## Title

Floodplain reconnection and sediment capture at Chorro Flats, San Luis Obispo County: Post-project appraisal one decade after construction



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Abstract

The Chorro Flats Floodplain Reconnection project in Morro Bay, California is referred to as a successful restoration project because of the thorough planning process and consideration of geomorphic processes in the project design. The Chorro Flats project was part of a suite of projects in the Chorro Creek watershed intended to reduce the sediment load into Morro Bay, a highly productive estuary threatened by an increased rate of infill. In this paper, we present a post-project appraisal one decade after construction. We evaluate the project through several research questions that examine floodplain reconnection, sediment capture, geomorphic changes, and post-project monitoring. Due to a convergence of fortuitous factors and thorough planning, the project achieved sediment capture through floodplain reconnection. In addition, the project achieved its secondary goals to develop in-stream habitat and a healthy riparian zone. We found that monitoring efforts were difficult to replicate, and that continued monitoring of the project is essential to evaluate the lifespan of the project and potential downstream impacts.

## Introduction

River restoration is a rapidly growing field in the United States with large investments (Bernhardt et al. 2005). Many lessons can be learned from a thorough analysis of restoration projects and the variety of goals they are intended to accomplish, such as reestablishment of fluvial processes, riparian zones, and freshwater fishery habitat (Bernhardt et al. 2005). However, these goals are rarely well defined, and post-project evaluations that use monitoring data to quantitatively measure success are conducted infrequently (Downs & Kondolf 2002).

This paper is an expanded post-project evaluation of the Chorro Flats Floodplain Enhancement Project (Chorro Flats) in San Luis Obispo County on Chorro Creek (Figure 1). We conducted additional document review, field monitoring, and interviews to expand upon research completed for the National River Restoration Science Synthesis post-project appraisal conducted in 2007.

### *Project Background*

Chorro Flats has been recognized as a successful restoration project because of the thorough planning process and consideration of geomorphic processes in the project design (Kondolf et al. 2006). The primary objective of the project was to reduce sediment inflow into Morro Bay, a highly biologically productive estuary. Flood control levees were removed from a 129-acre agricultural site, Chorro Flats, to reconnect Chorro Creek to its floodplain and to facilitate sediment deposition onto the floodplain  (Crawford Multari, & Starr et al. 1993b). Levees were originally constructed to maintain the channel condition and reduce flooding on agricultural lands (Crawford, Multari & Starr et al.

1993a). Chorro Flats has a drainage area of approximately 43 square miles, consisting of rangeland, farmland, brush, and woodland (Crawford, Multari & Starr et al. 1993a).

Prior to the Chorro Flats project, several studies of the Morro Bay watershed were conducted (Table 1). These studies initially suggested that littoral drift was the primary mechanism contributing sediment to Morro Bay (USACE 1975). Additional analysis found that erosion from the Chorro Creek watershed was contributing approximately 35,000 – 50,000 cubic yards/year of sediment to Morro Bay, resulting in a 25 percent decrease in bay volume over the past century (Haltiner 1988). This sediment transport rate suggested that Morro Bay would infill in 300 years, threatening the biological health of the estuary (Haltiner 1988).

As part of the *Morro Bay Watershed Enhancement Plan*, the Chorro Flats site in lower Chorro Creek was identified as an ideal site to reduce sediment deposition in Morro Bay (Soil Conservation Service 1989). The California Coastal Conservancy, on behalf on the Coastal San Luis Resource Conservation District (hereafter "the District"), purchased the 129-acre Chorro Flats property, formerly in agricultural production, in 1991 to implement this recommendation (Crawford, Multari & Starr et al. 1993a). An extensive planning process was initiated in 1993, beginning with development of a background report and an alternatives analysis (see Table 1). Three alternative scenarios were put forth with variation in acreage allotted for agricultural production, habitat restoration, and sediment removal (Crawford, Multari & Starr et al. 1993b). Following public input from the Morro Bay Task Force and Chorro Flats Advisory Committee, a conceptual plan was developed for passive sediment removal by removing and re-situating flood control levees, while maintaining some agricultural production and enhancing wildlife habitat (Crawford, Multari & Starr et al. 1994). Project objectives were to align the stream, reduce sediment, enhance fish habitat, maintain low impact agricultural production, increase public access, and establish funding mechanisms for project maintenance (Crawford, Multari & Starr et al. 1994).

Following completion and approval of the conceptual plan, a major fire known as the “Highway 41” fire burned 35 percent of the Chorro Creek watershed in August 1994 (CSLRCD 2002). This was followed by a severe winter in 1995 with two major floods with estimated recurrence intervals of 100-1000 years (CSLRCD 2002; Phillip Williams and Associates et al, 1996). The Natural Resource Conservation Service expanded a levee breach to 450 feet to allow sediment capture during the flood events (CSLRCD 2002). Increased sediment deposition modified site topography, and prompted a revision of the conceptual plan with refinements to channel design, plantings, and public access opportunities (Phillip Williams and Associates et al. 1996). Further public input was incorporated into the final conceptual plan (see Figure 2) (Phillip Williams and Associates et al. 1996).

After an extensive permitting process, funding was secured from various state agencies, and construction took place from July to November 1997. Approximately 10,800 native plants—including about 200 California sycamores (*Platanus racemosa)*, about 850 Black cottonwoods (*Populus balsamifera)*, and nearly 8900 red and arroyo willows (*Salicaceae laevigata & nigra*)—were planted in bands adjacent to the new channels to promote riparian vegetation growth. However, as-built drawings were not completed. Several flood events occurred in the El Nino winter of 1997-98, which deposited significant amounts of sediment on the site and caused Chorro Creek to avulse into and remain in Channel A, a newly constructed channel originally designed as a flood overflow channel (Figure 3). Log and boulder structures were installed in 1999 in Channel A to enhance steelhead summer rearing habitat (CSLRCD 2002).

A monitoring and maintenance plan was developed in 1998 by the District to meet permit requirements set forth by the Central Coast Regional Water Quality Control Board, US Army Corps of Engineers, and the California Coastal Conservancy. Monitoring focused on addressing local erosion problems, revegetation success, sediment capture capacity, channel configuration, habitat creation, and water quality improvement. The monitoring plan specified short-term activities for 1998-2000, and long-term activities for 1998-2003. Maintenance of native plantings, including replanting areas damaged during the 1997-1998 floods, was conducted by students at California Polytechnic State University San Luis Obispo, and California Conservation Corps members, which resulted in the establishment of a vibrant riparian plant community. Sediment trapping efficiency was determined from measuring sediment capture and from modeled sediment loads. Cross sections were taken to determine if the channel was developing a stable configuration (Figure 5) (CSLRCD 2002). Results from these monitoring efforts were summarized in the District's "Final Report to the State Coastal Conservancy" in 2002.

## Methods

To evaluate the Chorro Flats project, we conducted a through analysis of project documents, fieldwork on the site, and interviews with people involved in the planning process. We visited the project site on October 31st, November 1st, and November 2nd, 2008: first to plan our fieldwork, and then two more times to survey cross-sections, take soil cores, complete a pebble count, note the approximate location of in-stream structures, photograph the site, and visually assess sediment aggradation under the Chorro Creek Bridge. We evaluated the Chorro Creek project based on the following questions:

- *How did planning efforts contribute to successful implementation?*
- *Has the project reconnected Chorro Creek with its floodplain?*
- *Has the sediment capture component worked as well as intended?*
- *How have previously surveyed cross-sections changed over time?*
- *Is the monitoring plan being followed and how could it be improved?*
- *Are there unintended impacts on site or in other parts of the watershed?*
- *Following implementation, are project components working together or are they in conflict?*

We surveyed a total of seven cross-sections (Figures 6-12), two of which coincided with previous cross-sections. The remaining five cross sections were established near the locations of previous cross-sections for which permanent markers were never installed or could not be found. We monumented any unmarked cross-sections we surveyed with rebar, and recorded locations with a Global Positioning System (GPS) unit (Table 2). For each cross-section, an auto-level attached to a tripod was used to read measurements from a stadia rod positioned at changes in slope and features in the creek along the cross-section. We used a soil auger to unearth soil samples and we evaluated their composition (Table 3). We performed a pebble count under the Chorro Creek Bridge, and used the observed grain size distribution to calculate the median grain size (Wolman 1954). We also evaluated the Chorro Creek Bridge design drawings from Sullivan (1997) and took measurements of the area under the bridge to roughly approximate sediment deposition since the Chorro Creek Bridge was constructed.

