Channel Cross-Section Analysis in Alhambra Creek

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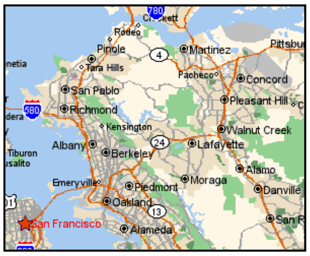
Abstract Land use in the Alhambra Creek Watershed, located in Contra Costa County, California, has changed over the past 50 years in some areas from cropland and rangeland to residential subdivisions and urban development. The effects of urbanization on watershed hydrology and stream geomorphology have been extensively explored. Streams in urban watersheds tend to increase in cross-sectional area, as changes in runoff-generating mechanisms result in larger peak flows than in non-urban watersheds. These geomorphic changes can have serious detrimental effects on both the quality of aquatic habitat and the stability of infrastructure and bridges. This study investigates historical channel changes in Alhambra Creek, focusing on the question of whether or not channel incision and expansion has occurred due to hydrologic changes since the 1950s. To answer this question, I resurveyed ten channel cross-sections and compared them to 1955, 1962, and 1971 cross-sections. I found that minor channel changes have occurred, including both local channel expansion and contraction. Due to the prevalence of bank revetment in my study reaches, it is difficult to determine if the observed changes in the past 30 to 50 years are a result of changes in hydrologic processes, recent and past efforts to stabilize the channel, or a combination of these factors. Surveying limitations and small sample size also affected the statistical strength of my results. Based on my understanding of the available current and historical cross-section data, I conclude that the Alhambra Creek channel morphology is generally stable, excluding local erosion problems exacerbated by in-stream structures.

Introduction

Urbanization and land development can have a variety of effects on watershed hydrology and stream geomorphology. Urbanization increases drainage density by replacing natural runoff routes with impermeable surfaces, streets, and stormwater drains. The more efficient drainage systems in urbanized watersheds result in an altered runoff regime with shorter lag times and higher peak discharges than in non-urban watersheds (Dunne and Leopold 1978). The increased frequency and magnitude of discharges in urbanized watersheds can cause channel enlargement over a wide range of temporal and spatial scales (Hammer 1972). Channel enlargement can occur through quasi-equilibrium expansion, where increases in discharge yield approximately proportional increases in channel width and depth. Channel enlargement can also occur through incision, or rapid channel deepening disproportional to the increase in discharge (Booth 1990). Channel incision is a common geomorphic response to increased peak runoff and sediment yields initiated by intense landscape disturbance; incision enables the channel to transport increased sediment load by increasing flow velocities and channel gradient (SFEI 2001).

Channel incision can lead to severe ecological and economic consequences. The floodplains of incised channels are flooded much less frequently than are floodplains of non-incised channels. Following incision, larger and larger flows are contained in the deepened channel, and more and more excess hydraulic energy erodes the channel bed and banks, leading to channel widening. This positive feedback mechanism prevents recovery of the pre-incised channel form. Incised channels rarely re-occupy their pre-incision floodplain. This reduction in overbank flows can disturb nutrient transport between the channel and the floodplain, adversely affecting riparian plant and benthic macro-invertebrate communities (Shields et al. 1994). Sediment produced from bank failures in incised river systems can affect local and downstream water quality (Ward and Stanford 1995, Thorne 1999). Incision can also have economic effects. Bank erosion and slumping can undermine bridges and other structures and threaten homes, creating an expensive maintenance problem for local government and creek-side property owners.

Watershed History The Alhambra Creek Watershed (Figure 1), in Contra Costa County, California, like many other San Francisco Bay Area watersheds, has experienced intense anthropogenic disturbances in the past few centuries. Cattle grazing was the predominant land use in the watershed during the early 1800's following the establishment of Mexican Land Grants (Alhambra Creek WPG 2001). After the City of Martinez incorporated in 1849,



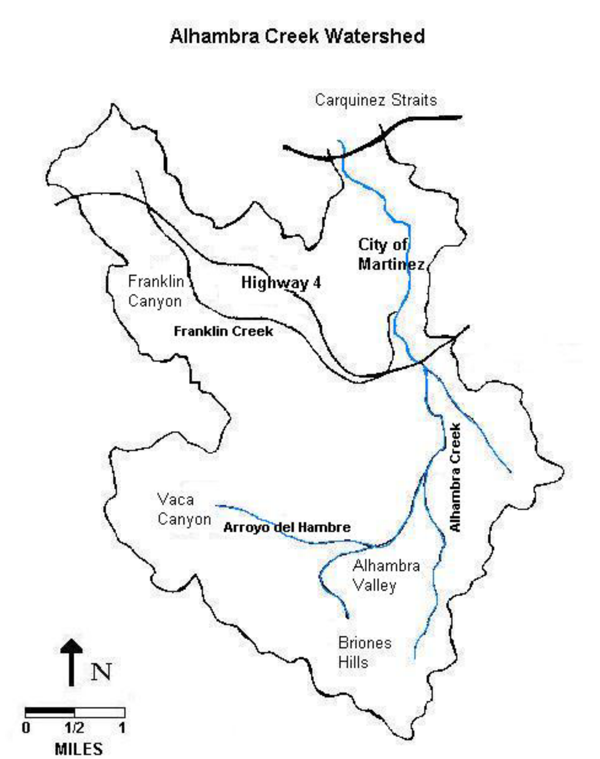


Figure 1. Alhambra Creek Watershed

agriculture in the watershed increased in the form of fruit and nut orchards (Holman and Associates 1999). Following the Industrial Revolution, technology-based infrastructure improvements allowed the expansion of residential development beyond the city limits. By the 1920's, industrial, commercial, and residential development had spread south to what is now Highway 4, and by the 1960's, housing had extended into Alhambra Valley (Alhambra Creek WPG 2001).

