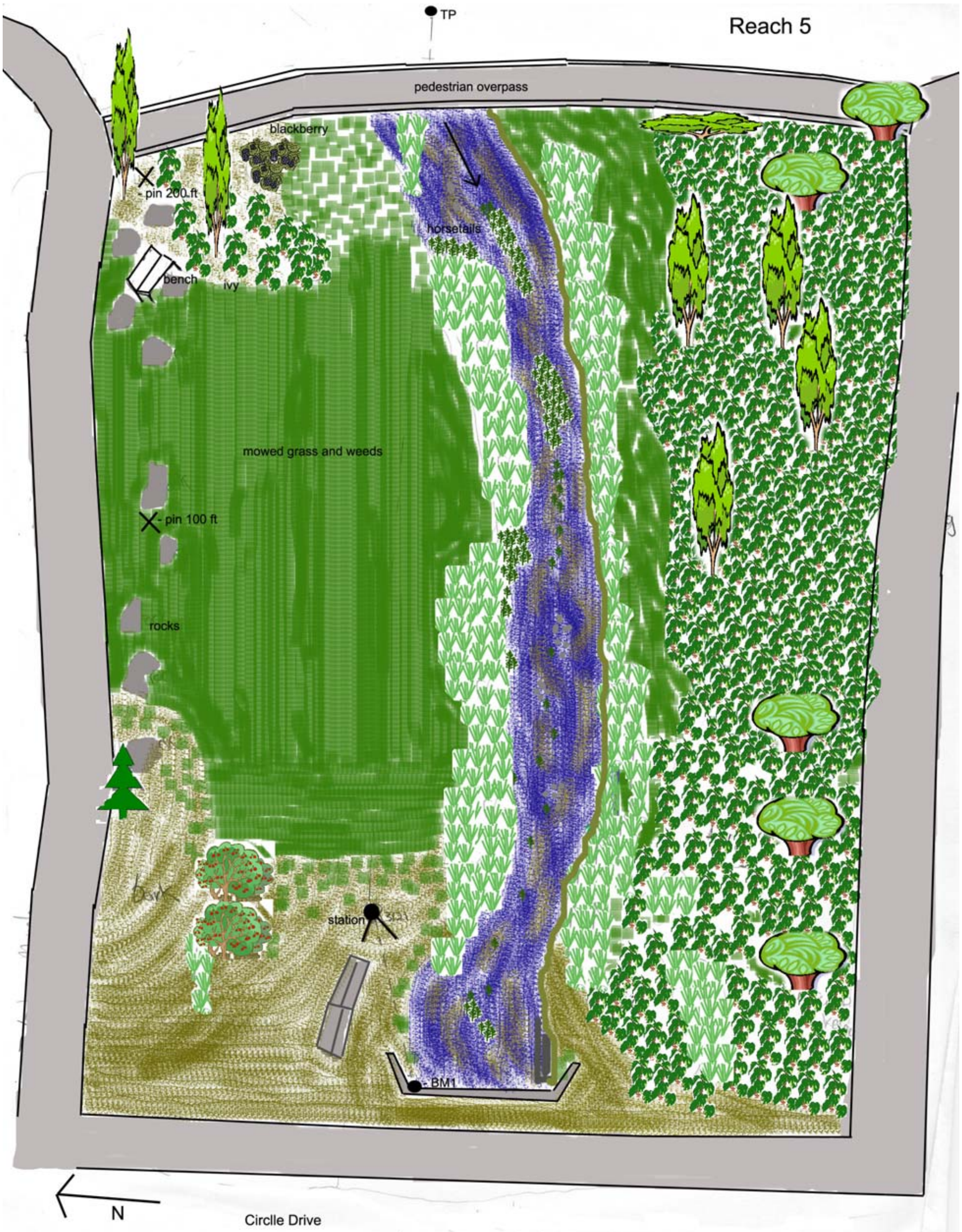


Figure C-3 – Reach 5 of Contra Costa College

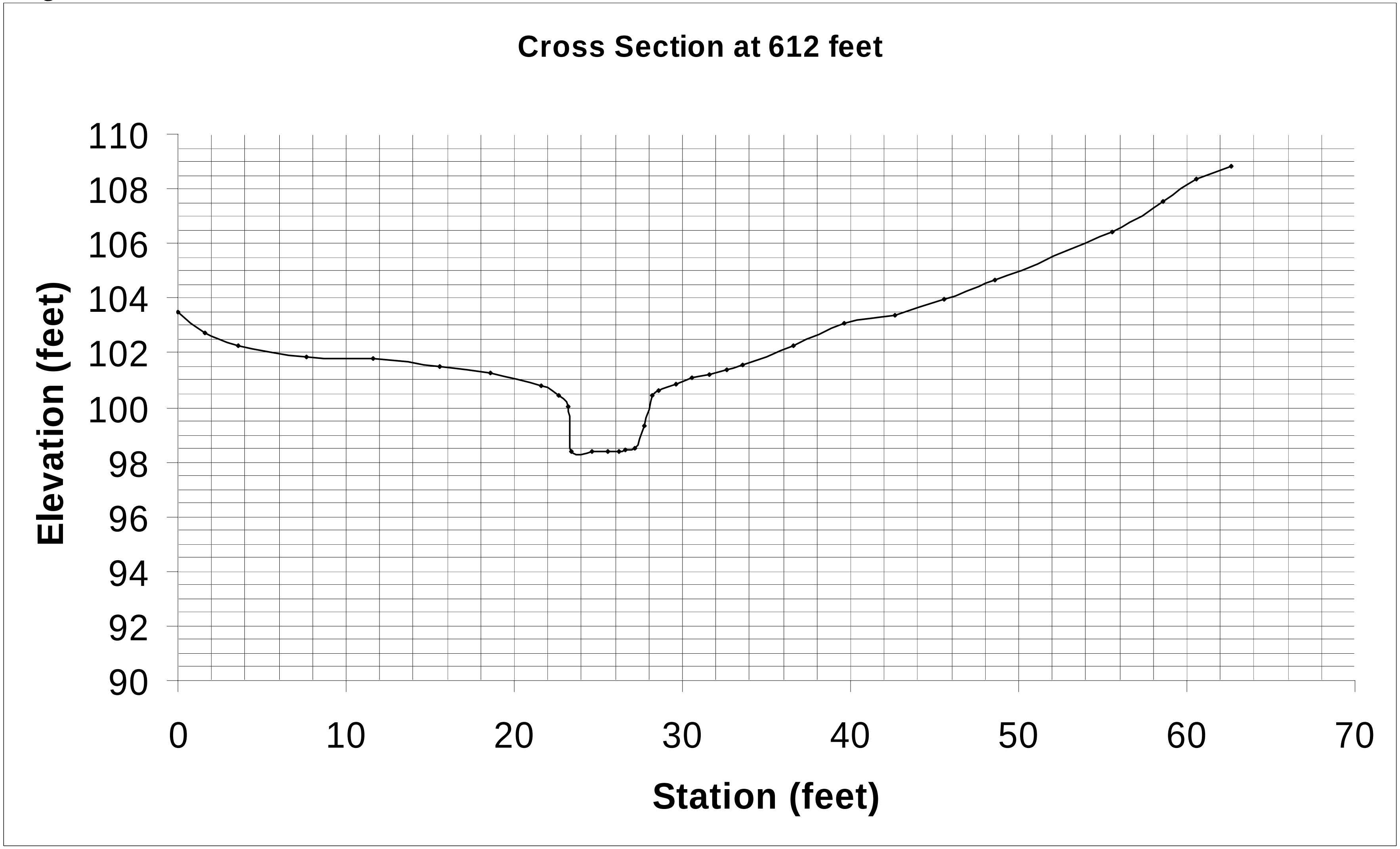
APPENDIX D – *Cross Section Notes*

Table D-1

Cross Section - *612 feet on the tape - same tripod placement as 660 feet on the long profile (BM2) - -looking up stream from left to right bank - long profile was paused to conduct x-section*

