Title

Post-Project Evaluation of Channel Morphology, Invasive Plant Species, and Native Fish Habitat in Putah Creek in Winters, CA Six Years After Channel Relocation

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Abstract

Putah Creek (drainage area = 2,000 km^2) drains the slopes of Cobb Mountain in Lake County, flowing 137 km southeastward into the Yolo Bypass near Davis, California. Lower Putah Creek, the 37km reach from the Solano Diversion Dam to the Yolo Bypass, is confined within a flood control channel. Dry Creek (drainage area = 44km^2) joins Putah Creek near Winters, California. Putah Creek is regulated by water releases from Monticello Dam at Lake Berryessa. Dry Creek flows only part of the year and has no dams. Southward channel migration of Putah Creek from the 1990's was threatening Putah Creek Rd., a paved county road following the south bank of the evaluated stream-section. The new location of the Putah Creek channel also reduced the amount of gravels entering Putah Creek from Dry Creek. This was significant because dams reduced the amount of course sediment available from upstream, leaving Dry Creek as one of the only natural sources of the gravels important to the ecology of Putah Creek.

In 2005, the Lower Putah Creek Coordinating Committee implemented a project to move the channel of Putah Creek northward to its approximate historical course. The project included the removal of invasive giant reed (*Arundo donax*), in part because *Arundo* appeared to have contributed to the unwanted channel avulsion. We evaluated the project performance towards the goals of 1. protecting Putah Creek Road, 2. keeping invasive plant species out of the area, 3. facilitating natural transport of Dry Creek gravels into Putah Creek, and 4. improving salmonid habitat. Our evaluation found that 1. Putah Creek has stayed within the general path of the design channel and is not returning to the southern pre-1997 channel which threatened the road,

2. there is a mix of native plant species (e.g. willow, cottonwood) and invasives (e.g. *Arundo*, blackberry) in the floodplain, 3. There is no physical barrier separating Putah and Dry Creek, 4. the channel and floodplain provide good habitat complexity for native fish, but fine sediments cover most of the potential spawning gravels.

Introduction

This report evaluates a restoration project undertaken at the confluence of Putah Creek and Dry Creek, in the town of Winters, California. The project was designed and carried out by the StreamWise restoration company of Mt. Shasta, CA. Our information on the original goals, methods and motives of the restoration project are largely informed by the "Dry Creek / Putah Creek Confluence Revised Restoration Proposal," prepared for the Lower Putah Creek Coordinating Committee by StreamWise. The proposal indicates that in 1997 Putah Creek changed its course at its confluence with Dry Creek. The creek channel cut southward through an existing roadbed, eroding the bank below a paved county road called Putah Creek Road. A gravel delta formed at the confluence of the two creeks, cutting off the pre-1997 channel (Figure 1). The proposal's authors suggest that a thick stand of the invasive plant Giant Reed (*Arundo donax*) provided the flow resistance which caused the creek to turn and cut into the easily erodible roadbed (StreamWise 2004). They believed that the gravel delta was a result rather than a cause of the channel avulsion, claiming that the peak flows of 11,485 cfs on Jan. 17, 1997 were "capable of moving volumes of gravel sediment similar to the delta at Dry Creek in a matter of minutes" (StreamWise 2004). The StreamWise report asserts that the 2004 location of the channel was a problem not only in terms of hazard to Putah Creek Road, but also in terms of gravel: "influx of coarse gravel from Dry Creek may tend to fill in remnant channels below the confluence and not supply significant volumes to the Putah Creek channel" (2004). This lack of gravel is a problem because the dams upstream of this site block the passage of most of the gravel that would historically have been transported downstream, and thus Dry Creek provides one of the major sources of gravels that can be used for salmonid spawning in Putah Creek.

In December of 2005, the restoration team removed all *Arundo* growing near the confluence and relocated the creek channel back to a more northward location to protect Putah Creek Road in a way that was more ecologically friendly and sustainable than the original plan of stabilizing the bank with rip-rap (Rich Marovich, Personal Communication, November 2011). Relocating the channel also ensured that Putah Creek could access the important gravel source of Dry Creek, and allowed an opportunity to create a riparian area which would provide good habitat for native fish.

The purpose of this report is to describe the current state of the restored area at the Putah/Dry Creek confluence and assess to what extent the restoration objectives have been met so far. Specifically, we looked at changes in erosion that were threatening Putah Creek Road, success of invasive plant removal, evidence that Putah Creek is accessing gravels supplied by Dry Creek, and whether or not the restored reach provides adequate salmonid habitat in terms of habitat complexity and presence of clean spawning gravels.

Watershed Context

The Putah Creek watershed encompasses over 2,000 square kilometers within Lake, Napa, Solano, and Yolo counties (Figure 2). The creek itself begins in Lake County off of Cobb Mountain. Lower Putah Creek, the 37km reach from the Solano Diversion Dam to the Yolo Bypass, is confined within a flood control channel. Lower Putah Creek is fed by controlled flows from Lake Berryessa and the Monticello Dam, northwest of the study area (Solano Co.Water Agency 2008). Lake Berryessa, formed by the Monticello Dam, is one of California's largest reservoirs with a capacity of 1,602,000 acre-feet, providing agricultural irrigation as well as municipal and industrial water supplies (Sacramento River Watershed Program 2011) (Figure 3). Construction of the Monticello Dam in 1957 caused a decrease in sediment load and flow levels in Putah Creek (Figure 4). The Dry Creek watershed covers an area of 44 square kilometers and is an unregulated, intermittent stream which contains water less than one month out of the year on average (StreamWise 2004). Putah Creek is very different today than it was a century ago. Changes include decreased flows, decreased sediment load from upstream, fish barriers in the forms of dams, and the influx of invasive *Arundo.*

Project Site

The restored reach we studied lies about 2.4 miles below the Solano Diversion Dam on the South edge of Winters, CA. The reach begins at the confluence of Putah Creek and Dry Creek, continuing approximately 1,000 feet downstream (Figure 3). In the 1870's, a portion of Putah Creek was redirected into an irrigation ditch south of the former channel to protect nearby land from flooding. Other human interventions over the last century include the removal of riparian vegetation, flood-control levees, bridges that have cut off floodplain access and the upstream dams. The Monticello Dam and Solano Diversion dam, constructed in the late 1950's, have buffered flood-flows (Figure 4). These lower flows within Putah Creek increased the surface water slope of the unregulated Dry Creek at its confluence with Putah Creek, leading to the down-cutting of Dry Creek (StreamWise 2004).

Rivers with large dams can experience an effect known as "hungry water", in which water below a dam is low in sediment content and therefore has extra energy which is spent on bank erosion (Kondolf 1997). Putah Creek experienced this effect, and incised "over 20 feet below historic[al] elevations" in some areas (StreamWise 2004). Monitoring data from 2002-

2004 shows the lateral migration and incision which occurred during this period (Figure 5). StreamWise targeted winter releases in 2004 as the primary factor of the major channel changes seen between 2002 and 2004 (StreamWise 2004).