Project Goals In order to manage the Alhambra Creek Watershed for its ecological, aesthetic, and economic resources, an understanding of geomorphic processes is necessary. Geomorphological assessments are important for the design and evaluation of successful stream restoration projects (Sear et al. 1998, Kondolf 2000a). Several projects are currently being planned for different locations in the Alhambra Creek Watershed. These projects involve potential realignment of the stream channel, reconstruction of channel terraces, and removal of failing bank revetment. The Urban Creeks Council (UCC) is planning a restoration project for Alhambra Creek along the Martinez Adult Education Campus. In order to produce an appropriate creek bank design, UCC plans to review hydrologic reports and historical data, and conduct field data collection (Igor Skaredoff, pers. comm.). As the consequences of failure could be severe, an understanding of the geomorphic history and setting of the watershed is crucial for the proper design of this and other projects.

I hypothesize that urbanization has led to channel incision and widening in Alhambra Creek in the past 50 years. The goal of my research is to identify if channel incision, as described above, or other changes in stream geomorphology have occurred because of changes in land use in the Alhambra Creek Watershed. In this paper, I will apply the method of resurveying historical cross-sections, a tool of historical channel analysis that is used commonly for geomorphic watershed assessment. I will measure channel incision in Alhambra Creek by comparing historical survey data to resurveyed, current channel conditions. Using these channel morphology data, I will then explain the significance of my findings, and make recommendations for future studies.

Watershed Characteristics Alhambra Creek drains 16.5 mi^2 in northern Contra Costa County, California, and flows through the City of Martinez before entering the Carquinez Straits. Flowing north from its source in the Briones Hills at 1,100 feet, Alhambra Creek is joined from the west by Arroyo del Hambre, which drains 2.5 mi^2 of upper Vaca Canyon and Alhambra Valley, and by Franklin Creek, which drains 5.0 mi^2 and traverses Franklin Canyon from the west. All of the streams in the watershed are intermittent, with flows proportional to seasonal precipitation (USDA, 1997). Rolling hills and small valleys comprise the basin topography with elevations ranging from sea level to 1500 feet. The basin geology consists mainly of sandstones and shales (Haydon, 1995). The regional climate is Mediterranean, with warm dry summers and mild wet winters. Average annual precipitation ranges from 18 to 22 inches, with 90 percent of rainfall occurring between November and April (USDA, 1997).

Methods

Historical Channel Analysis Historical channel analysis refers to the use of a variety of methods to document prior geomorphological conditions and changes in those conditions over time. Depending on the type of historical data available, the level of precision desired, and the purpose of the analysis, a wide variety of methods may be applied. Lawler (1993), Kondolf (1995), and Trimble (1998) provide useful reviews of some of these methods. This research project focused on the use of resurveyed cross-sections as a primary method of historical channel analysis. Measuring the magnitude and direction of channel change through repeated cross-section surveys can help predict future channel stability. In the context of this research project, my use of historical cross-section survey data requires making two assumptions. First, any channel changes identified are greater than the error limits of the methods used to detect them. Lawler (1993) recommended meticulously resurveying each cross-section multiple times in order to detect these error limits; however this level of precision was not feasible given the time limitations for this project. Second, resurveyed cross-sections are at the exact location and angle across the stream as the historical cross-sections. Lawler (1993) stated that in order to ensure the exact reproducibility of measurement, the cross-section ends should be permanently monumented by stakes set back approximately one channel width from the bank-top.

Historical Survey Data Collection In order to obtain information on historical creek cross-sections, I searched the holdings of the UC Berkeley libraries for historical maps, survey notes, and elevation data for Alhambra Creek. I interviewed staff of the Contra Costa County Historical Society and the Martinez Museum for relevant historical survey information. I also interviewed staff of the Contra Costa County Public Works Department, Flood Control Division, and the City of Martinez Engineering Department and reviewed selected file information in these offices. Several streamside property owners were interviewed about the particular issues associated with their local reach, including if any studies or reports existed for that reach.

Historical Survey Data Extraction and Analysis In some historical documents, cross-sections were graphical plots, but in other historical documents the survey data were only presented in plan view. In these documents, the decimal points of the elevations were consistently listed in a straight row across the stream channel. In the absence of actual field notes, I assumed that this alignment was an intentional indication of the horizontal position of the sighting for each elevation. I inferred the width of the stream channel, as well as the distance between different elevations, from the placement of the decimal point in the elevations listed. This allowed me to create graphical plots that showed cross-section width and depth.