We interviewed Linda Chipping, a local resident and board member of the District, who has been involved in the Chorro Flats project since the late 1980s. Ms. Chipping provided access to all the information the District had on the Chorro Flats project, including documents, photographs, plans, maps, and electronic files from the late 1980s to 2002. Her husband, Dr. David Chipping, a retired geology Professor from the California Polytechnic State University, San Luis Obispo, provided insight into the development of the Chorro Flats project and potentially important geomorphic issues unique to the site. We also interviewed Dr. Jeffrey Haltiner, P.E of Philip Williams & Associates, who has been involved with work in the Morro Bay watershed since 1987. Dr. Haltiner also provided us with access to all the documents Philip Williams & Associates had relating to the Morro Bay watershed from the mid 1970s to 2002.

## Results and Discussion

*How did planning efforts contribute to successful implementation?*

We reviewed project documents generated during the planning phase and interviews with those involved in the planning process and found that planning efforts were more complete than most river restoration projects. The Chorro Flats project was part of a long-term watershed scale effort to reduce infilling of Morro Bay, which established a well-defined goal for the restoration project. This greater context in which the Chorro Flats project was initiated engaged the active local community. The planning process involved several iterations of the design plan and extensive public involvement (J. Haltiner, Phillip Williams & Associates, Ltd., personal communication, November 11, 2008). We learned during interviews with project planners that several events during the initial project conception were key to the ultimate success of the project. Specifically, the landowner's willingness to sell the Chorro Flats site was a necessary factor, without which the planning process would not have been able to move forward (J. Haltiner, Phillip Williams & Associates, Ltd., personal communication, November 11, 2008). Furthermore, an existing levee breach provided the opportunity to demonstrate that the site was optimal for sediment capture prior to construction (L. Chipping, CSLRCD Board Member, personal communication, November 2, 2008).

*Has the project reconnected Chorro Creek with floodplain* & *has the sediment capture component worked as well as intended?*

The Chorro Flats project has prevented approximately 225,000 tons of sediment from entering Morro Bay (Morro Bay NEP 2005). Associated planning documents attest to the consideration given to process restoration. Geomorphic review, initially not included in planning efforts, was incorporated during plan refinement and provided valuable insights for achieving the primary project goal of lateral connectivity with the floodplain. Historic cross-sections from 1998 and our surveyed cross-sections show this reconnection (Figures 6-12). Sediment deposits on the floodplain during floods and the bedload material migrates during high flow (Knighton 1998; Tetra Tech 1998; D. Chipping, California Polytechnic State University, San Luis Obispo [retired], November 11, 2008). Riparian vegetation captures sediment and causes riparian berms to form along Channel A, which was confirmed by our soil core observations (Table 3).

While lateral connectivity has been reestablished, channel migration processes were not observed or reported. The creek avulsed into Channel A during the winter 1997-1998 flood (Figure 2). While this channel avulsion was not planned for in the project design, it may provide an unintended benefit that could have been difficult to obtain through the permitting process. The creek flow remains in Channel A, with the original channel now serving as a flood overflow channel. Flow was not observed in the original channel during recent field visits. The new channel location has been reinforced by installation of habitat structures such as root wads and wing deflectors. These structures were initially installed in 1999, following construction to reestablish lateral connectivity. They have been reinstalled and repaired as necessary following major flood events, further preventing channel migration (L. Chipping, CSLRCD Board Member, personal communication, November 2, 2008).

*Is the monitoring plan being followed and how could it be improved & how have previously surveyed cross-sections changed over time?*

The District developed a monitoring and maintenance plan in 1998 to comply with permit requirements set forth by the local RWQCB, USACE, and State Coastal Conservancy. The plan identified short-term (two years following construction) and long-term (five years following construction) activities to track erosion issues and re-vegetation needs, and to assess if the project is meeting its goals and objectives (CSLRCD 2002). Results of these monitoring activities were included in the CSLRCD Final Report to the State Coastal Conservancy in 2002.

Since that time, it is unclear from talking with current District board members and staff if monitoring is taking place at Chorro Flats. Monitoring of sediment capture is particularly relevant for predicting the amount of time until Chorro Flats fills completely, which was estimated to be 35 years in 2002. Sediment capture can be influenced by dynamic geomorphic processes that evolve over time as channel form changes in response to floods.

After reviewing the monitoring and maintenance plan in the 2002 District report, we attempted to re-survey a number of cross-sections on the channel. However, this proved to be difficult. After obtaining all electronic files and reviewing the documents the District had on the Chorro Flats project, we only found one map that showed the relative locations of cross-sections (Figure 4). Prior to visiting the site, we had also been informed that approximately ten cross-sections had been monumented (C. Stubler, Cal Poly San Luis Obispo, personal communication, October 2008). We found the locations of only two previously surveyed cross-sections based on approximate locations indicated in Figure 4, and re-surveyed those. The 2002 District report contained a graph of only one of these two cross-sections and we were unable to find any cross-sections in the electronic files or documents from the District and Phillip Williams & Associates. Considering the amount of effort that presumably went into surveying the channel cross-sections in Fall of 1997 and summer of 1998, it is unfortunate that these monitoring efforts are not replicable, with exception of one cross-section.

After further investigation, we found at least two other entities have done separate monitoring activities. In a 2003 report prepared for the Morro Bay National Monitoring Program, monitoring activities included an examination of two different channel cross-sections that were surveyed in 1997, 1998, and 2000 to document changes in channel morphology. The cross-sections were located where Chorro Creek Road intersects Chorro Creek and at the Chorro Creek Bridges. In addition, the City of Morro Bay is also conducting monitoring at Chorro Creek Bridge in response to sediment aggradation at the bridge (D. Chipping, Cal Poly San Luis Obispo [retired], personal communication, November 2008). Monitoring of the site by all involved parties stopped in 2003, with the possible exception of monitoring by the City of Morro Bay.

The lack of coordination in monitoring efforts is unfortunate considering the level of coordination between different agencies during the planning and implementation of the project. The agencies appear to have not discussed monitoring with each other or decided to monitor on their own. The majority of cross-sections were not replicable due to a lack of published data, unavailable survey information, or misplaced monuments.

It is essential to document monitoring efforts to evaluate a restoration project to ensure that others can replicate the surveys, or the information from the initial monitoring effort is unable to be used constructively for future studies. In addition to placing monuments at cross-section sites, GPS coordinates should be included, because handheld GPS units are inexpensive and user-friendly, and coordinates can be pinpointed more easily than monuments in areas where excessive vegetation growth has occurred, or where there are large amounts of sediment deposition. Also, rather than monitor for successive years after the project was completed, the agencies involved could initiate “event-driven” monitoring after large flow events, thereby focusing their limited resources on measurements that will likely depict important changes (Downs and Kondolf 2002).

Because of the lack of data on previously surveyed cross-sections and our difficulty locating the cross-section sites, we were only able to compare one of our cross-sections with previously surveyed cross-sections. At this cross-section, the channel incised significantly from Fall 1997 to Summer 1998 (Figure 9). From the survey in Summer 1998 to our survey in 2008, the channel bottom appears to have been relatively stable. The 'bumps' in the cross-sectional profile are due to sediment captured by vegetation along the sides of the channel. The channel may have incised slightly and developed a steeper slope from the creek bed to the floodplain.

*Are there unintended impacts on site or in other parts of the watershed?*

In November 1996, the City of Morro Bay finished construction on the Chorro Creek Bridge, replacing Twin Bridges, which had been closed due to flooding an average of seven days a year from 1990 to 1995 (Sullivan 1997). The City of Morro Bay and San Luis Obispo County had planned on replacing Twin Bridges since the early 1980s (Sullivan 1997). The crossing at Chorro Creek immediately downstream of the Chorro Flats project is the primary transit corridor connecting the towns of Los Osos and Morro Bay. The shortest alternate route involves about 20 miles of driving. In addition, the cost of closing Twin Bridges was estimated at $32,000 per day (Fugro West 2008). The Chorro Creek Bridge was constructed at a total cost of $1,728,000 and was designed to pass a 100-year flood (Sullivan 1997), thus it should not be flooded nearly as often as was the old Twin Bridges.