Evaluated Project

The original restoration objectives for this project were formulated through a participatory process with the stakeholder community (StreamWise 2004). For our evaluation, we divided the original project's objectives into four categories: Stopping erosion threatening Putah Creek Road, removing invasive plants, facilitating access of gravels from Dry Creek, and improving salmonid habitat quality.

Restoration Actions Taken

Channel Relocation

After removing the invasive *Arundo*, the restoration team redirected the Putah Creek channel toward the mouth of Dry Creek and a new channel was dug in the approximate pre-1997 channel location (StreamWise 2004). The restoration team used buried tree trunks to stabilize the bank for this relocation (StreamWise 2004), (Rich Marovich, 05 Nov 2011). The proposal states that channel design should discourage any erosion hazard near Putah Creek Co. Road, yet allow the stream to migrate within certain boundaries. The location of the new design channel was also chosen because it provided an easy path for gravels to move from Dry Creek into Putah Creek. According to the StreamWise report, the 2004 location of the channel was a problem in terms of gravel influx because "influx of coarse gravel from Dry Creek may tend to fill in remnant channels below the confluence and not supply significant volumes to the Putah Creek channel". With upstream dams already reducing the sediment load of Putah Creek, Dry Creek is a crucial supply of Putah Creek's streambed with spawning gravel for salmonid habitat. The StreamWise proposal also stated that native fish life cycles were threatened by suspended fines and silted gravels, though it offered no bedload analysis to support or explain this (StreamWise 2004). The proposal claimed that the reduction of lateral erosion after creation of a new channel would reduce fine sediment influx.

Pond Excavation and Designed Floodplain Fill

Restoring historical elevations to the channel to allow access to the former floodplain was incompatible with existing development. Instead, the former channel was filled in to floodplain level and graded after the excavation of a new channel. This provided a lower floodplain accessible to water in the constructed channel. The purpose was to disperse flood waters over the new floodplain to slow lateral erosion by encouraging dissipation of energy. The restoration team obtained fill material from identified sites chosen for minimized ecological disruption (Figure 6).

Revegetation

After redirecting the creek into the constructed channel, the restoration team revegetated the disturbed "Pond and Fill" site and planted native plants in areas most prone to erosional stress along the channel banks, especially the outer edges of bends (StreamWise 2004). The revegetation also included seeding of native grasses, though these seeds were washed away in the high flows that followed soon after the seeding was done (Rich Marovich, 05 Nov 2011).

Methods

After reviewing the goals and objectives of the proposal guiding the restoration effort and speaking with Rich Marovich, Streamkeeper for the Putah Creek Coordinating Committee, we established the following performance criteria:

1. Low levels of lateral erosion and enough stability of the channel form to avoid recapture of its southern channel.
2. Minimal presence of invasive plants.
3. Path for gravel to enter Putah Creek from Dry Creek remains unobstructed.
4. Fish habitat improvement (specifically diverse habitat and clean spawning gravels).

To accomplish our evaluation, we compared 2005 survey conditions with those existing today to establish whether the progression of actual changes are consistent with those sought through this project's goals. Our post-project monitoring of the site involves both qualitative and quantitative observations; evaluating the creek in its current location and condition to inform recommendations for improvements and future monitoring. We supplemented our observations with information from an interview with Rich Marovich, a streamkeeper for the Solano County Water Agency (Appendix C).

<u>Site Mapping</u>

We documented the November 2011 condition of the site with photographs tied to GPS coordinates and used GPS points to map out areas of interest along the restored creek (Figures 7,10). This mapping was aimed at identifying locations of high erosion, sediment deposition, native fish habitat and invasive species growth to create a general picture of the current state of the channel and floodplain. We divided the restored reach into ten 100 foot sections starting at the Dry Creek confluence and going downstream in order to make the areas we mapped easier to locate (Figure 7).

<u>Topographic Surveys and Aerial Photograph Interpretation</u>

We re-surveyed two of the 2002 creek bed transects as close as possible to the original project locations. Our Transect DP-1b started at the left bank pin for the original DP-1 transect. Our second transect was along the original DP-3 transect, though the left bank endpoint had to be estimated since we could not locate the left bank pin (Figure 8). Our assessment of geomorphological changes was supplemented by aerial photos from Google Earth available over a period of several years before and after project construction. We used photos taken between 2004 and 2009 to gain an understanding of changes in vegetation and topographic features. Since no transect topographic survey data for as-built conditions was available, we used LiDAR data from a DWR survey conducted in 2005 to compare our transects to as-built conditions (Figure 8). We also measured depth and width along a longitudinal profile (Figure 9).

Invasive Plant Species

We mapped the distribution of *Arundo* using GPS (Figure 10). Since the original project was largely motivated by the perceived detrimental influence of *Arundo* on the channel, its continued absence is critical to successful and sustainable restoration.

Sediment Size Analysis

In our field notes (Appendix D) and maps (Figure 7, Appendix D) we noted areas with fine sediment, clay, clean gravel, or gravel with embedded fines. We also conducted a pebble count at the mouth of Dry Creek to get an idea of the size distribution of sediment entering Putah Creek from this tributary. For our pebble count we measured the widths of one hundred pebbles selected at random from the surface of the dry creek bed. We defined the width as the diameter of the smallest sieve hole that a given pebble could pass through.

Fish Habitat Quality Assessment

Our pebble count at the mouth of Dry Creek allowed us to assess whether the sediment entering Putah Creek is an appropriate size for salmonid spawning. Native fish in Putah Creek fare better with high water quality, low water temperatures, fast-flowing water, and structurally complex habitats (Marchetti and Moyle 2001). We examined the literature for information on water quality that could be relevant to native fish. We also mapped different stream habitat characteristics, such as woody debris and alternating pool/riffle features.

Results

Site Mapping

We found locations that could be confirmed for comparison with historical photos six years post-project were very limited. Our photographs are divided into 100 foot segments of the river, and therefore will hopefully be useful for comparing with future stream conditions. Our photos and maps show channel form and the results of revegetation. The documented map correlated with GPS from our observations of relevant attributes such as facies distribution, riffles and pools, erosion and woody presence, can be used as a record of current conditions (Figure 7). Our team also created a hand-drawn map accompanied by field notes (Appendix D).

Select photos of the creek are in appendix A and field notes are in appendix D.

Channel Form, Erosion, and Sedimentation

There were some changes in the channel shape within a few months of its construction due to extremely high flows in January of 2006, though this variation from the design location was minimal (Figure 11), (Rich Marovich, 05 Nov 2011). The creek has scoured a deep pool under transect DP-3 in the time since the design channel was built (Figure 12). Although the left bank along DP-3 has become slightly steeper since 2005, the right bank has adopted a shallower gradient. Transect DP-1b, which is located at the confluence of Putah and Dry Creek, also shows a deepening pool (Figure 13). Our transects cover only pools, but we also observed many riffles. These riffles have all formed in the years following channel construction, since the constructed channel had a flat bottom and uniform depth (Rich Marovich, 05 Nov 2011).

According to Marovich, post-project monitoring a year after the project found that gravel movement from the Dry Creek bed was in process. Upon return for a later survey however, Marovich found the gravels covered by fines (Rich Marovich, 05 Nov 2011).