Once the cross-section data were extracted from historical survey documents, they were numbered, tabulated, and plotted in Excel. Channel width was defined as the horizontal distance from left bank top to right bank top, and channel depth was defined as the difference in elevation between right or left bank top (whichever was highest) and the channel thalweg (defined as the deepest point in the channel). Longitudinal profiles were also plotted from historical documents based on the channel length between thalweg elevation measurements. These distances were usually consistent with the stationing on the documents, but were verified with a calibrated map wheel. I also plotted a longitudinal profile for Alhambra Creek from the USGS 1:24000 map series (Briones Valley, Benicia, Vine Hill, and Walnut Creek quadrangles) using a map wheel to trace the creek length and read off elevations. The USGS longitudinal profile was used to verify channel thalweg elevations from the reach survey data. I also measured the sinuosity of the creek for each reach. This was done by measuring the length of the channel over the reach (with a map wheel) and dividing by the length of the valley as described by Gordon et al. (1992). Longitudinal profiles were fitted with linear regressions in Excel to calculate the slope of each reach.

Field Surveys Based on the historical survey data that was gathered, two reaches were identified where historical cross-sections could be resurveyed. Reach 1 extends from the northern end of Wanda Way approximately 4500 feet north to the western end of Phyllis Terrace. Reach 2 extends from Tahoe Drive approximately 1600 feet north to Pleasant Hill Road East. Figure 2 denotes the location of historical cross-sections for each reach, as well as resurveyed historical cross-sections. An initial reconnaissance of these study sites was conducted to contact property owners and identify historical survey locations. Field data were collected during October 2001 and March 2002 for the 11 cross-sections. I selected the most complete cross-sections represented by the historical data; specifically, those that contained at least five elevation points.

Cross-sections were identified in the field based on distance from known locations (e.g. corners of buildings and property lines). Smeltzer et al. (2000) identified lateral control, or the ability to confirm a cross-section's exact location, as one of the key limitations in accurately resurveying historical cross-sections, and recommended field reconnaissance to verify the accuracy of surveyed benchmarks before actually resurveying the site. In the absence of absolute benchmarks, I used my best judgment to identify the approximate location of the cross-section, based upon channel configuration, property boundaries, and distance from houses and other structures. Some cross-section sites were inaccessible due to either the presence of heavy in-stream vegetation or the lack of a solid bank for positioning the level. Along with 2-3 field helpers, I surveyed the channel cross-section at each site with a Topcon transit level, stadia rod, and measuring tape, using survey methods as described by Kondolf (2000b). Channel elevations were measured at the top of bank, water surface, thalweg, and at any significant slope breaks. At each cross-section, field sheets were completed with data on channel morphology (surveyed