Despite the proximity of the Chorro Flats project to the Chorro Creek Bridge, and the overlap of the planning period for both projects, there is no evidence that there was any communication between the agencies working on the two different projects about downstream effects of the Chorro Flats project on the Chorro Creek Bridge. There is evidence that the creek is aggrading under the bridge and depositing large amounts of sediment. We estimated that the cross-sectional area under the bridge has been reduced by approximately 25% from about 2300 $ft^2$ to about 1700 $ft^2$ due to sediment deposition. In addition, the City Council of Morro Bay adopted a resolution in 2003 to contract out services for sediment harvesting at the Chorro Creek Bridge at a cost of $12,000 (Morro Bay City Council Minutes 2003). If the City of Morro Bay had actively sought to work with agencies involved in the Chorro Flats project, the bridge could have been designed to accommodate for sediment deposition, and thereby prevent future maintenance and unanticipated flooding.

*Following implementation, are project components working together or are they in conflict?*

In addition to the primary goal of sediment capture, a number of secondary goals were articulated in the planning process, including establishment of native vegetation and enhancement of fish habitat. We observed a healthy stand of riparian vegetation at Chorro Flats. Willows tend to predominate directly adjacent to the river. Considering that willows tend to self-colonize and have done well at the site, it may not have been necessary to plant nearly 8,900 willows because they may have propagated naturally.

Since 1999, 34 log and boulder structures were installed at the project site for habitat purposes at a cost of $145,384 (CSLRCD 2002). We observed that a number of these structures had been covered with sediment. Considering the expense of these structures, and the location of the Chorro Flats site close to the mouth of the Chorro Creek, these funds may have been better spent elsewhere.

Conclusion

The Chorro Flats project successfully met its primary goals defined in the planning process, which were specifically related to sediment capture. However, our review of activities following project completion indicates that additional monitoring is necessary to evaluate long-term project performance, considering the dynamic nature of the restored processes of floodplain reconnection. It is difficult to assess the projected 35-year lifespan of the project without long-term, replicable monitoring. While sediment yield models can provide an estimate of sediment accumulation, field assessment can provide a more accurate projection. It is unclear if a funding mechanism has been identified to provide funds for long term monitoring. The majority of the monitoring and maintenance budget was allocated for riparian vegetation establishment, which may have occurred without introduction of native species and a similar result may have been obtained through natural colonization and invasive species control.

Planning for Chorro Flats took place in a watershed-scale context and examined erosion processes, which contributed to project success. The District and the Natural Resource Conservation Service initiated a number of sediment control projects in the upstream watershed to reduce sediment input and erosion. These projects prevented over 190,000 tons of soil erosion (Morro Bay NEP 2005). The Chorro Flats project alone would not have reduced sediment loads into Morro Bay as effectively without the other restoration projects in the watershed. A sediment capture project is planned for the upstream portion of the watershed in the Chorro Creek Ecological Reserve (Morro Bay NEP 2005; J. Haltiner, Phillip Williams & Associates, Ltd., personal communication, November 11, 2008).

Although the project has performed well with the creek in its current single thread channel form, it is worthwhile to consider that the original morphology may have been different. Historic evidence suggests that Chorro Creek displayed braided and sometimes meandering characteristics, and migrated along the valley floor (Philip Williams & Associates et al. 1996). Since project construction, the channel configuration has remained stable, most likely due to the root wad and boulder structures. If these structures were to wash out, the channel may revert to a braided form.

Additional studies would be valuable to gain a greater understanding of restored geomorphic processes. Detailed topographic surveying of the floodplain to evaluate sediment deposition and future storage availability should be considered. This will provide a more accurate projection of the project lifetime. In addition, measuring bedload transport rates would be useful to understand the permanence of sediment capture at Chorro Flats. Fish surveys at regular intervals could also be conducted in order to evaluate the success of salmonid habitat restoration.

The success of Chorro Flats in accomplishing its goals can be attributed largely to its process-based approach of removing levees to reconnect Chorro Creek to the floodplain, the extensive planning process, and the documentation leading up to the construction. However, the lack of replicable monitoring and coordination among agencies after the construction of the project hamper our ability to quantitatively evaluate the projects' success over time. Evaluation of the performance of the project in the future will be especially important as the project nears its sediment capacity, and its ability to pass floods is diminished.

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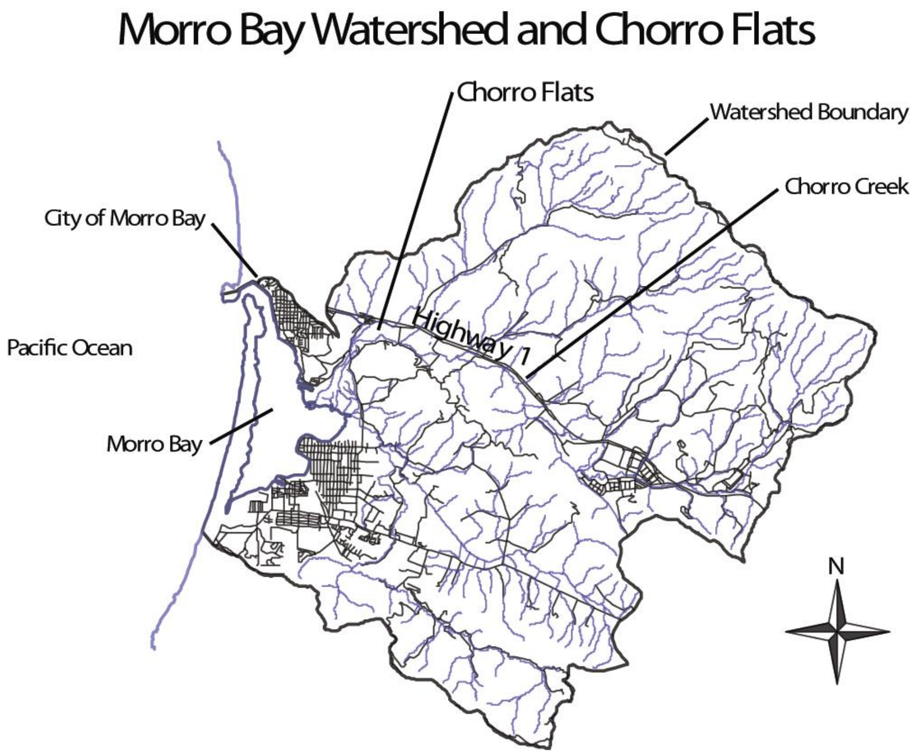


Figure 1. Morro Bay Watershed and Chorro Flats (From CSLRCD, 2002).

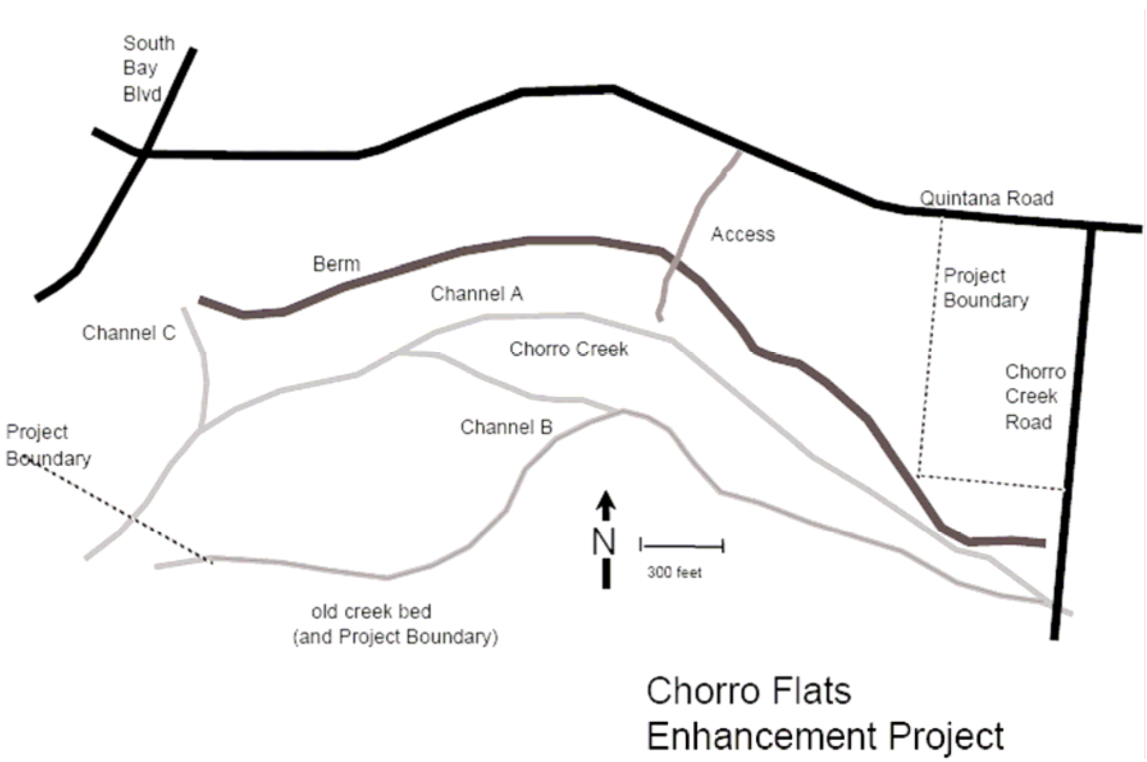


Figure 2. Site Plan (From CSLRCD, 2002).