Our survey of transect DP-1b shows that there is no new gravel delta forming at the confluence of the two creeks. There appears to be a large amount of aggradation in the middle of the transect (Figure 13) but it is unclear whether this is all due to natural deposition or whether some was due to mechanical moving of the soil that occured after elevation measurements in 2005. Either way, there is still a wide pool cutting through where the gravel delta used to be, and the bed of Dry Creek transitions smoothly into Putah Creek (Figure 14), so there is no barrier blocking gravels from moving from one stream into the other.

Vegetation

We found a combination of native and invasive plant species growing in the riparian corridor. It is obvious by the size (~DBH > 15cm) of some native trees that they have been there since before the restoration project, but others were planted recently (mostly willows). The most notable invasive species were Himalayan blackberry and *Arundo*. Although the *Arundo* was all removed with herbicides in 2005, some large (over ten feet in diameter) patches have grown back (Figures 10,15). Streamkeeper Rich Marovich affirmed that there is much less *Arundo* than there was before the project began, and showed us locations where dead *Arundo* stalks prove that spraying with herbicides has been successful.

Fish Habitat and Sediment Size

The only large woody debris we found in the water was located in two beaver dams. There are large trees along the southern bank, but canopy cover directly over the creek ranged from zero to only about 25% (estimated visually). There is a combination of pool and riffle habitat (Figure 9). About 30% of the length of our 1000 foot longitudinal profile is pools and about 40% is riffle. There are many gravel bars and areas with gravel in the creek bed, but most of the in-stream gravel is silted over. In general, riffles where the fast-flowing area is less than 15 feet wide have clean gravel (such as between 146 and 200 feet along our longitudinal profile and around 540 feet). In contrast, wider areas had mud, clay, or silty gravel in the streambed.

Post-Project monitoring observations in 2006 included numerous indicators of aquatic health from the invertebrate community, specifically two distinct species of stonefly, which do not thrive in low-oxygen environments (Wildlife Survey and Photo Service 2006). These habitat conditions are also beneficial to native fish.

Researchers have observed native fish in Lower Putah Creek, though salmonids are relatively rare (UC Davis 1998, Marchetti and Moyle 2001). According to the Putah-Cache Bioregion Project findings, the Dry Creek confluence had one to two orders of magnitude more native larval fish between 1994 and 1998 than the other sites sampled in Putah Creek (UC Davis 1998) (Details in Appendix E). This suggests a past native preference for spawning and rearing at the Dry Creek site and shows the importance of providing adequate habitat at this location. Salmonids use clean freshwater gravels to cover their eggs during incubation. One study of 135 salmonid spawning sites found that median grain sizes in these sites ranged from 5.4-78mm, with 50% of the medians falling between 14.5 and 35mm. One species which was included in the gravel study and has been found in Putah Creek is Chinook salmon, which had a median grain size of 31-66mm among California sites (Kondolf and Wolman 1993). Our pebble count at the mouth of Dry Creek showed a median grain size of 16mm (Figure 16). This is at the low end of the 5.4-78mm range for spawning gravels found by Kondolf and Wolman (1993). Although the median is not in the 31-66mm range found for California Chinook, we did find pebbles in this size range. In fast flows, pebbles would theoretically become roughly sorted by size and potentially create gravel beds in Putah Creek with a larger median grain size. The presence of pebbles within the size range used by spawning salmonids within Dry Creek shows that it is possible for spawning habitat to be formed by the gravels it holds.

Young fish which have access to floodplains have empirically observed higher growth rates, known as the ‘‘flood pulse advantage” (Figure 17). This advantage is a feature of floodplains which opens up the river system to greater and more diverse food resources, also providing shelters for hiding, increasing the successes of native fish survival against predators and other environmental circumstances. Along with supporting the largest fisheries, floodplain rivers also host greater diversity along with the services of surface water filtration, groundwater recharge, recreation, fish, timber and other plant resources with flood-management for low maintenance costs (Opperman et.al. 2010). Photographs of the restoration site from 2008 show that the creek has inundated the floodplain since the restoration project, meaning it is possible for fish to access the floodplain at least part of the year (Figure 18).

Discussion

Channel Morphology and Erosional Hazards

The changes we observed in channel shape were minimal, and do not create a hazard for Putah Creek Road (Figure 19). In some locations, the creek migrated outside of its design channel (Figures 8). It is now under-cutting the north bank of the flood control channel and depositing sediment into the stream bed which may be counter to the efforts to establish fish spawning gravel which needs to be clean gravel.

To help determine whether erosion from the banks is negatively affecting the spawning gravels, future research should create a sediment budget for this section of Putah Creek which includes sources from lateral erosion, flow through the dams, runoff, and Dry Creek. It is debatable whether the current erosion is due to instability in the current creek form or due to natural and even desirable small migrations of the creek bed. The presence of fine sediments could also be due to the inability of low, controlled flows to flush the gravels clean (StreamWise 2004, Kondolf 1997). Marovich observed clean gravels immediately after the relatively high flows of 2006, which suggests that allowing greater releases from Monticello Dam might address the siltation problem.

Fish Habitat

The gravel size and quantity seem sufficient to provide salmonid spawning beds, though most gravel in the streambed is silted over. The creek has evolved from the homogeneous design channel to have a series of riffles and pools (Figure 9), (Photos A.6 and A.8) as well as meanders with gravel bars (Figures 20 and 21). This increased complexity is good for fish habitat since it offers places for fish to hide from predators and rest from fast flows, and leads to the cool water native fish need (Marchetti & Moyle, 2001).

Fish habitat quality at one site alone is not enough to restore a creek, and the restoration project we have evaluated here is just one of a number of other ecological restoration projects along Lower Putah Creek. These sites provide nodes of habitat that adapt to land ownerships challenges (details in Appendix B). Any future alterations to the Dry Creek confluence restoration site, including varying dam releases, should take into account the high habitat value of locations downstream. For example, increasing the amount of water releases could help juvenile salmon spawned at the Dry Creek confluence reach the rearing grounds in the Yolo Bypass.

Summary

The StreamWise project proposal does not include any alternative scenarios. No mention was made as to the feasibility of other options such as re-locating the Putah Creek Co. road. Though the proposal states that the channel should be allowed to migrate within a controlled region, it does not differentiate what types of erosion may be helpful or harmful to restoration objectives. As for addressing the underlying issues which led to the initiation of this project, though it is theorized by StreamWise that the channel would not migrate from the design channel aside from a major release event, the credibility of this statement seems uncertain as the run-off from Dry Creek along with low Putah Creek flows will most likely continue the sediment transport process. In designing our evaluation, we had to infer many of the criteria for success of the restoration project ourselves. Articulating clear metrics of project success within the project proposal could aid in accomplishing the goals of restoration, offering specific attributes which can be monitored for appropriate responses. Such metrics could include quantity of gravels transported, a sediment budget analysis of bedload contribution sources, flow levels required for the design floodplain inundation, and water temperatures, to name a few.