From LB to RB	STA	BS	FS	HI	EL	WS	FS - WS	EL (WS)	Notes
				110.67					
64.2	0		7.19		103.48				LB Fence Edge, 7th pole from street
62.6	1.6		7.93		102.74				
60.6	3.6		8.4		102.27				
56.6	7.6		8.8		101.87				
52.6	11.6		8.9		101.77				
48.6	15.6		9.15		101.52				
45.6	18.6		9.41		101.26				
42.6	21.6		9.87		100.8				
41.6	22.6		10.22		100.45				
41	23.2		10.63		100.04				LB Bank Edge
40.8	23.4		12.3		98.37	0.98			LB Edge Water
39.6	24.6		12.27		98.4	1			
38.6	25.6		12.28		98.39	1			
38	26.2		12.26		98.41	0.99			
37.6	26.6		12.25		98.42	0.98			
37	27.2		12.19		98.48	0.93			
36.5	27.7		11.32		99.35	0.06			RB Edge Water
36	28.2		10.22		100.45				RB Bank Edge
35.6	28.6		10.05		100.62				
34.6	29.6		9.84		100.83				
33.6	30.6		9.6		101.07				
32.6	31.6		9.48		101.19				
31.6	32.6		9.28		101.39				
30.6	33.6		9.09		101.58				
27.6	36.6		8.43		102.24				
24.6	39.6		7.6		103.07				
21.6	42.6		7.28		103.39				
18.6	45.6		6.72		103.95				
15.6	48.6		6		104.67				
8.6	55.6		4.22		106.45				
5.6	58.6		3.15		107.52				
3.6	60.6		2.3		108.37				
1.6	62.6		1.83		108.84				

Figure D-1


Cross Section at 612 feet
Elevation (feet)
110
108
106
104
102
100
98
96
94
92
90
0
10
20
30
40
50
60
70
Station (feet)

APPENDIX E – *Discharge and Flood Frequency*

Table E-1. Discharge and average velocity estimates.

Sta	Width	Depth	Area	Rev	Time
44.4	0.5	0.25	0.125	15.75	30
44.9	0.5	0.33	0.165	14	30
45.4	0.5	0.39	0.195	24.75	30
45.9	0.5	0.39	0.195	19.5	30
46.4	0.5	0.41	0.205	26	30
46.9	0.5	0.43	0.215	24.5	30
47.4	0.5	0.35	0.175	28.75	30
47.9	0.5	0.32	0.16	25	30
48.4	0.5	0.42	0.21	25	30
48.9	0.5	0.48	0.24	16.5	30
Total			1.885		
Average velocity	0.74				

MANNINGS RESULTS

v=c(s^.5R^.67)/n

Site	Q (cfs)	V	R	C
Low Flow (Rain flow)	1	0.35	0.7	1.49
Bankfull	3	0.43	0.9	1.49
Back Calculation	3	0.74	0.7	1.49
Valley Top	62	0.68	1.9	1.49

1 rectangle=1 ft2

Table E-3. Back-up calculations for n* estimates

	Low Flow	Bankfull	
n			
n0:(material involved)	0.026	0.026	
n1: (Degree irregularity)	0.01	0.01	
n2: (Variations)	0.005	0.005	
n3: (Obstructions)	0.02	0.02	
n4: (Vegetation)	0.01	0.01	
m5: (Meandering)	1	1	
N	0.071	0.071	.049 (from pictures)

Table E-4. Comparison of flood frequency values.