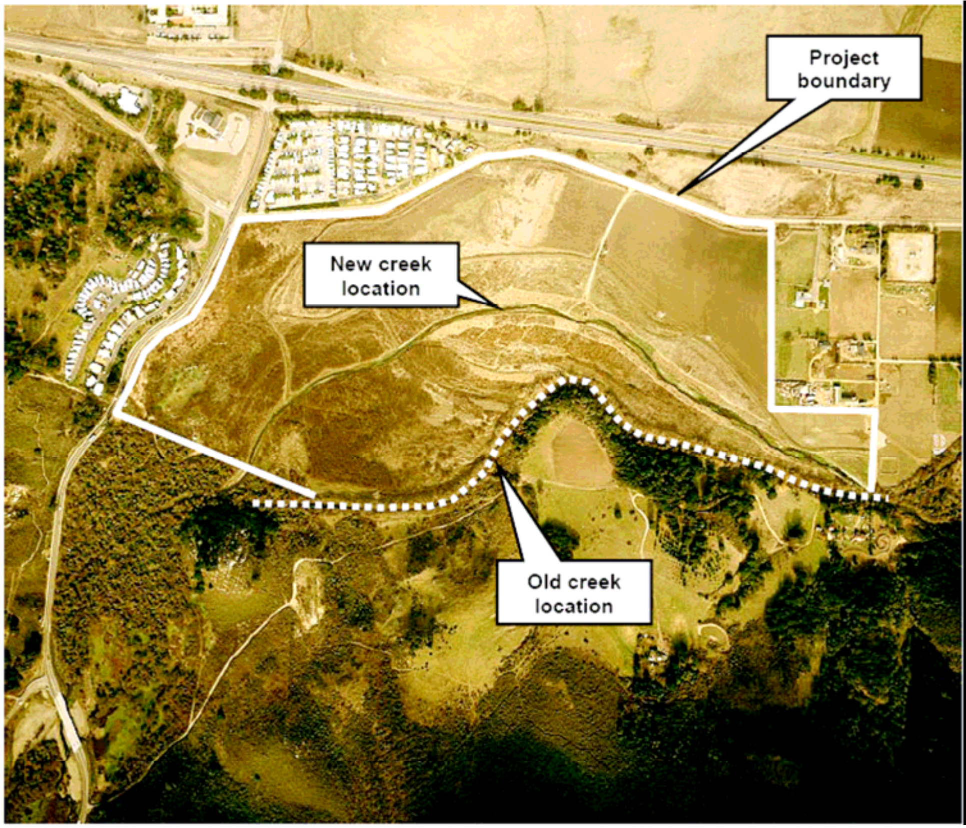

Figure 3. Aerial Photo of Site and Vicinity, January 1999 (from CSLRCD, 2002).

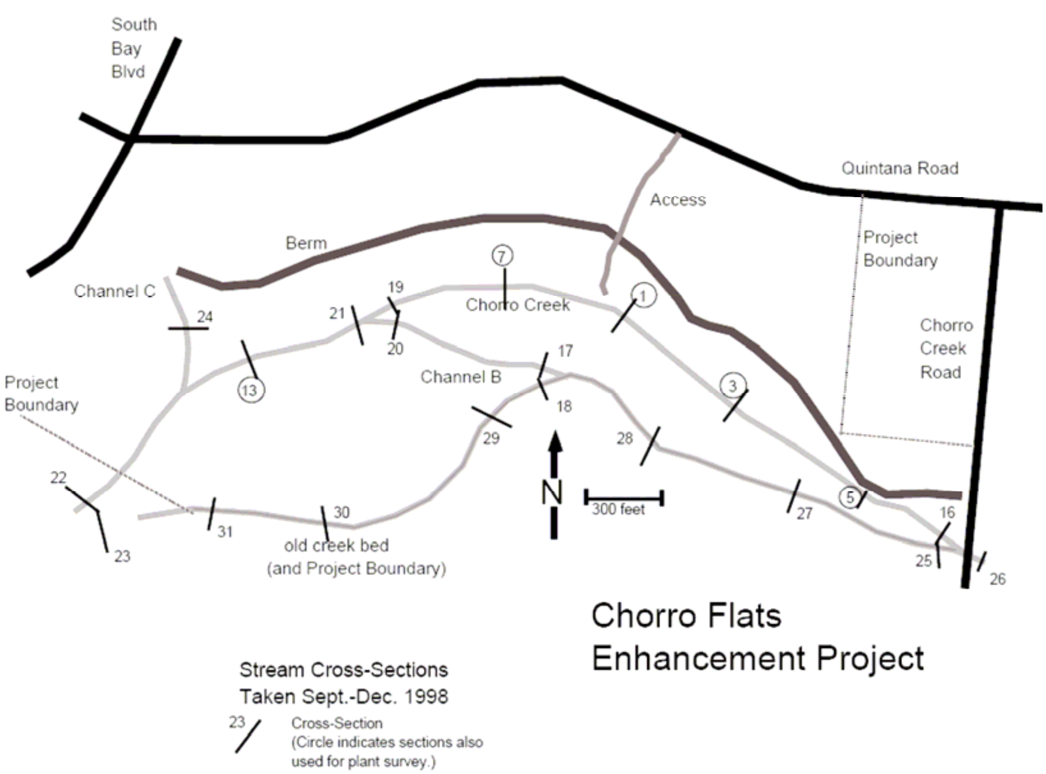

Figure 4. Cross-section locations 1998. (from CSLRCD, 2002).

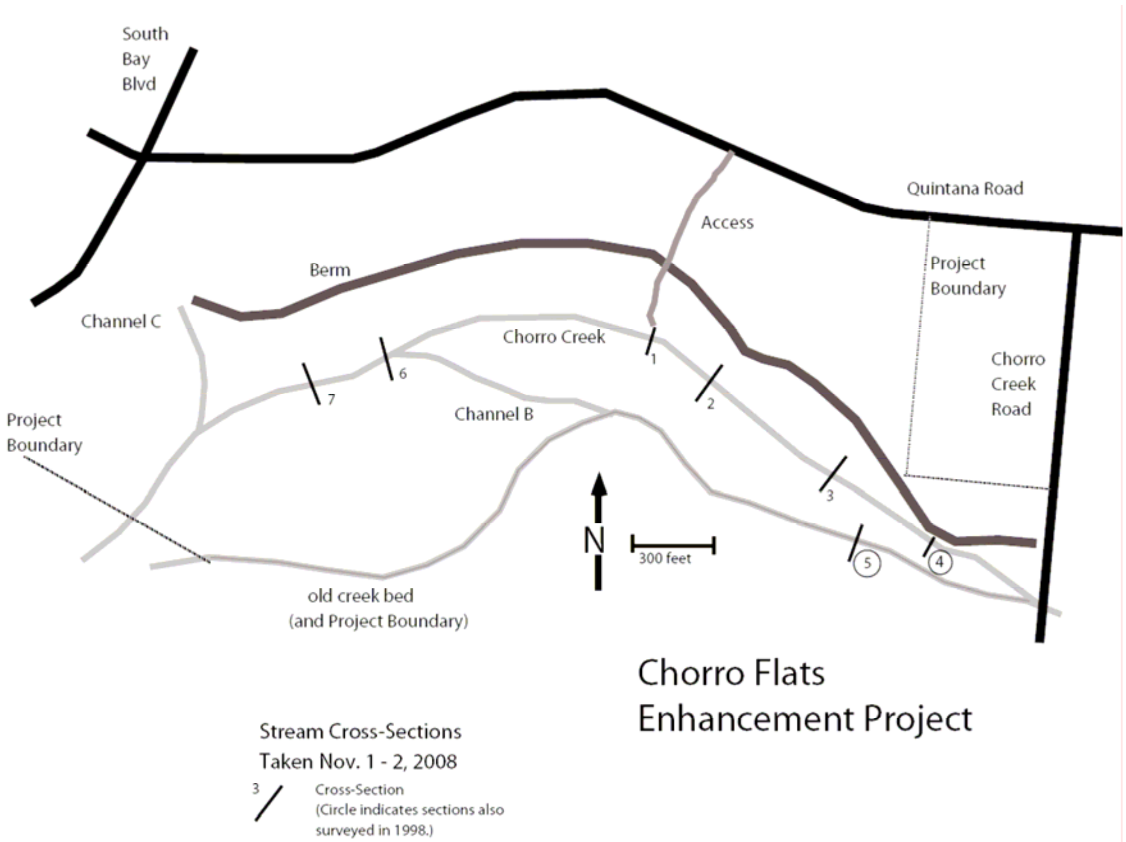


Figure 5. Cross-section locations 2008.