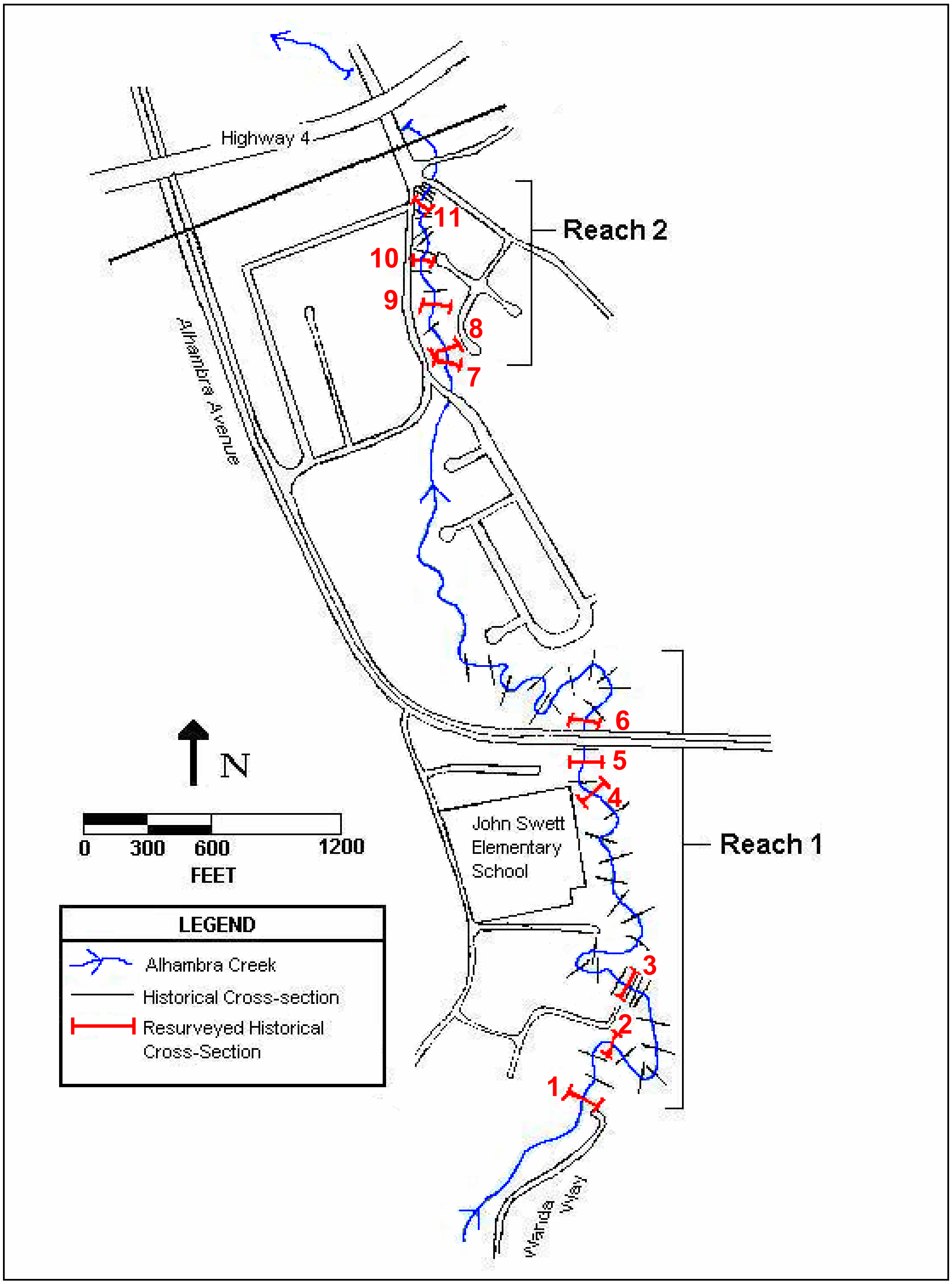


Figure 2. Reach-scale map showing historical cross-sections and resurveyed historical cross-sections

elevations), vegetation (in-stream and bank species, as well as canopy cover), bed substrate (average grain size and appearance), bank composition (natural or revetted), and approximate bank slope. Photographs were taken at each site, noting the location of the survey tape and level.

The primary goal of my study was to measure changes in channel form by comparing resurveyed cross-sections with historical cross-sections. Specifically, I assessed changes in channel width and depth since the historical cross-sections were surveyed, because these changes can indicate rates of channel incision and widening. Survey elevation data was plotted in Microsoft Excel© for comparing with historical cross-section data, using either the top of left bank or the top of right bank as a reference point for comparison, depending on the curvature of the channel and perceived stability of bank elevation. In order to quantify channel form for statistical analysis, I calculated channel widths and depths as was done for the historical cross-section data.

Statistical Analysis I chose the oldest historical data available for each cross-section, and then grouped the data into two categories: past (1955, 1962, or 1971) and present (2001 or 2002). For cross-sections 7 and 10, data were available from both 1955 and 1962. However, I chose to use the older data (from 1955) for my statistical comparison. I used JMP (a SAS Institute Inc. statistical software package) to plot the distributions of past and present channel dimensions. I then calculated the change in width and depth for each of the 10 cross-sections. I performed a Wilcoxon signed-rank test, which is a nonparametric analogue to the paired-sample t-test, to compare past and present channel dimensions. This nonparametric test is more applicable than the paired-sample t-test because the cross-section dimension data are not normally distributed.

Results

Historical Survey Data Table 1 lists and describes historical survey documents that provided direct information for the 2 reaches (11 cross-sections) in this investigation. Historical cross-sections on as-built bridge documents were also uncovered during this data collection effort. However, as these bridges are located near the mouth of Alhambra Creek, I excluded them from my field surveys as they would not be expected to show evidence of incision. As a result of the gradient of the creek at these bridge locations, aggradation would most likely be observed. In addition, several of the bridges were located near a recent flood control project in downtown Martinez, where dredging and channel modifications have taken place recently.

Based on these factors, I excluded the bridge cross-sections from my field surveys, and focused on the historical data sets that were more extensive. Appendix I contains the results of my historical data collection efforts, and includes references for historical maps, photographs, and reports on the Alhambra Creek Watershed, in addition to other sources of channel survey data.

Document No.	Title	Author	Date	Description	Cross-sections	Scale	Reach no.
1	Alhambra Creek topography from 1000' downstream of Alhambra Ave, upstream to Wanda Way.	F.B.R.	May 1971	Plan view survey. No. R-423.	39	1" = 50'	1
2	Alhambra Creek topography with contours from 1000' downstream of Alhambra Ave, upstream to Wanda Way.	F.B.R.	May 1971	Plan view survey with predicted flood elevations. No. R-424.	Benchmarks for April & May surveys	1" = 50'	1
3	Alhambra Creek from 1000' downstream of Alhambra Ave, upstream to Sheridan Road.	F.B.R.	April 1971	Plotted cross sections, 4 sheets. Nos. S-319-322.	39	1" = 10'	1
4	Alhambra Creek from Pleasant Hill Rd. upstream 1200'.	H.E.C.	June 15, 1955	Plan view survey. No. FC-5-8009-D, FD22.	25	1" = 50'	2
5	Alhambra Creek from Pleasant Hill Rd. upstream 1600'.	J.T.F.	April 1962	Plan view survey. No. FD-1513.	20	1" = 50'	2

Table 1. Historical Survey Documents (scale: 1" = 50')
All documents obtained from Contra Costa County Flood Control and Water Conservation Department.