	Upstream of Gage	Upstream of College
Q2	270	171.99
Q10	360	229.32
Q100	520	331.24
Qmaf	290	184.73

	Planimeter	In square miles	Fraction of Area above Gage
Total Area	11.44	1.657971014	
Area above gage	9.1	1.31884058	
Area above College	5.8	0.84057971	0.637363

APPENDIX F – *Water Quality*

Water Quality

Figures F-1, F-2, F-3, and F-4 show the results from our point-in-time water quality samples at the Headwaters, Rollingwood, the College, and Breuner Marsh. Temperature and pH were the lowest at the headwaters. It is worth noting that the headwaters was consistently in lower ranges of measured water quality values, while Breuner Marsh was typically in the higher ranges. Rollingwood and the College oscillated between the extremes, sometimes surpassing the upper values. The nitrate test showed that, at most, there was .01 parts per million (ppm) of Ammonia in all four sites, with no difference between the results at each site.

Table F-1. Water quality results for four sampling sites along Rheem Creek.

Site	Temp (˚C)	pH	DO (µg/L)	Conductivity	Ammonia
Headwaters	13.90	7.52	8.40	654	< or = 0.13
Rollingwood	15.17	8.02	8.47	751	< or = 0.13
Community College	14.63	7.76	8.52	1149	< or = 0.13
Breuner Marsh	14.80	7.98	9.80	1060	< or = 0.13

Figure F-1. Temperature trends for four sites.

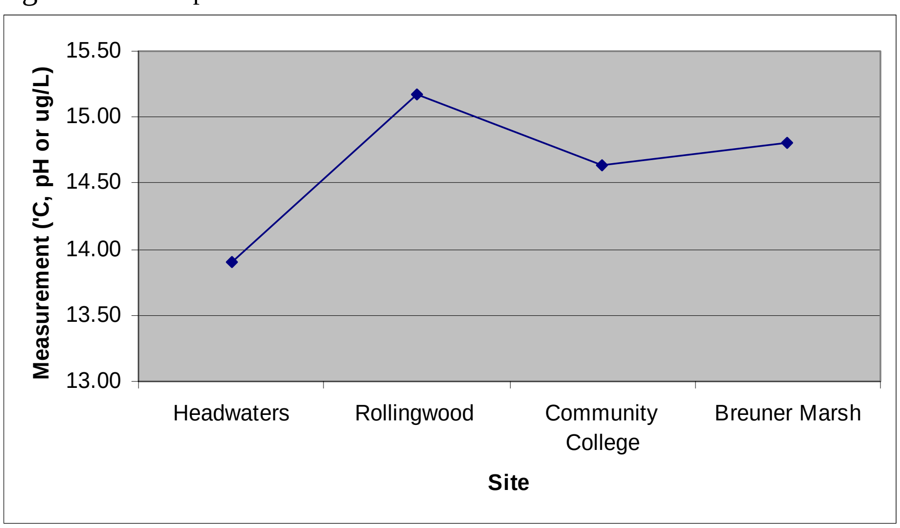


Figure F-2. pH trends for four sites.