Although the original project objectives may fit into a process-oriented view of restoration through the proposal of a floodplain, the opportunities within the watershed context may not have been considered. The floodplain designed for this project may function in the form of flood-control, but fish benefits from the flood-pulse advantage are more likely to be achieved in lower, wider floodplains (Opperman et.al.2010). The Yolo Bypass has been identified as such a system, which could offer the benefits to juvenile fish after completing their larval stage at the confluence which fish already use for spawning (Natural Heritage Institute et.al. 2002). Considering the role of the project site within the context of the watershed could have led the restoration team to prioritize around the fish life-cycle, making juvenile access to the Yolo Bypass part of the proposed strategy.

In terms of hazards to Putah Creek Road, erosion on the south side of the creek is limited to few minor areas. There is more erosion on the north side of the creek which may be contributing fine sediment to the channel. It is debatable whether this erosion is due to instability in the current creek form or due to natural and even desirable small migrations of the creek bed. The reduction of flooding downstream of dams can lead to the buildup of fine sediment from tributaries since there are not many high flows which can was this away. The encroachment of vegetation (such as *Arundo*) into the active channel is also a common occurrence downstream of reservoirs due to the reduction in streambed scouring by high flows. Further research should investigate the role of lateral erosion in the presence of silt in Putah Creek's gravel beds, as well as the beneficial effects that might be achieved from occasionally increasing flow releases to flush fine sediment out of gravel beds. Such releases could also provide juvenile fish with access of the floodplain at the Yolo Bypass (Kondolf 1997).

Overall, the positive aspects of the creek's current state are that the stream form is developing complexity, there is no longer an imminent risk of erosion at Putah Creek Road, and there are gravels entering the stream. Issues that may still need to be addressed are that many spawning gravels are embedded with fine sediment, and the Arundo needs to be removed again. We hope the findings in this monitoring project will be useful for making decisions in how to proceed with management of Putah Creek, as well as for planning future restoration projects in this and other similar watersheds.

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Figures

Figure 1. This 2005 Google Earth photo shows the gravel delta formed at the confluence of the creeks.

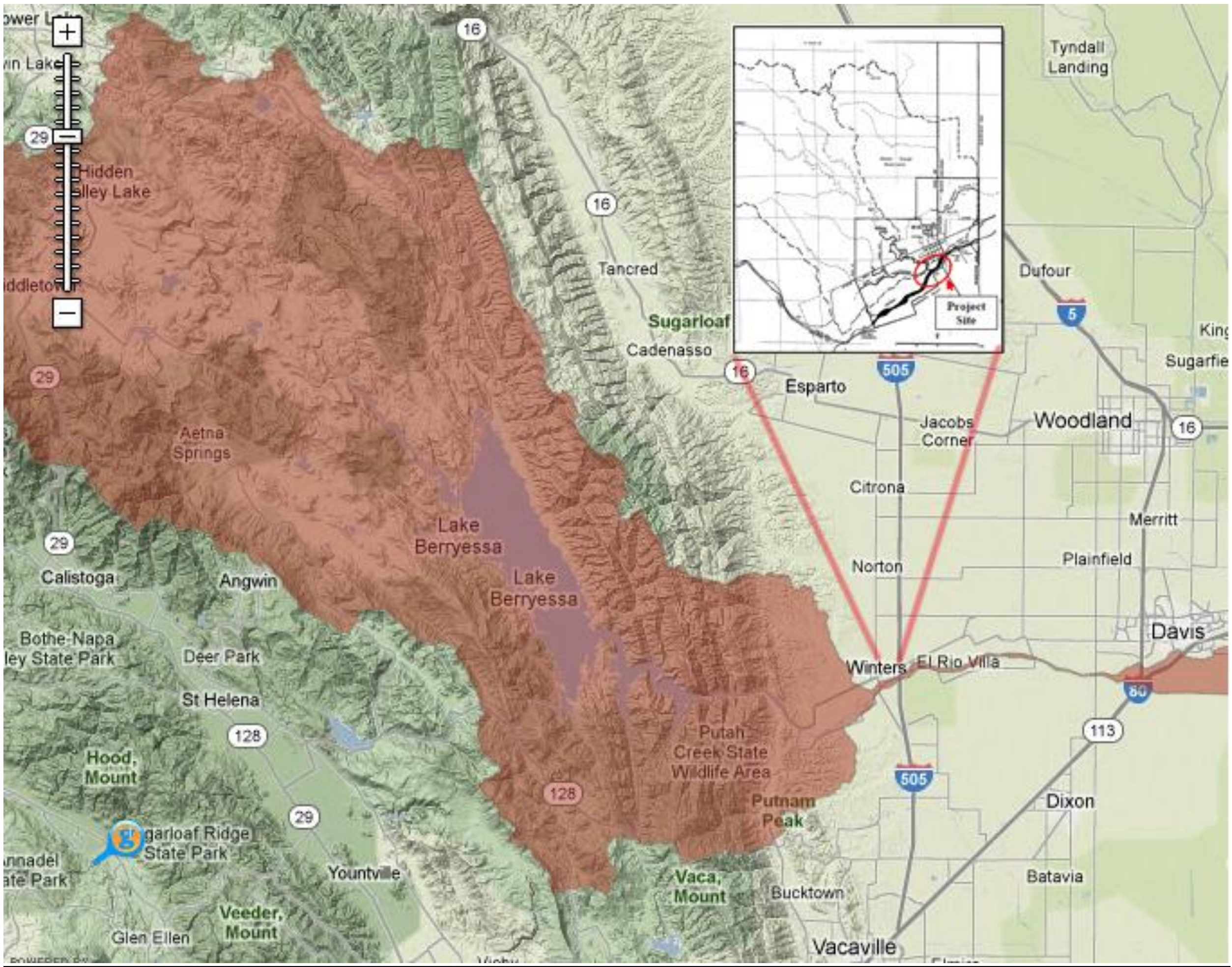


Figure 2. Putah Creek Watershed. Source: Sacramento River Watershed Program 2011, <http://www.sacriver.org/aboutwatershed/roadmap/watersheds/westside/putah-creek-watershed>