Reach Descriptions Reaches 1 and 2 are underlain by younger alluvium (Haydon, 1995). The drainage area upstream of Reaches 1 and 2 is approximately 9 square miles, slightly more than half the total Alhambra Creek watershed drainage area. Reach 1 had a greater sinuosity (2.160) than Reach 2 (1.170) (see Table 2). Several tight meander bends were observed in Reach 1, with necks narrower than the meander points. The channel form is that of a typically "incised" channel, with steep banks (slopes between 60 and 90 degrees) and a channel bed well below the floodplain. The slope of Reach 1 is 0.0073, and the slope of Reach 2 is 0.0056. The surrounding land use is residential, with many houses and structures very close to the creek.

Reach	Channel (thalweg) distance (feet)	Downvalley distance (feet)	Sinuosity Index= Channel (thalweg) distance/ Downvalley distance
1	4535	2100	2.160
2	1229	1050	1.170

Table 2. Reach sinuosity

Riparian vegetation throughout these reaches consists mainly of oak trees (*Quercus* sp.), California buckeye (*Aesculus californica*), and California bay (*Umbellularia californica*) with an understory dominated by English ivy (*Hedera* helix), periwinkle (*Vinca major*), and introduced blackberry (*Rubus ulmifolius*). Willow trees (*Salix* sp.) and big-leaf maple (*Acer macrophyllum*) as well as poison oak (*Toxicodendron diversilobum*) and Himalaya berry (*Rubus discolor*) were also observed in the upstream portion of Reach 1. At several locations throughout Reaches 1 and 2, trees had recently collapsed into the stream, removing the stabilizing effect of their root masses. Trees on the banks and the adjacent floodplain had exposed roots.

Figure 3. Cross-section 1 at former bridge abutment. 3/19/02.

Cross-Section Surveys Historical survey dates for the 11 cross-sections are listed in Table 3. Cross-section locations are denoted on Figure 2. Cross-section dimensions are given in Table 4, and plots are shown in Appendix II. Cross-section 3 (located just downstream of a small driveway bridge) was excluded from further analysis because the historical survey data did not extend beyond the bridge foundation to the natural channel banks. This made it impossible to accurately align the current and historical data, because I was unable to tell if the channel bed next to the bridge foundation had been scoured since 1971.

Cross-Section	Reach	Year of Historical Survey	Date of Resurvey
1	1	1971	3/19/02
2	1	1971	3/19/02
3	1	1971	3/19/02
4	1	1971	3/3/02
5	1	1971	3/3/02
6	1	1971	3/19/02
7	2	1955, 1962	10/28/01
8	2	1962	10/28/01
9	2	1955	10/28/01
10	2	1955, 1962	10/28/01
11	2	1955	10/21/01

Table 3. Cross-Section Survey Dates

Six of the ten cross-sections' channel morphology were likely influenced by anthropogenic in-stream structures. Cross-section 1 (Figure 3) is located at a former bridge abutment for a road that used to join Wanda Way to the Muir-Strentzel gravesite (a National Park Service property). The width is obviously constrained by the bridge foundations, while the depth has increased by 1.45 feet.

Cross-Section	Past Width (feet)	Present Width (feet)	Change (feet)	Past Depth (feet)	Present Depth (feet)	Change (feet)
1	30	28.5	-1.5	14.8	16.25	+1.45
2	41	49	+8	11.8	12.76	+0.96
4	53	55.4	+2.4	15	15.5	+0.5
5	43	36.6	-6.4	16	17.65	+1.65
6	54	56.9	+2.9	13.3	17.54	+4.24
7	30.87	28	-2.87	10.14	11.74	+1.6
8	34.2	38.4	+4.2	10.8	12.55	+1.75
9	32.5	20	-12.5	13.5	11.07	-2.43
10	35	32	-3	16.2	14.47	-1.73
11	43	38	-5	16	12.92	-3.08

Table 4. Cross-section Dimensions

Cross-section 6 is located 40 feet downstream of the Alhambra Avenue bridge, which forms a 10 by 10 feet culvert. Approximately 1.4 feet of erosion was measured at the right bank bridge foundation on 3 March 2002 (Figure 4). This erosion is most likely due to a combination of channel adjustment following incision and the hydraulic effects of the small culvert. Erosion was evident on both banks, although the left bank represents more of a concern for property-owners. Figure 5 shows a temporary solution to this problem, in the form of a tarp covering secured by rope and tires. Both the channel width and depth have increased at this cross-section, by 2.9 and 4.24 feet, respectively.

Figure 4. Erosion at downstream end of Alhambra Avenue bridge, right bank. 3/3/02.

Cross-sections 7 and 8 are located farther downstream in Reach 2, where the use of crib walls and rip-rap to control bank erosion is prevalent. Sagging wooden crib walls and scattered chunks of concrete typify the bank composition in this reach. Figure 6 shows the right bank at cross-section 8, where four wooden crib walls and pieces of rip-rap (of unknown installation date) exert an influence on the channel morphology. Width and depth changes between these two cross-sections were variable, while decreases in these dimensions may be attributable to bank-stabilizing structures.

Figure 5. Bank erosion at cross-section 6. 3/19/02

Figure 6. Crib walls and rip-rap near cross-section 8. 10/28/01

The morphology of cross-sections 9 and 10 appears to be heavily influenced by the presence of a large wall of concrete pieces that comprises most of the right bank in the vicinity of these cross-sections. Historical survey data for these locations shows a much wider channel with a higher right bank. I speculate that the right bank was graded for development following the 1955 survey, and then further reshaped during the construction of the wall (about 5 years ago). Figure 7 shows the wall on the right bank, looking downstream near the location of cross-section 9. Note the large concrete chunks in the channel bottom that were placed to stabilize the creek elevation at that point.