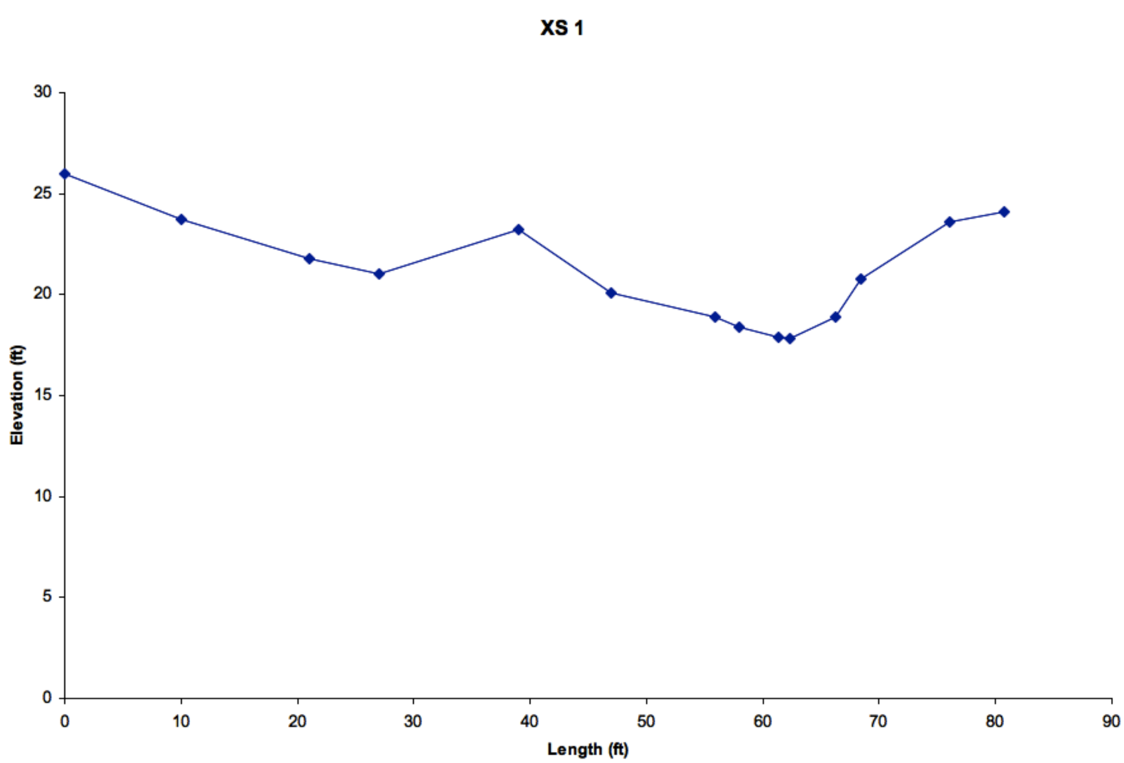


Figure 6. Cross-section 1.

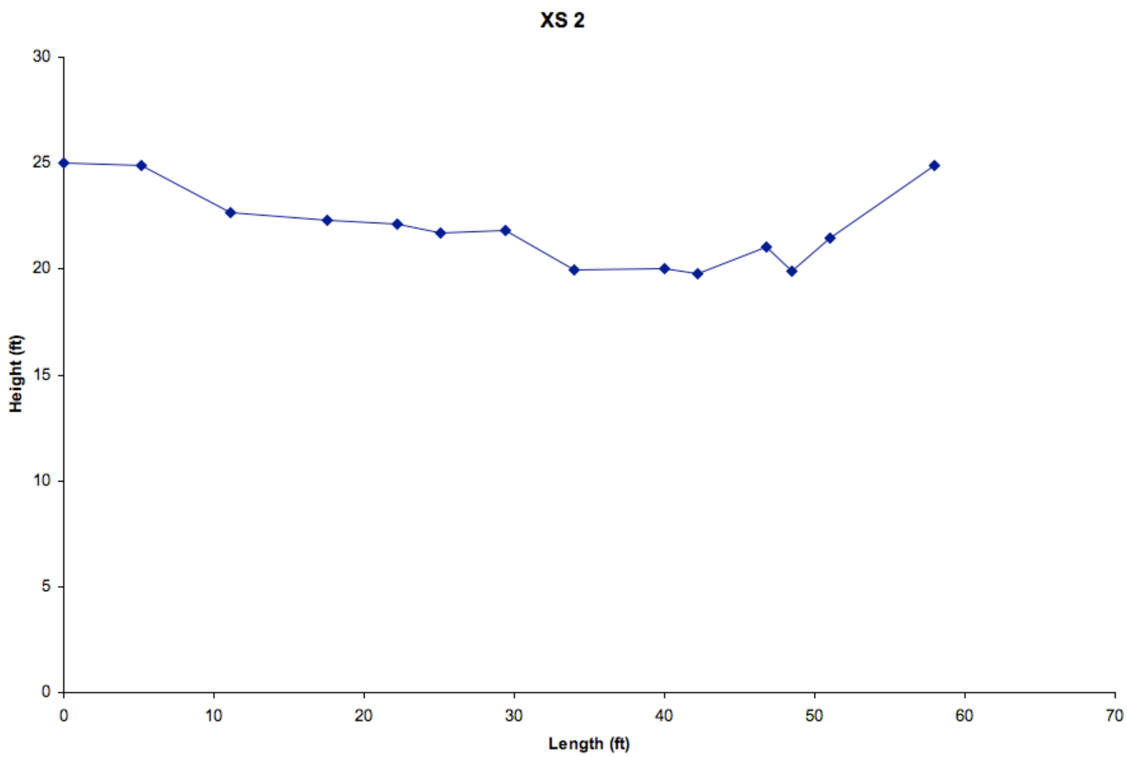


Figure 7. Cross-section 2.

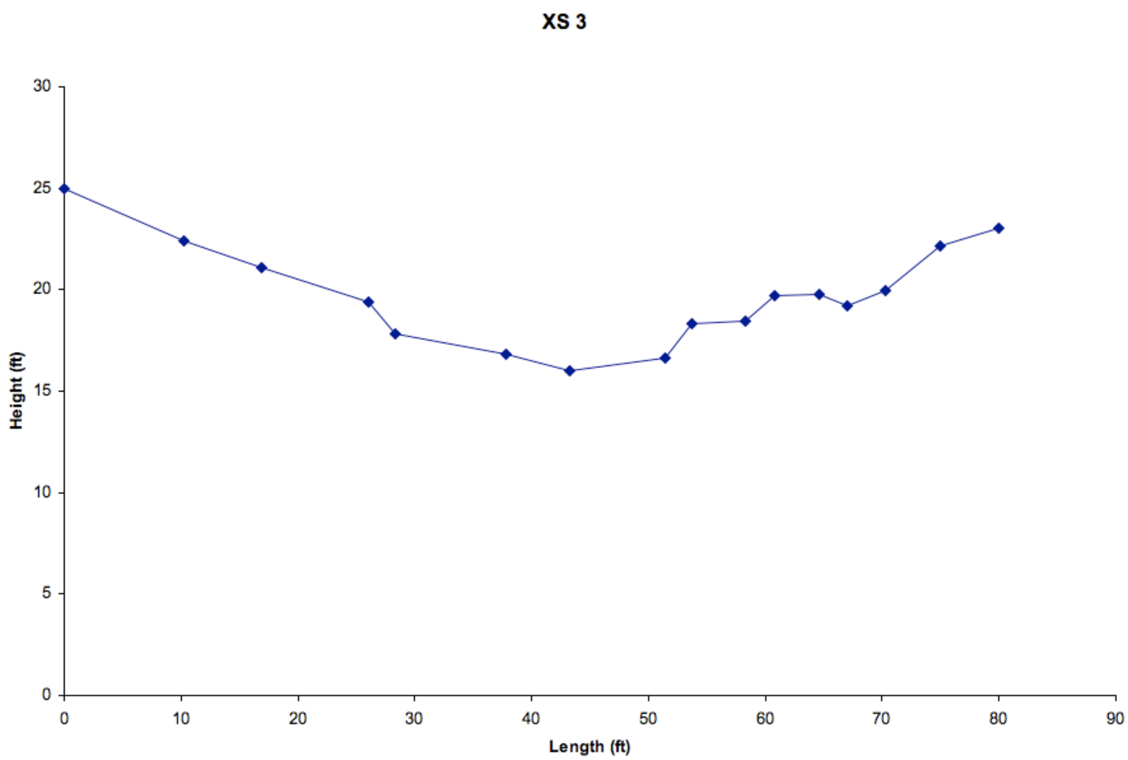


Figure 8. Cross-section 3.