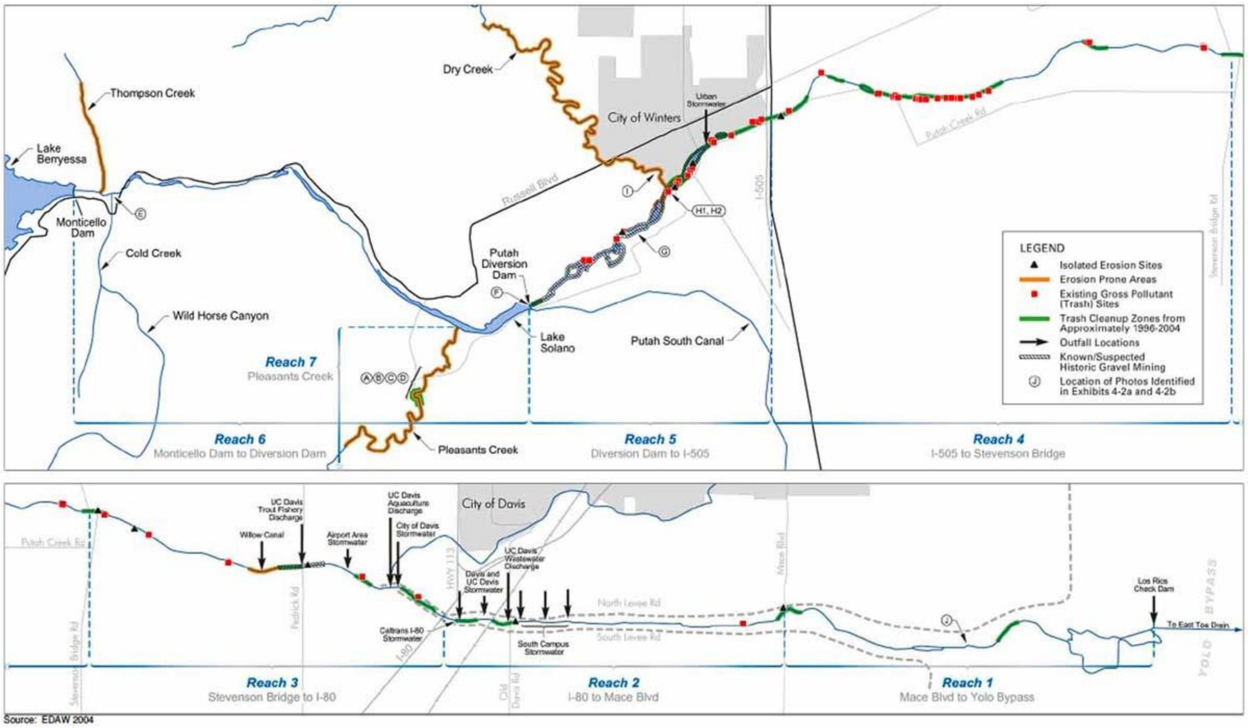


Figure 3. Lower Putah Creek Reach. Source:EDAW 2004

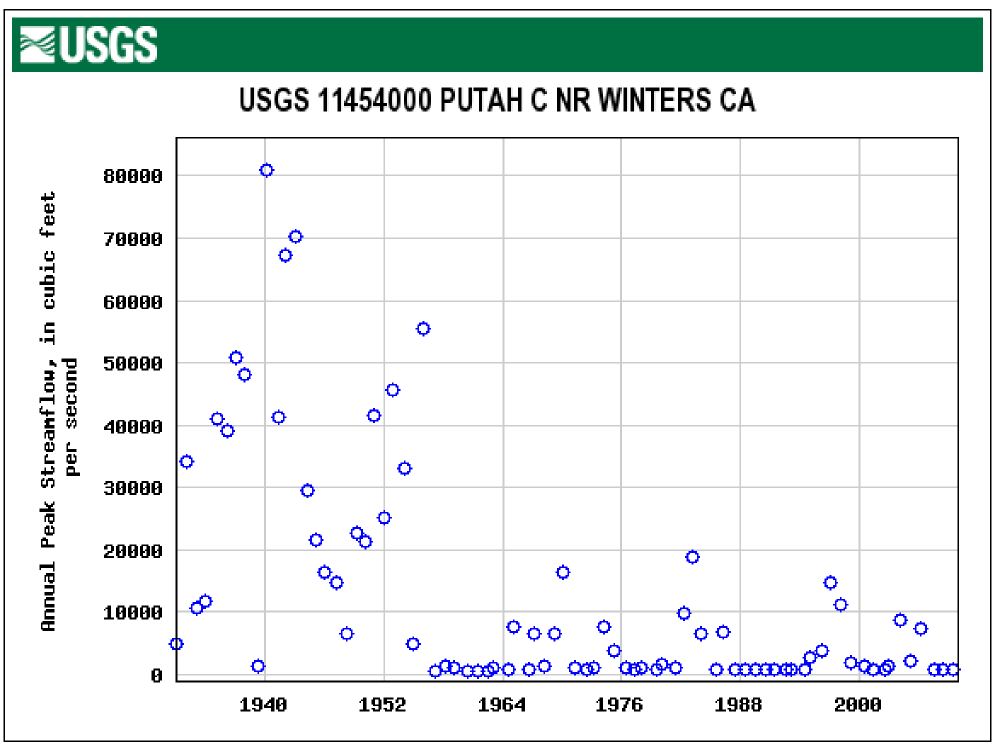


Figure 4. Annual peak streamflow in Putah Creek. Note drastic decrease after completion of the Monticello dam in 1957. Source: <http://nwis.waterdata.usgs.gov>.

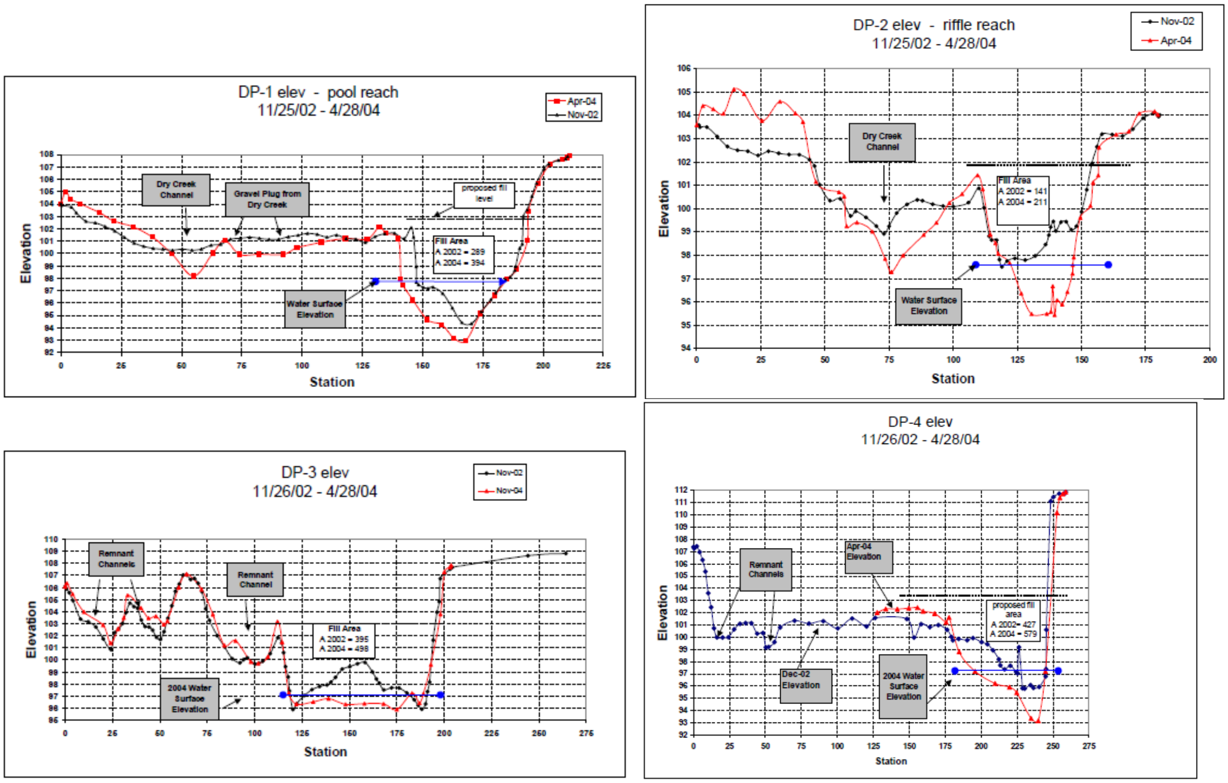


Figure 5. Transects from 2002 and 2004. (StreamWise 2004).