The remaining four cross-sections had largely natural banks (i.e., without revetment of any kind) and were fairly stable, with the exception of cross-section 4, whose shape appears to have been affected by instability of an oak tree directly upstream.

Figure 7. Concrete wall at cross-section 9. 10/28/01.

Statistical Analysis The channel widths and depths for both past and present survey dates were not normally distributed. The *null* hypothesis of the Wilcoxon signed-rank test was that present widths and depths were less than or equal to past widths and depths. However, this null hypothesis could not be rejected because for both width and depth, the T-statistic (34 and 23, respectively) was greater than the T critical; T (0.05 (1), 10) = 10. These tests along with observations of the cross-section plots in Appendix II confirm that the channel morphology of Alhambra Creek has remained fairly stable in the past 50 years. The observed mean difference between present and past channel widths (-1.377 feet) is an artifact of the bank revetment at the 10 cross-sections, and is especially influenced by cross-section 9, where the concrete wall greatly reduced channel width. The observed mean difference between present and past channel depths (0.491 feet) seems more plausible (i.e., a half-foot of systemic channel incision could have occurred in the past 50 years), but also lacks statistical significance. In general, the channel morphology of Alhambra Creek appears to have changed very little in the past 30 to 50 years, with the exception of local erosion problems caused or exacerbated by in-stream structures (e.g. bridges and bank revetment).

Discussion

Effects of In-stream Structures In-stream structures contributed to both observed changes in channel morphology over time, as well the uncertainty in assessing systemic channel changes accurately. For instance, the Alhambra Avenue bridge appears to play a significant role in channel incision and widening at cross-section 6. The culvert causes a downstream scouring effect, as evidenced by the large pool just beneath the bridge spillway. The bank and bed erosion at cross-section 6, therefore, might simply be an result of the bridge-induced hydraulics and not a reflection of systemic channel adjustments following changes in watershed land use and hydrology. Similarly, constrained channel banks (due to either abandoned bridge abutments, crib walls, rip-rap, or concrete retaining walls) might lead to localized incision by redirecting the flow of water; therefore the origin of this incision cannot be attributed solely to changes in watershed hydrology.

Difficulties and Limitations of Historical Data Comparison Results of this study largely depended on the accuracy and validity of historical survey data. However, this requirement for accurate and valid data was not precisely met. An example of unreliable historical data pertained to Documents 4 (1955) and 5 (1962). Since the two survey maps covered the same reach of Alhambra Creek, I assumed that the channel configurations would align well if they were overlaid in plan view. Yet, when I superimposed the two maps, certain meander bends in the creek were up to 15 feet apart. One explanation is that the creek meandered greatly during this period of seven years, carving out a new configuration. Another explanation is that one or both of the survey documents contain erroneous survey elevations.

Another discrepancy was identified while plotting longitudinal profiles for the available historical data. The thalweg elevations at the downstream end of Reach 1 (as extracted from Documents 1, 2, and 3) were 10 feet lower than the thalweg elevations at the upstream end of Reach 2 (as extracted from Documents 4 and 5). This leads to the assumption that all surveyed elevations in both documents are suspect, despite the fact that both documents referenced their survey stationing to established features (e.g., road crossings). Document 1 elevations aligned closely with a long profile plotted from USGS quadrangles, while Document 4 thalweg elevations averaged 10 to 20 feet higher than the USGS channel elevations. This leads me to believe that Documents 1, 2, and 3 are reasonably accurate and more trustworthy, while Documents 4 and 5 contain arbitrary elevations. For the purposes of this project, however, arbitrary elevations can still offer useful survey data for width and depth comparisons.

Effects of Cattle Grazing Based on the results of my research project, urbanization and recent land use changes are likely not the cause of the incised channel form visible in Alhambra Creek today. More likely is that the channel is recovering from the effects of intense cattle grazing in the 18th and 19th centuries. Intense grazing modifies or temporarily removes vegetative cover that would reduce and delay fluvial transport of rainfall and sediment to major river channels during rainstorms. A heavily grazed landscape thus transports more water and more sediment to the channel more quickly. The effect is increased instantaneous peak runoff for a given storm. Concentrated runoff initiates channel head advance, gullying, and drainage network expansion, all of which reinforce increased runoff peaks and fluvial transport of sediment from hillsides to the alluvial channel network.

Urbanization might have caused further incision beyond that caused by cattle grazing, but not of a magnitude that I was able to detect with my research. Localized erosion, however, is a significant problem, and may be correlated with in-stream structures as well as the high sinuosity in the middle reaches of Alhambra Creek. Darby and Simon (1999) indicated that increased meandering in the middle reaches of streams is a common byproduct of channel adjustment following incision. The sinuosity of Reach 1 (2.160) probably plays a significant role in the active channel erosion (eroding meander bends and tree falls) observed between cross-sections 1 and 6. The migration rate in bends tends to reach a maximum where the ratio of radius of curvature to channel width (or sinuosity) falls in the range of 2-3 (Nanson and Hickin, 1986). This high sinuosity implies that the channel is adjusting to a much earlier, rather than a recent, source of incision. I speculate that this earlier incision was caused by cattle grazing and began well before urbanization influenced watershed hydrology.