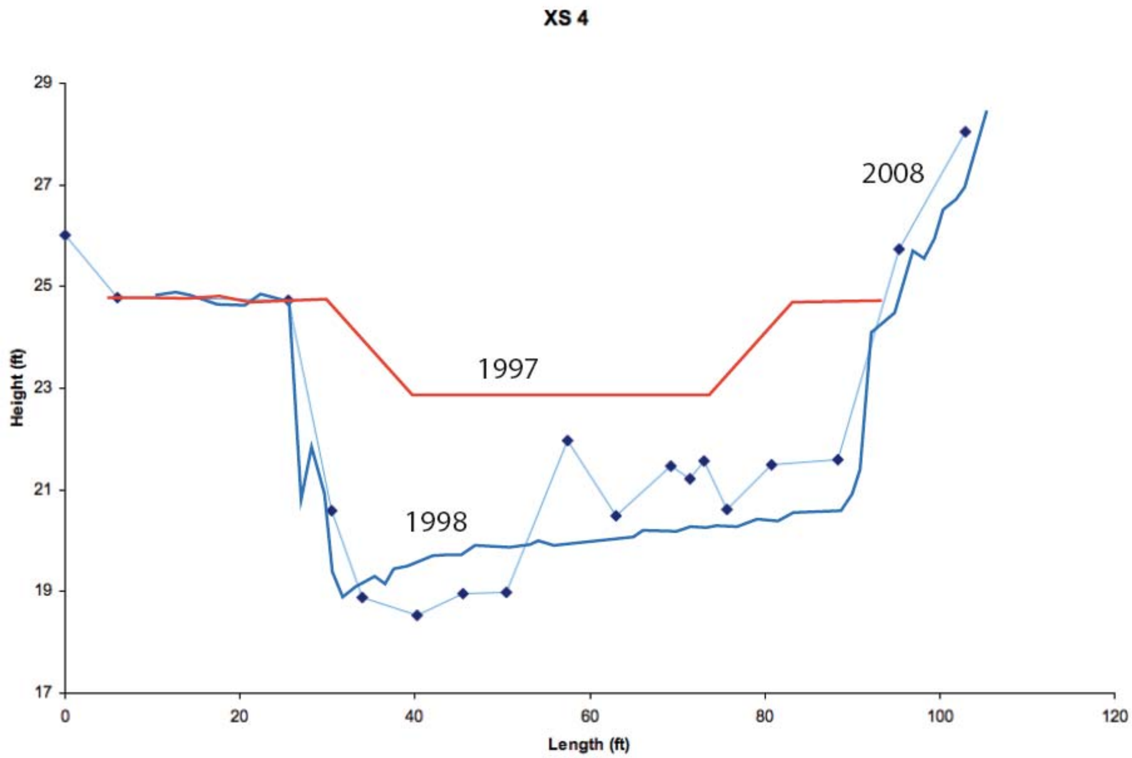


Figure 9. Comparison of 1997, 1998, and 2008 cross sections at XS4 (old XS 5).

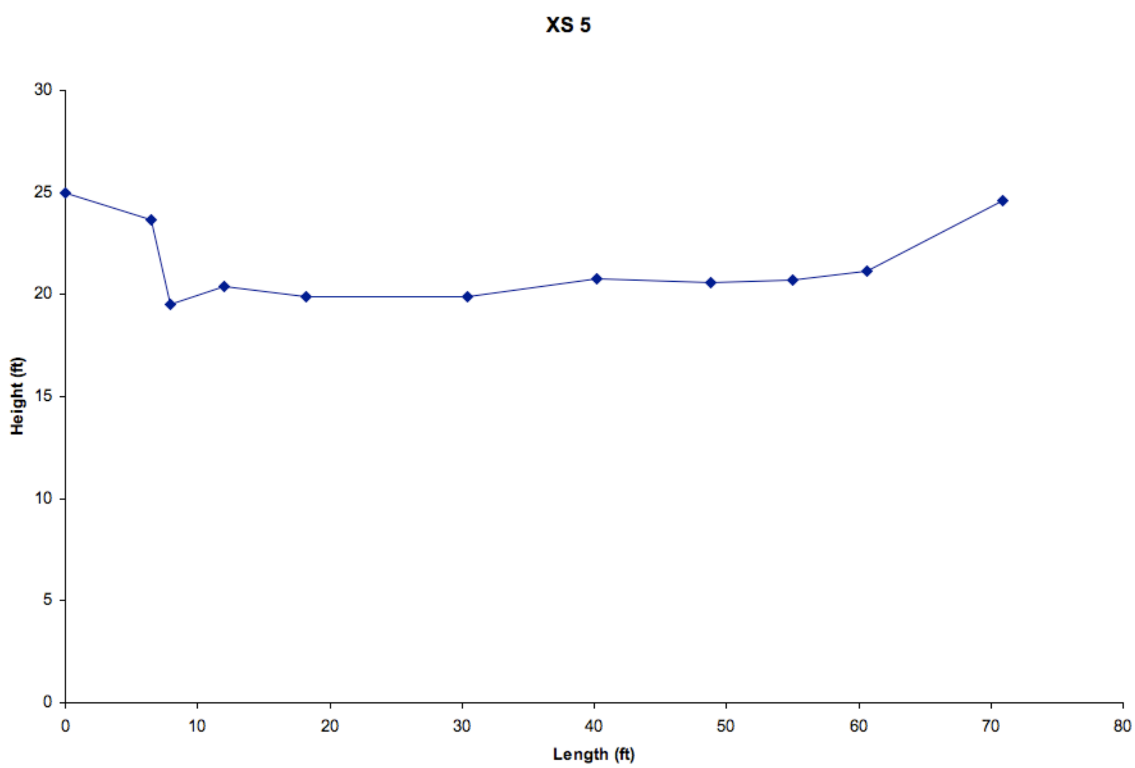


Figure 10. Cross-section 5.