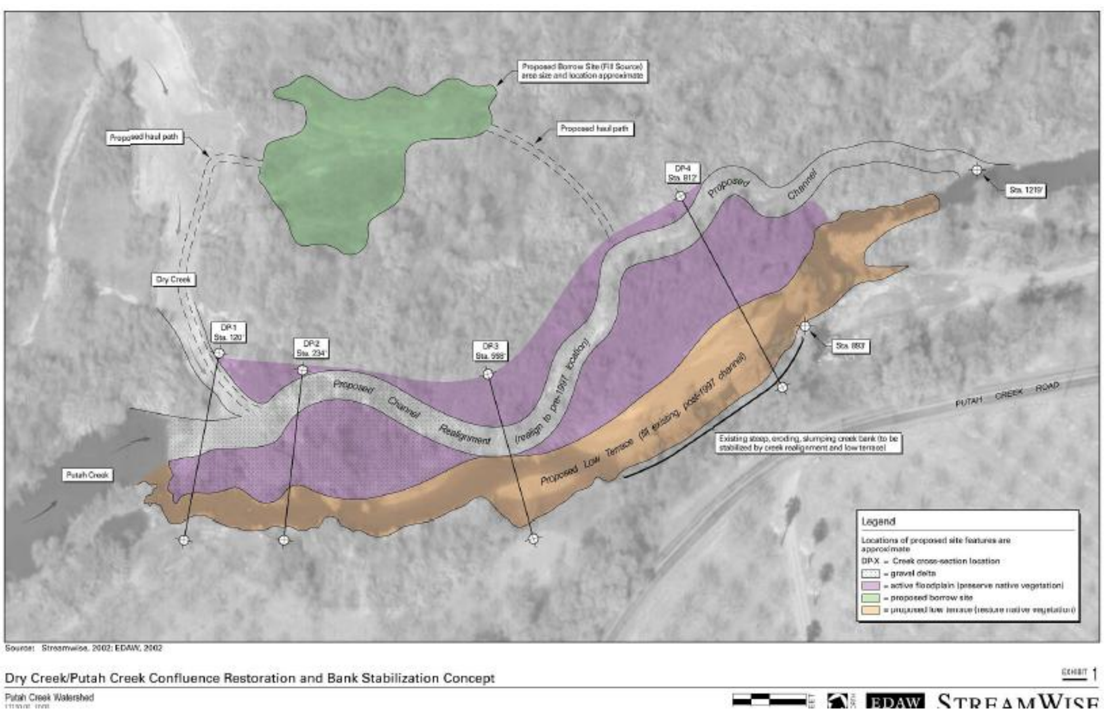


Figure 6. Cross-Sections and Proposed Alignment. This shows the proposed channel realignment, along with the locations of the four surveyed cross sections. Source: StreamWise, 2004.

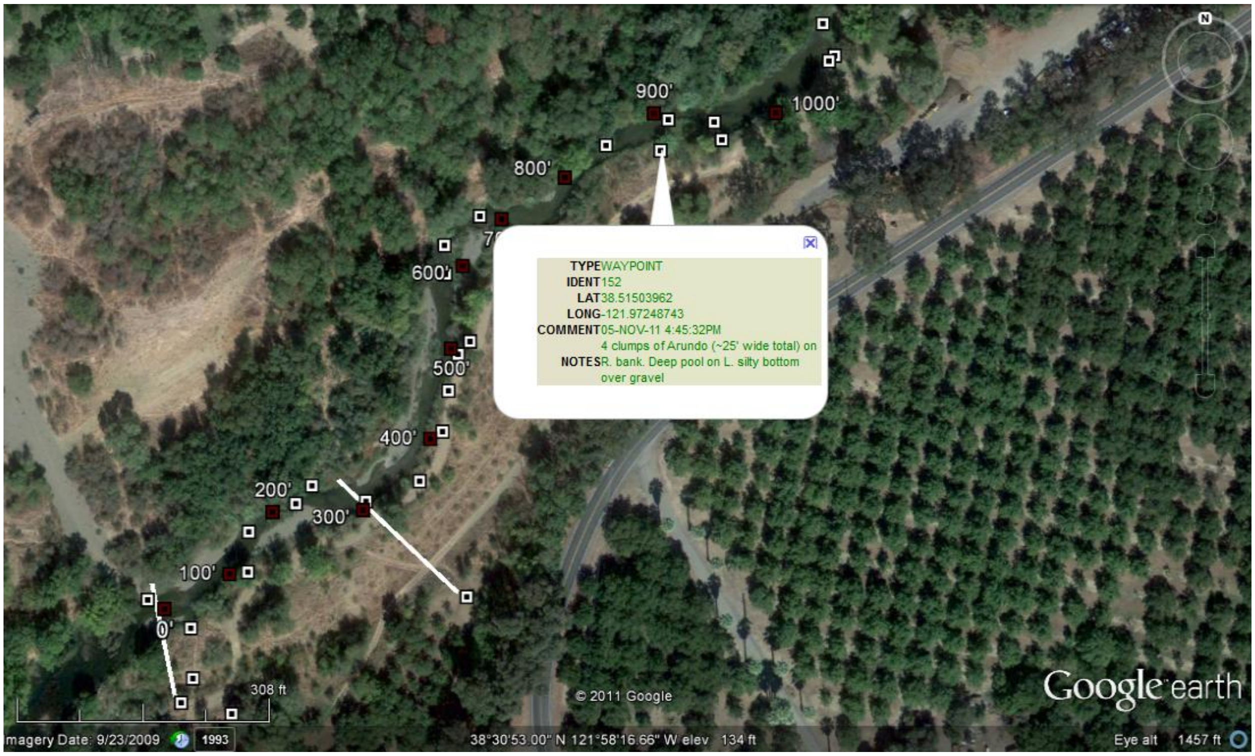


Figure 7. Screenshot of Google Earth showing our waypoints as squares. Red squares are the dividers of the 100 foot sections. White lines are the two transects we surveyed in 2011.