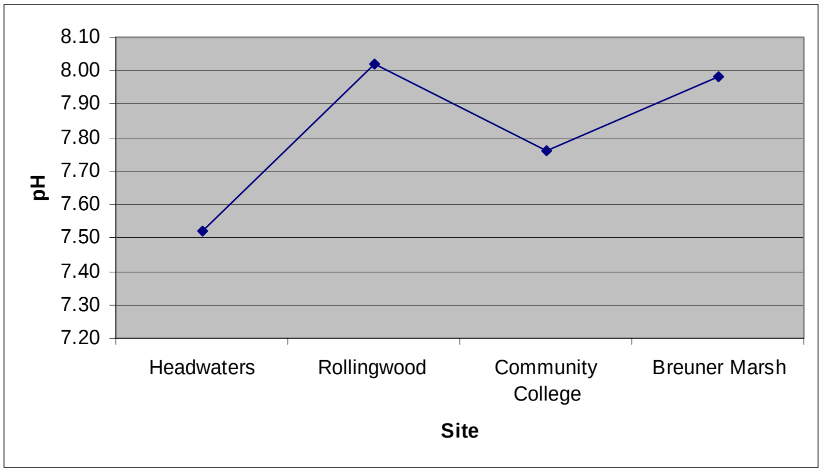


Figure F-3. Dissolved oxygen trends for four sites

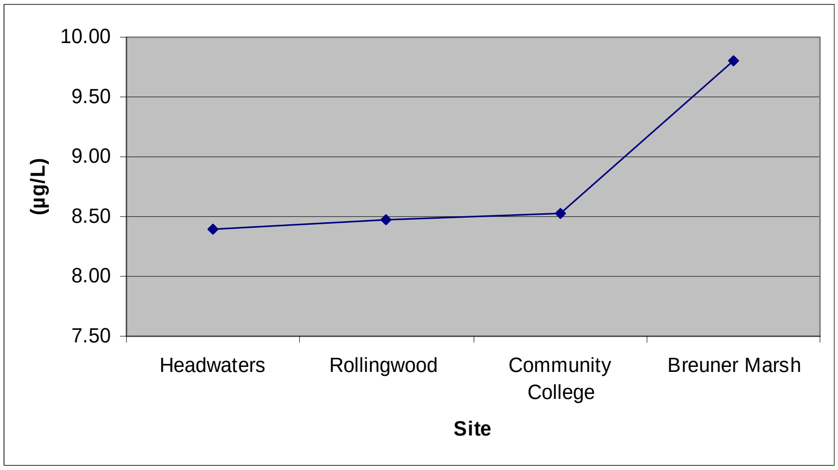
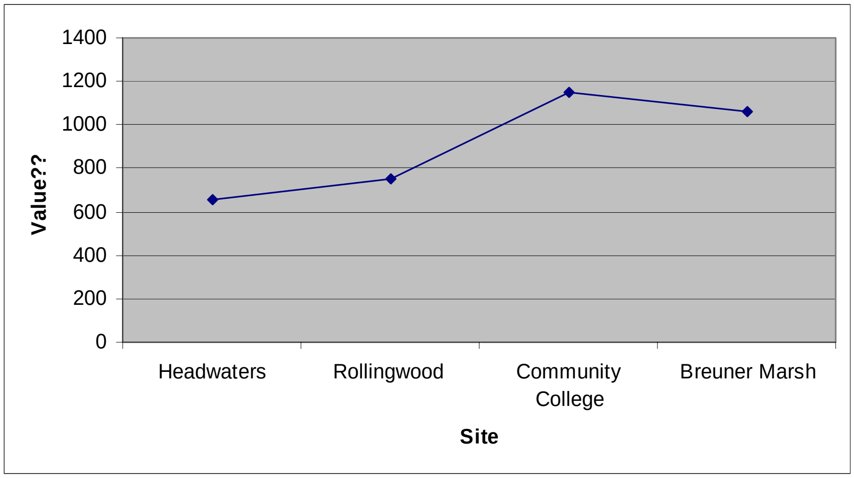


Figure F-4. Conductivity trends for four sites.