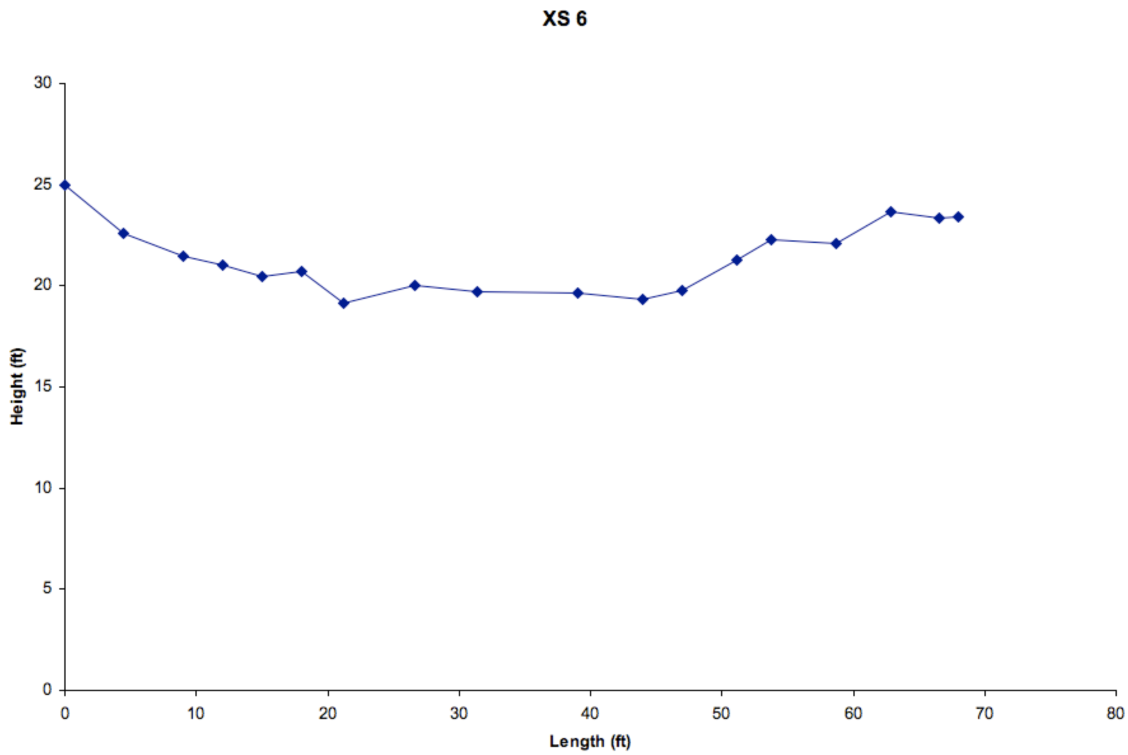

Figure 11. Cross-section 6.

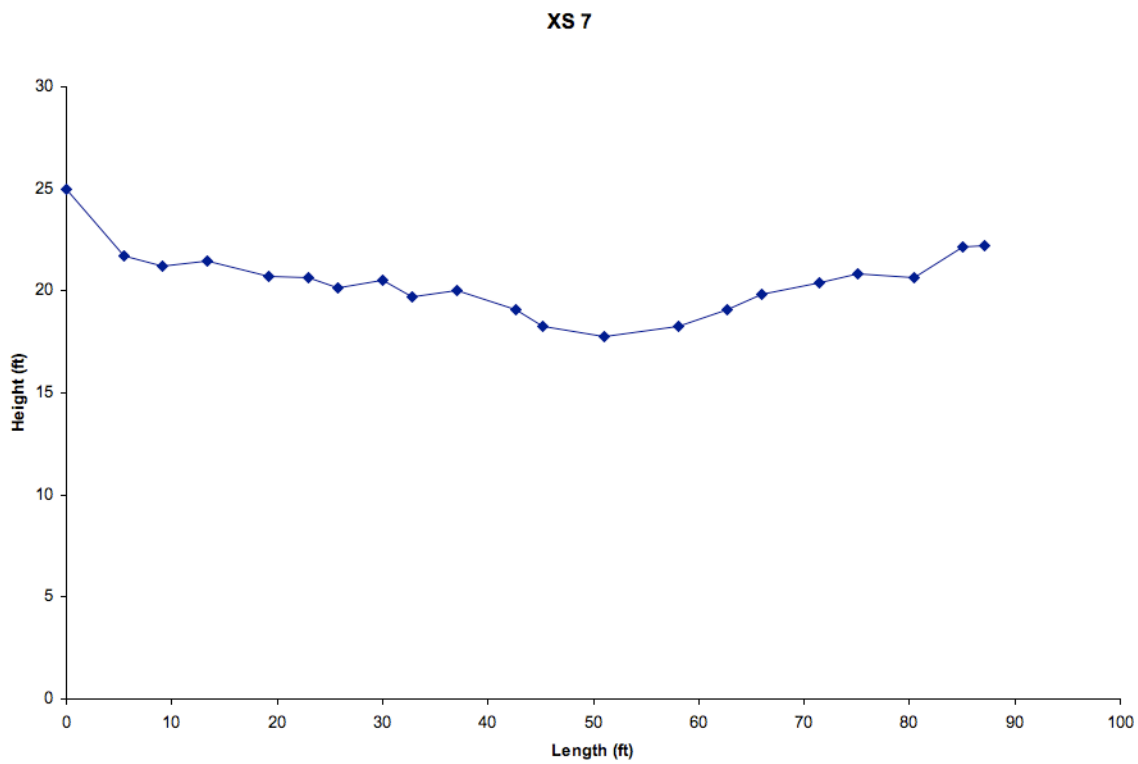

Figure 12. Cross-section 7.

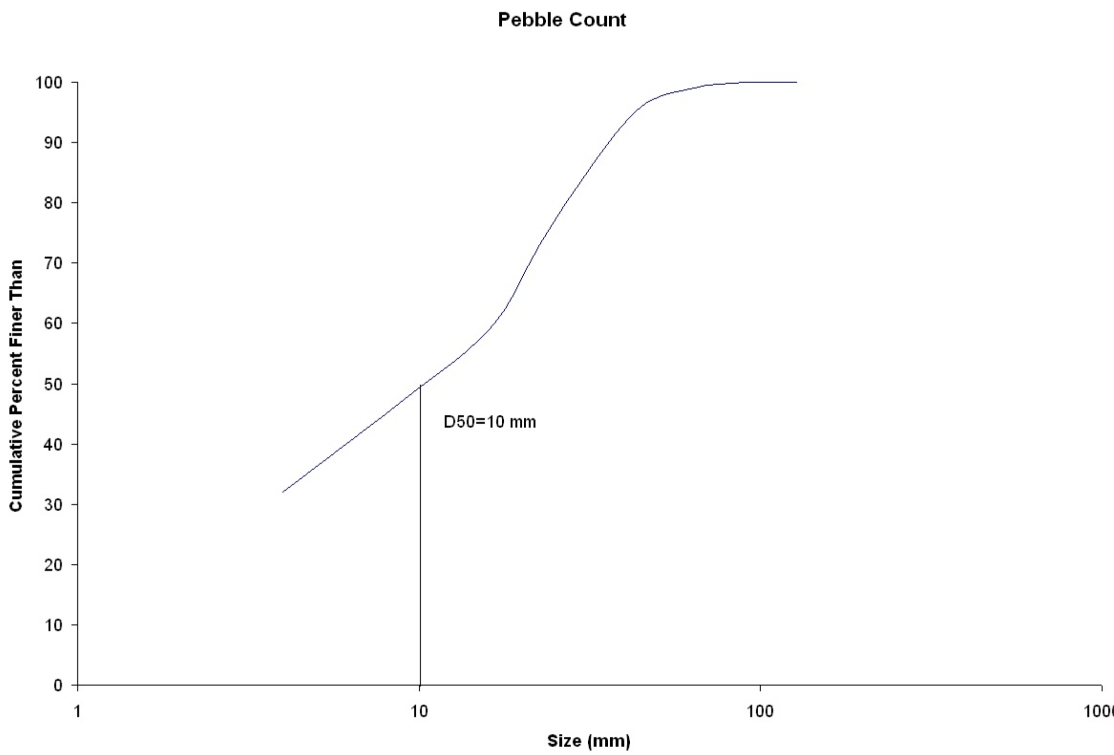

Figure 13. Pebble count under Chorro Creek Bridge.

Table 1. Timeline of documents related to Chorro Flats Floodplain Enhancement Project