Recommendations Dating the observed channel incision would provide an indication of where Alhambra Creek lies in standard "channel evolution" models, and how long it will take before the channel can sustain riparian habitat comparable to pre-disturbance conditions. To determine exactly when the onset of this incision occurred, historical data for the Alhambra Creek watershed should probably not be relied upon as the main source of evidence. Instead, a comprehensive assessment of channel condition, using field-based evidence of channel changes, would be more useful. Methods include dating riparian vegetation, analyzing bank stratigraphy and bed surface grain size distributions, and locating former floodplains and terraces through vegetative analysis.

Conclusions Based on the results of my limited historical cross-section analysis, I conclude that the overall channel morphology of Alhambra Creek has changed very little in the past 30 to 50 years, with the exception of local erosion problems caused or exacerbated by in-stream structures (e.g. bridges and bank revetment). The original premise of my research project was that changes in runoff-generating mechanisms (caused by urbanization) would lead to changes in channel morphology, and that these changes could be detected by resurveying historical cross-sections. Limitations of historical data sources constrained the spatial scope of this resurveying effort. A tremendous variety of in-stream structures also complicated any interpretations of changes in channel morphology in the past 30-50 years. The inability to detect significant channel incision, however, indicates that the incision probably occurred 100 to 200 years ago, and that Alhambra Creek is currently adjusting to this historic land use change as well as the geomorphic effects of in-stream structures.

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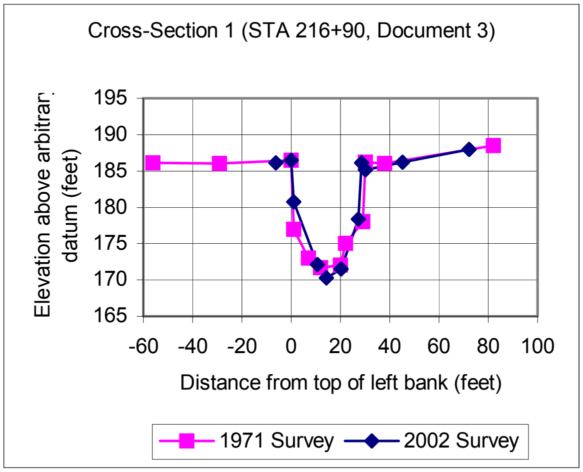
*Not reviewed by the author.