APPENDIX G – *Longitudinal Profile Supplemental Graphs*

Figure G-1 – Pool Riffle Sequence on Reaches 5, 4, and 3 at Contra Costa College

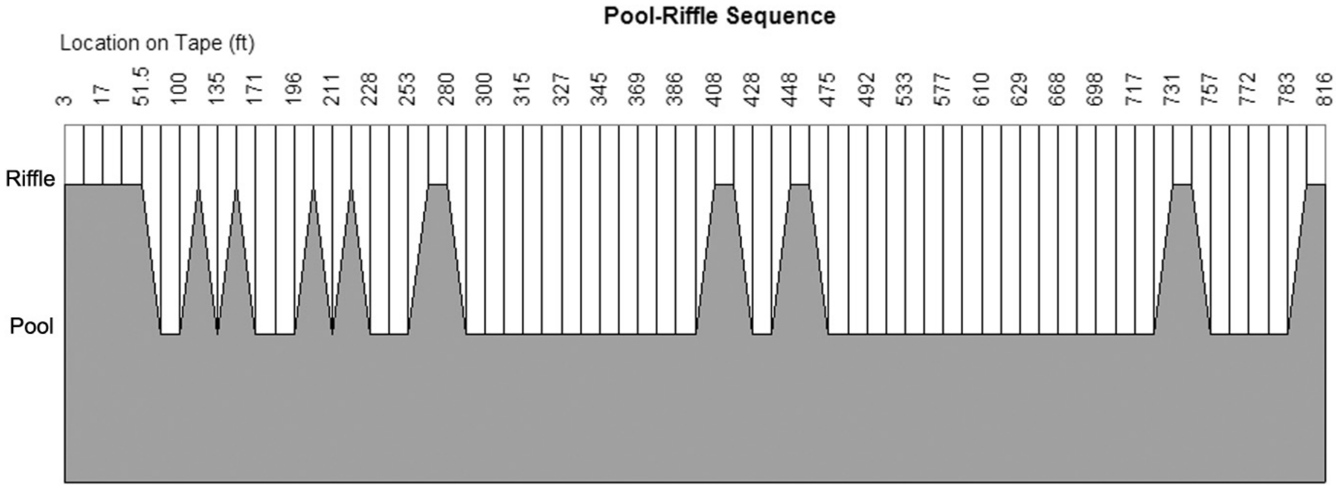


Figure G-2 – Stream Bed Depth on Reaches 5, 4, and 3 at Conta Costa College.