| YEAR | DOCUMENT | CONTENTS |
|---|---|---|
| 1975 | United States Army Corps of Engineers. "Sand Transport Analysis of Morro Bay." | Compiled bathymetry data from 1857 – 1974, and documented contributions of littoral drift, Aeolian sand transport, and creek sediment inflow. Concluded 90% of deposition in navigational channels in Morro Bay due to littoral drift, and recommended sand trap. |
| 1979 | Pillsbury, N. "Erosion Sources in Morro Bay Watershed." Prepared for San Luis Obispo County Planning Department. Dated: March 1979 | Summarized known sources of erosion in Morro Bay watershed. |
| 1988 | Haltiner, J. Phillip Williams & Associates, Ltd. "Sedimentation Processes in Morro Bay," Prepared for Coastal San Luis Resource Conservation District, State Coastal Conservancy. | Mapped bathymetry and topography of Chorro/Los Osos Delta, and examined historical changes in bathymetry of bay and morphology of delta. Found that Morro Bay has decreased in volume by about 25% in the last century, mostly from creek-borne sediment, with greatest impacts in south bay and delta areas. Projected that Morro Bay could infill with sediment in 300 years. Human activities of last 150 years have greatly accelerated watershed erosion. |
| 1989 | USDA Soil Conservation Service. "Morro Bay Erosion and Sediment Study" Prepared for Coastal San Luis Resource Conservation District, State Coastal Conservancy. | Identified sediment sediment yields and five primary source areas (rangeland, brushland, woodland, cropland, and urban lands), and methods to reduce sediment loading. |
| 1989 | USDA Soil Conservation Service. "Morro Bay Watershed Enhancement Plan." Prepared for Coastal San Luis Resource Conservation District, State Coastal Conservancy. | Identified implementation measures to reduce erosion in Morro Bay watershed and slow sedimentation. Identified Chorro Flats property as ideal sediment retention site. |
| 1990 | Morro Group and Tenera Environmental. "Freshwater Influences on Morro Bay." Prepared for The Bay Foundation. June 1990. | Identified inflows to Morro Bay from surface runoff, and defined sedimentation effects on biological communities. |
| 1993 | Crawford Multari & Starr, Jones and Stokes Associates, Philip Williams & Associates, Ltd, Habitat Restoration Group, and John Parker and Associates. "Existing Conditions Background Report, Chorro Flats Enhancement and Management Plan, Final Draft 1.0." Prepared for: Coastal San Luis Resource Conservation District, State Coastal Conservancy. | Summarized background information on Chorro Flats site (topography, hydrology, land use, etc.), and constraints and opportunities of this site. |
| 1993 | Crawford Multari & Starr, Jones and Stokes Associates, Philip Williams & Associates, Ltd, and Habitat Restoration Group. "Analysis of Options and Alternatives Report, Chorro Flats Enhancement and Management Plan." | Reviewed the constraints and opportunities of the Chorro Flats site, and identified key issues related to three proposed alternative approaches. |
| 1994 | Crawford Multari & Starr, Jones and Stokes Associates, Philip Williams & Associates, Ltd, and Habitat Restoration Group. "Conceptual Plan - Chorro Flats Enhancement & Management." Prepared for: Coastal San Luis Resource Conservation District, State Coastal Conservancy. April, 1994. | Expanded upon the selected alternative, including identification of specific site components, project implementation steps, and financing. |
| 1995 | Carpenter, M. "Determination of Suspended Sediment Discharge for Chorro Creek and Morro Bay National Monitoring Program." Cal Poly at San Luis Obispo. | Developed monitoring protocol for monitoring suspended sediment loading from Chorro Creek watershed. Student senior project. |
| 1996 | Philip Williams & Associates, Ltd, Jones & Stokes Associates, Crawford, Multari & Starr, and Engineering Development Associates. "Chorro Flats Enhancement and Management Plan, Conceptual Plan Refinement/Final Design Issues." Prepared for: Coastal San Luis Resource Conservation District, State Coastal Conservancy. Dated: January, 1996. | Discussed modification and expansion of several key elements of the conceptual plan. In addition, the document addressed issues related to the proposed design channel, and the impacts on the site from a major fire and significant flood events which occurred following preparation of the conceptual plan. |
| 1997 | Engineering Development Associates and Jones & Stokes Associates, Inc. "Construction Specifications for Chorro Flats Enhancement Project." | Specified requirements for construction of project design. |
| 1998 | Tetra Tech Environmental Services. "Sediment Loading Model for Morro Bay." Prepared for Morro Bay National Estuary Program. | Determined sediment event yields for Morro Bay watershed (Chorro Creek and Los Osos Creek), estimated average historical yield and compared to previous studies. |

| | | |
|---|---|---|
| 1999 | Tetra Tech Environmental Services. “Hydrodynamic Circulation Model for Morro Bay.” Prepared for Morro Bay National Estuary Program. | Model to predict suspended sediment transport and sediment deposition into Morro Bay |
| 1999 | Morro Bay National Estuary Program. “Turning the Tide for Morro Bay: Comprehensive Conservation and Management Plan for Morro Bay.” | Management plan for Morro Bay National Estuary Program. |
| 2002 | Phillip Williams & Associates, Ltd. “Morro Bay Sedimentation: Historical Changes and Sediment Management Opportunities to Extend the Life of the Bay.” Prepared for Central Coast Regional Water Quality Control Boar. Dated: August 20th, 2002. | Summarized existing sediment loading studies and proposed sediment management opportunities. |
| 2002 | Central Coast Regional Water Quality Control Board. “Total Maximum Daily Load for Morro Bay, CA” | Issued TMDL for sediment loading in Morro Bay for 30,020 tons/yr. Required 50% reduction in estimated current sediment loading to Morro Bay. |
| 2002 | Coastal San Luis Resource Conservation District. 2002. “Chorro Flats Enhancement Project, Final Report to the California State Coastal Conservancy.” Available from: http://www.coastalrcd.org/frameset.html. Date Accessed: September 28, 2008. | Evaluated project post-completion, including a description of the project, maintenance activities and monitoring results; strategies for long-term maintenance and monitoring; and lessons learned. |

Table 2. GPS Coordinates from Chorro Flats

| Waypoint ID | Location | Latitude | Longitude |
|---|---|---|---|
| 003 | left bank access road | 35.36037306 | -120.81752345 |
| 004 | access road end | 35.36046216 | -120.81747777 |
| 005 | Structure 1 | 35.36041765 | -120.81736403 |
| 007 | XS1 | 35.36019486 | -120.81742588 |
| 008 | Structure 2 | 35.36003703 | -120.81658149 |
| 009 | XS2 | 35.35993821 | -120.81670219 |
| 010 | Structure 3 | 35.35901754 | -120.81516160 |
| 011 | XS3 | 35.35893205 | -120.81527785 |
| 012 | XS4 (1998 XS5) | 35.35825445 | -120.81399710 |
| 013 | XS 5 RB (1998 XS27) | 35.35826803 | -120.81458115 |
| 014 | Twin Bridges | 35.35448411 | -120.82795573 |
| 015 | XS6 | 35.36004416 | -120.82088920 |
| 016 | XS7 | 35.36007157 | -120.82110839 |

| Table 3. Soil Samples from Cross Sections | |
|---|---|
| | |
| XS 1 | |
| Distance from benchmark (meters) | Description |
| 1.2192 | silty clay |
| 8.5344 | sand, small-medium cobbles @ 6 in. depth |
| 11.8872 | fine sand, small-medium cobbles @ 6 in. depth |
| 16.4592 | small to medium coarse gravel small |
| 21.0312 | sand to 8 in. depth |
| | |
| XS 2 | |
| Distance from benchmark (meters) | Description |
| 0.6096 | fine sand |
| 6.7056 | medium coarse sand |
| 12.192 | samll gravel, max size 1.5 in. |
| 16.002 | coarse sand to 6 in. depth |
| | |
| XS 3 | |
| Distance from benchmark (meters) | Description |
| 0.24384 | coarse sand, 8in depth to clay hardpan |
| 3.9624 | coarse sand, 8in depth to clay hardpan |
| 7.0104 | fine sand to, 12in depth to clay hardpan |
| 10.668 | small - medium size gravel |
| 16.764 | fine sand to 10in., wet clay 10 to 14in, |
| | |
| XS 4 | |
| Distance from benchmark (meters) | Description |
| 0.9144 | dry clay with few small cobbles to 5in. Depth |
| 7.52856 | coarse sand to 12 in. depth |

| | |
|---|---|
| 10.24128 | small gravel |
| 17.6784 | fine sand, no cohesion |
| 20.1168 | fine sand, no cohesion |
| 24.0792 | fine sand, small gravel @ 8in. Depth |
| 27.432 | clay |
| | |
| XS 5 | |
| Distance from benchmark (meters) | Description |
| 1.9812 | clay, silt |
| 3.6576 | small cobbles |
| 12.25296 | medium cobbles |
| 14.87424 | small cobbles |
| | |
| XS 6 | |
| Distance from benchmark (meters) | Description |
| 1.524 | silty clay, wet, cohesive, roots @ 3in. Depth |
| 5.6388 | silt, roots @ 3in. Depth, wet clay @ 12in. Depth |
| 16.1544 | wet sand @ 1in. Depth, dry fine sand below to boulder @ 6in. |
| 17.9832 | wet, coarse sand @ 4in. Depth |
| | |
| XS 7 | |
| Distance from benchmark (meters) | Description |
| 1.70688 | fine silt to 5in. Depth, dark silt @ 1.5" depth |
| 7.1628 | wet clay to 5in. Depth |
| 11.33856 | dry coarse sand and small cobbles to 8" depth |
| 19.9644 | dry coarse sand and small cobbles to 6" depth |
| 22.76856 | fine cohesive sand, no cobbles to 8" depth |