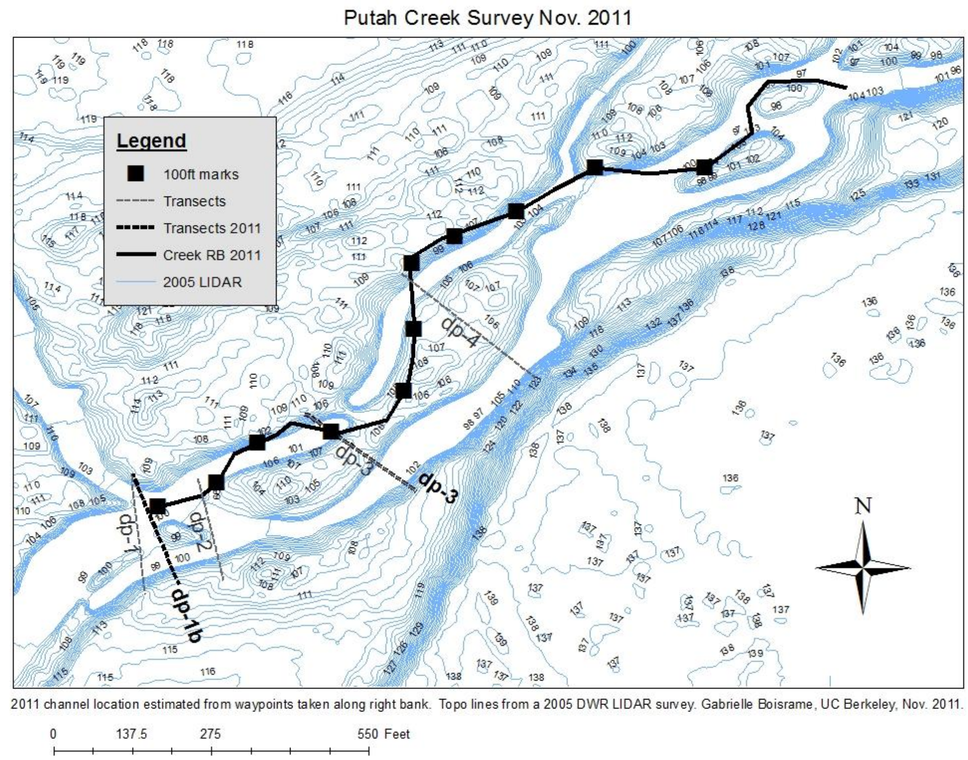
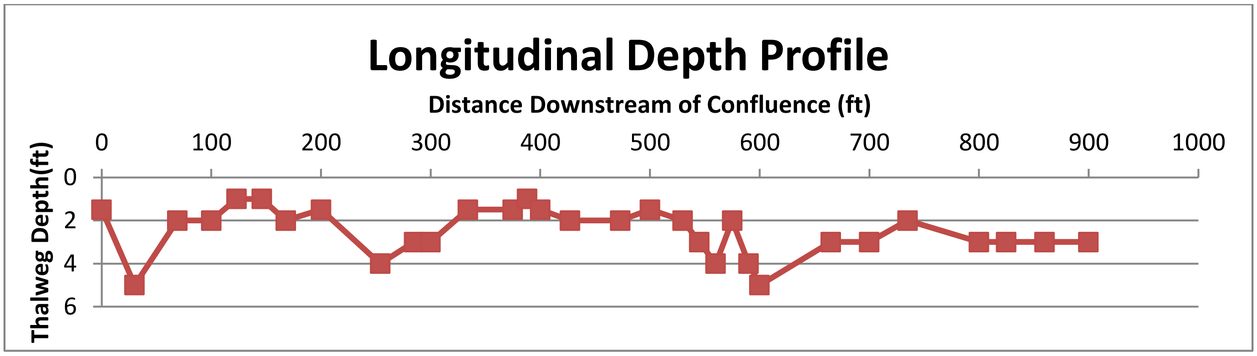


Figure 8. Topographic lines from a 2005 LIDAR survey done when the new channel was nearly complete. Crosses show our 100 foot marks for reference. The heavy black line is the approximate location of the right bank of the creek from our 2011 survey. Grey dashed lines show original transects and thick black dashed lines show the transects we surveyed (dp-1b and dp-3).



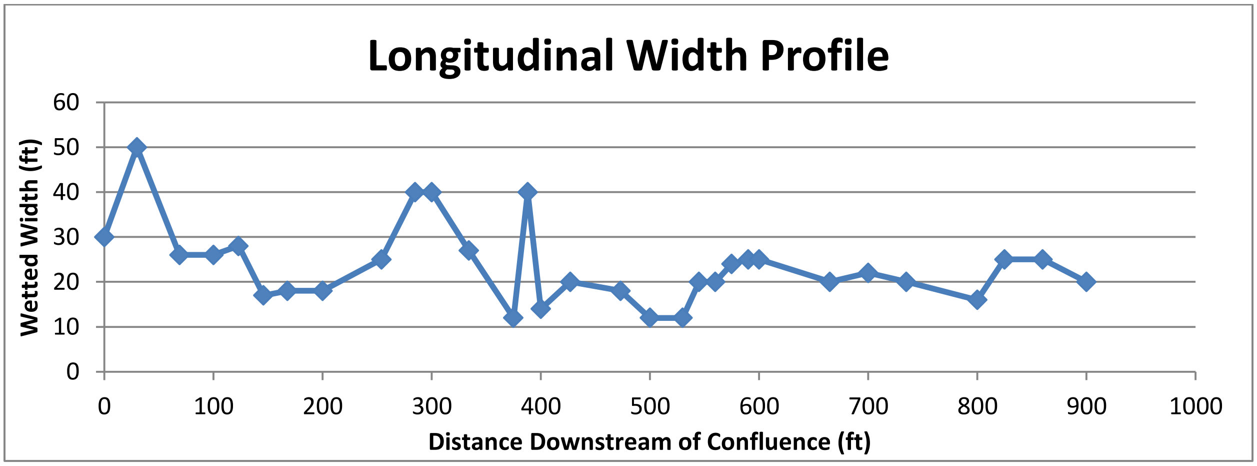


Figure 9. Longitudinal profile of Putah Creek showing variations in width and mix of riffle and pool features. (Deep areas are pools and most shallow areas are riffles). Starting at the confluence with dry creek, we measured the width and thalweg depth every 100 feet and at any points in between where there were large changes in either width or depth. Note that the depth axis and depth axis are ordered differently. This is to make the depth line easier to interpret (deeper areas are lower rather than higher).