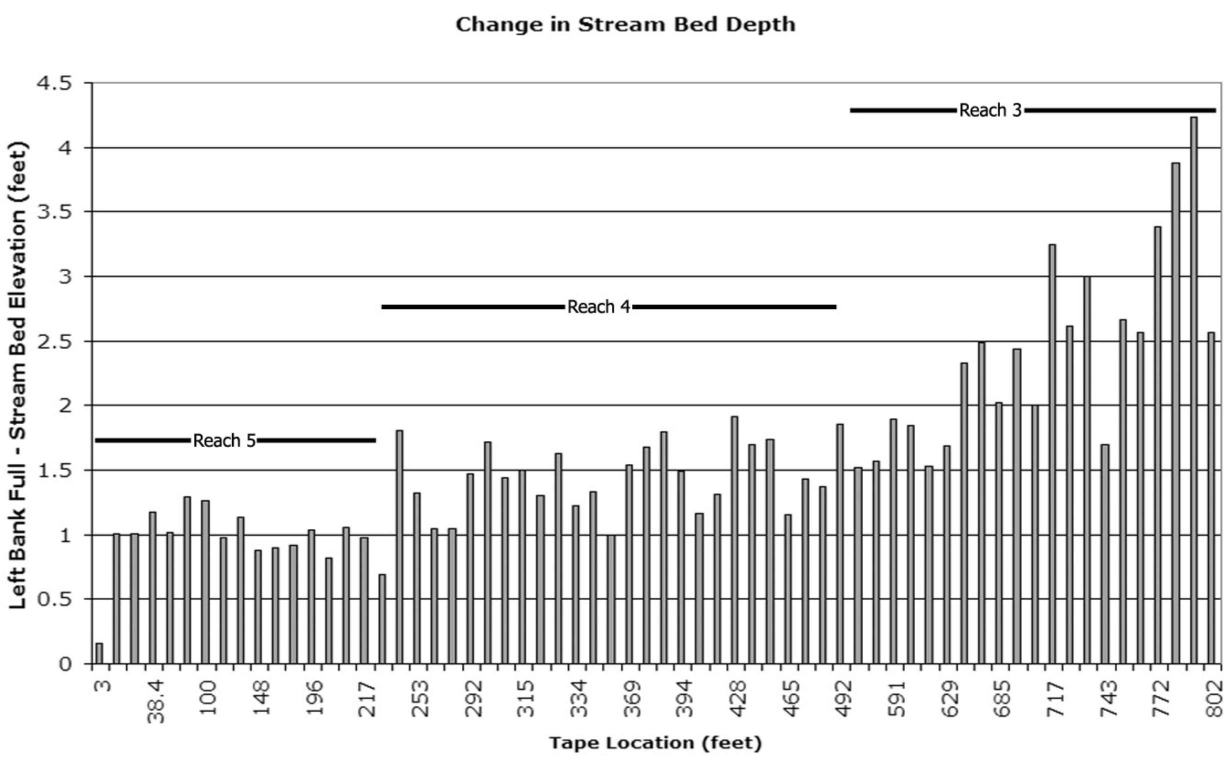
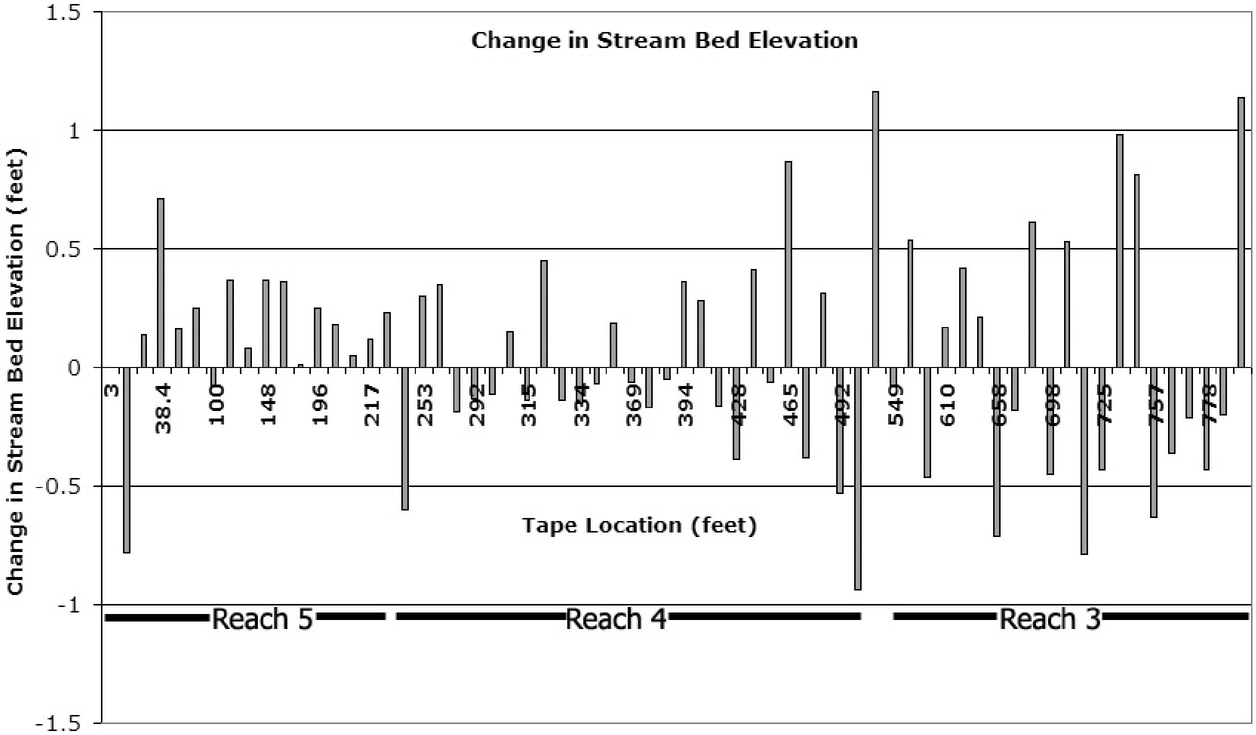


Figure G-3 – Change in Point-to-Point Stream Bed Elevation on Reaches 5, 4, and 3 at Conta Costa College.



Benchmark 1

Photo G-1 – Benchmark 1, at downstream extent of Reach 5

Benchmark 2

Photo G-2 – Benchmark 2, at downstream extent of Reach 3