Appendix II. Cross-section Plots.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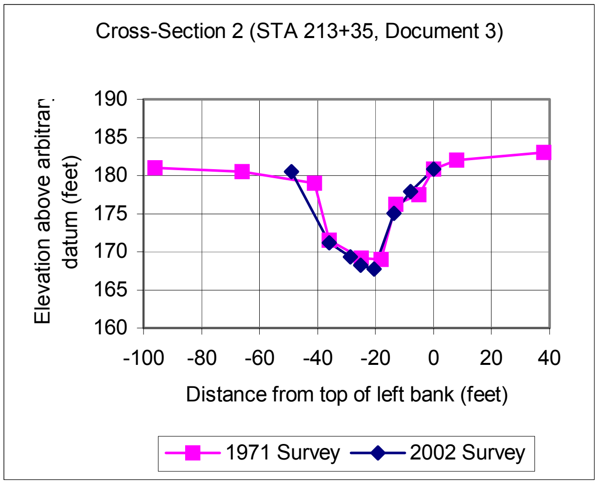
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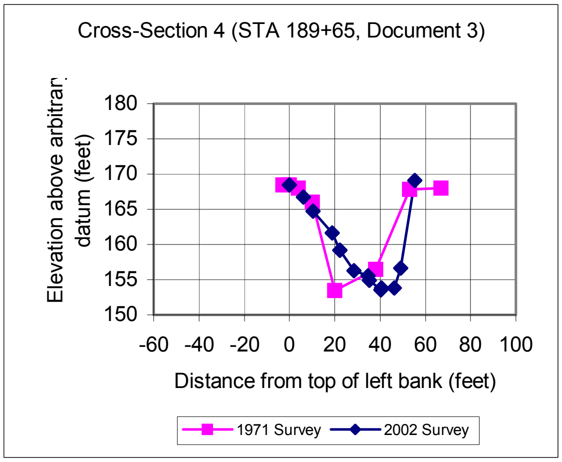
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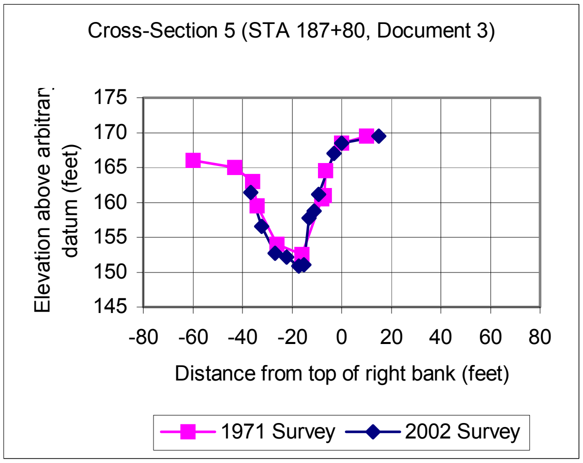
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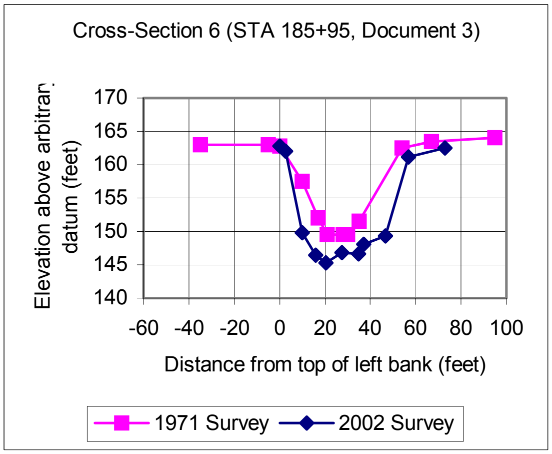
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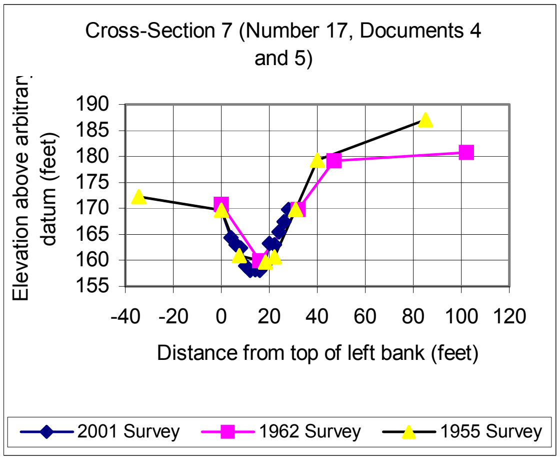
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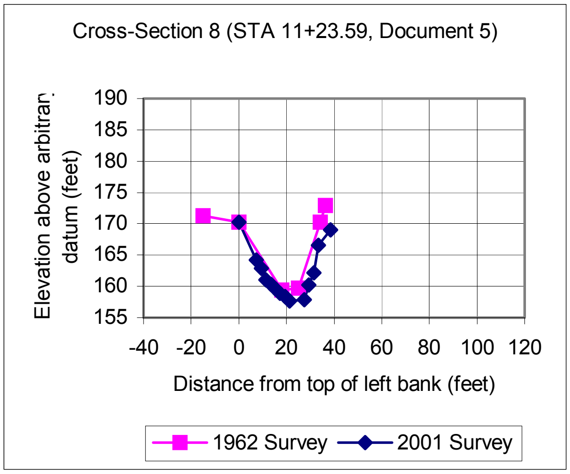
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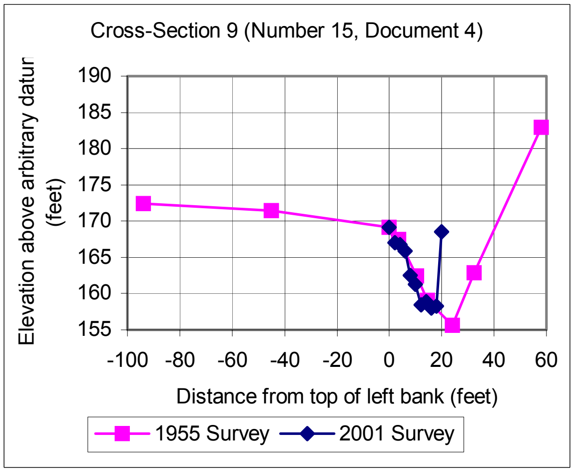
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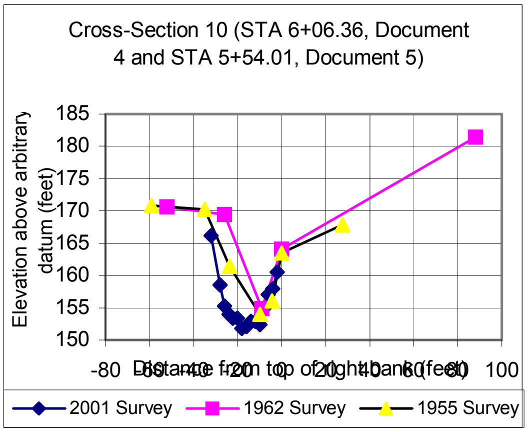
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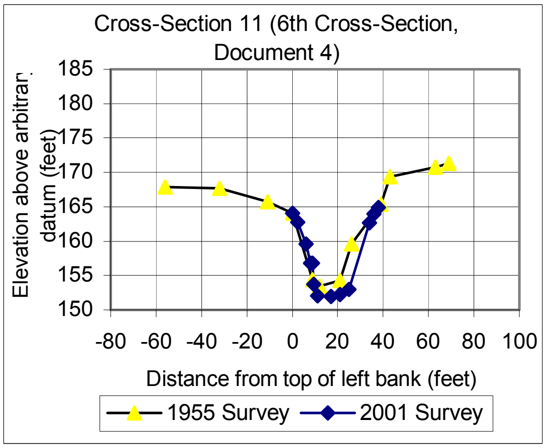
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