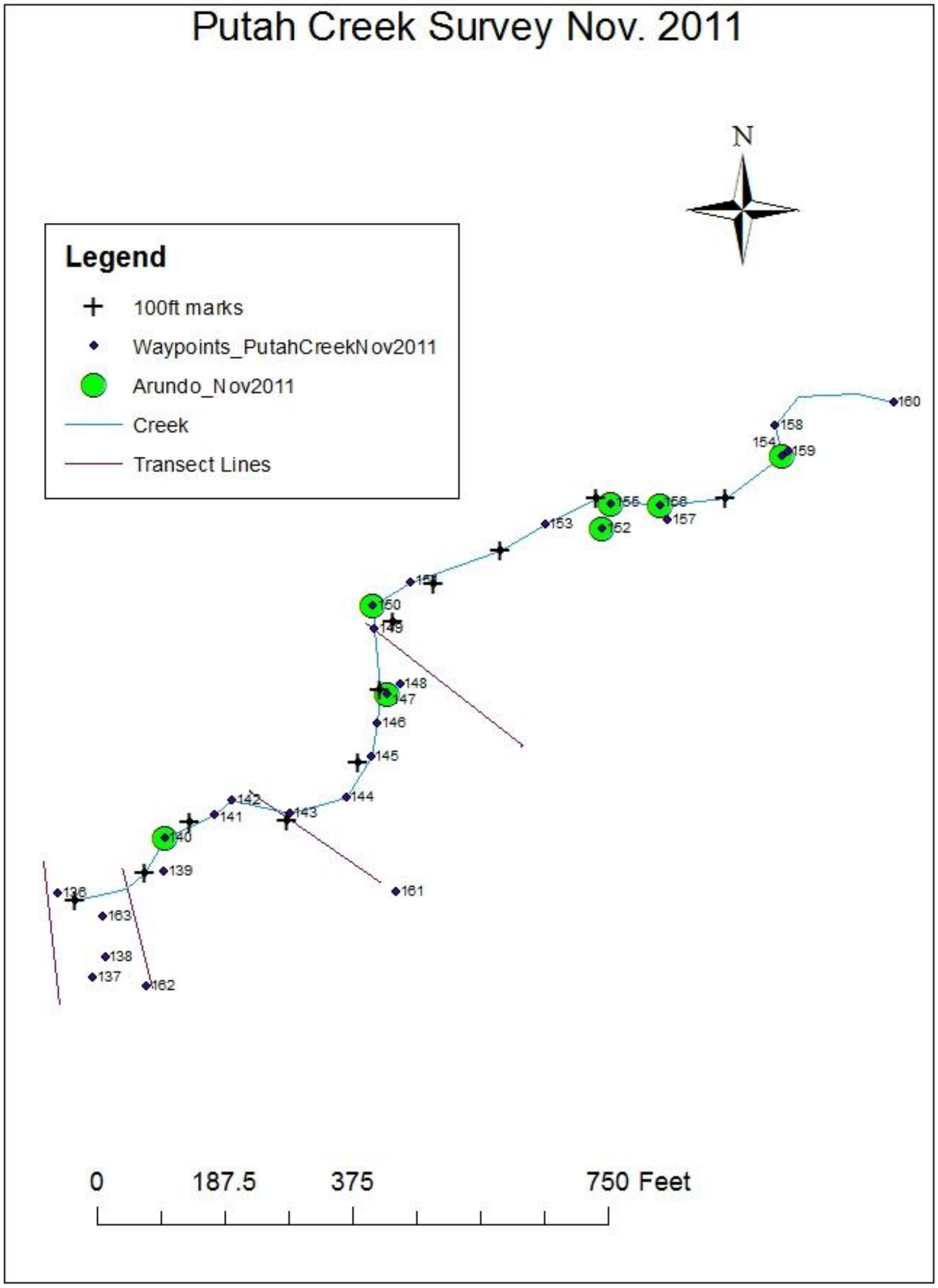


Figure 10. Plot of waypoints (for matching with pictures in appendix A and notes in appendix D), *Arundo*, and original survey transects. Locations where Arundo was noted are shown in green. The original transect lines from the project proposal are shown to help orient this with maps such as figure 6.

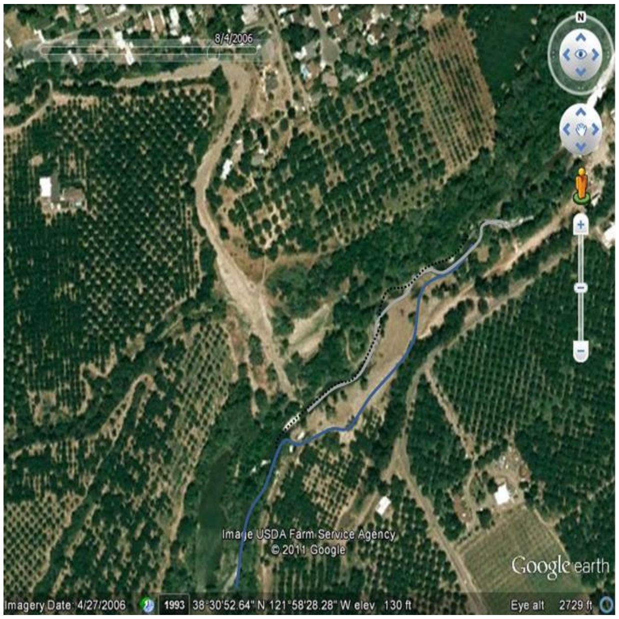


Figure 11. This is the aerial photo taken most immediately following the channel relocation. The blue line shows the approximate location of the 2005 channel. The black dotted line marks where the channel is in this picture (August 2006). The grey solid line shows the approximate path of the design channel as shown by LIDAR in 2005.

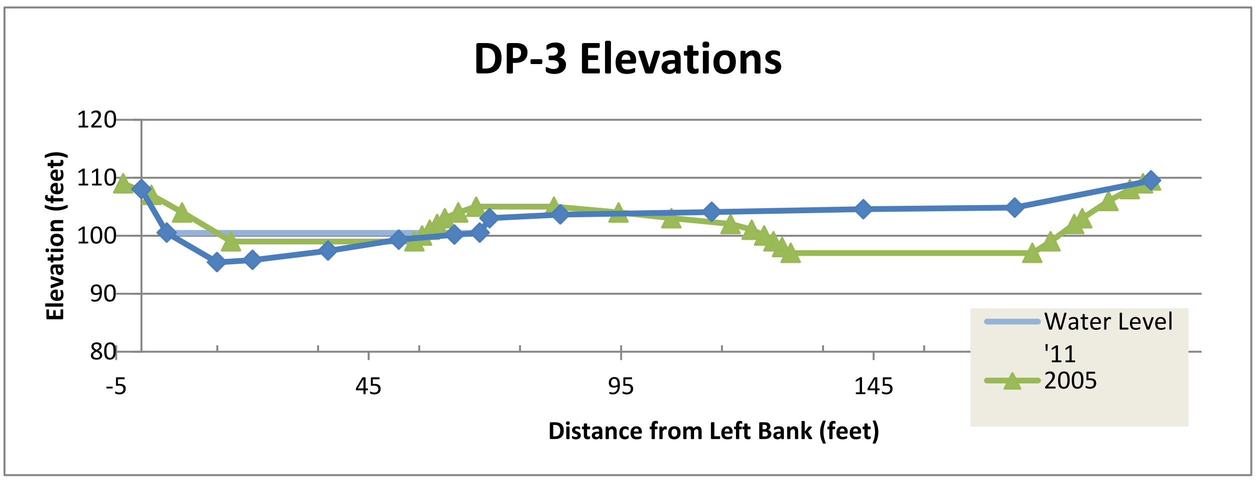


Figure 12. These lines show elevation along transect DP-3, starting with 0 at the left bank pin. The blue line shows our measurements in 2011. Elevations within the pool were difficult to measure and therefore are only expected to be accurate to within about one foot. The green line shows the elevations in September 2005, as measured using LIDAR. This shows that the channel has widened slightly at this point, and along the left bank the channel incised and the bank became steeper.

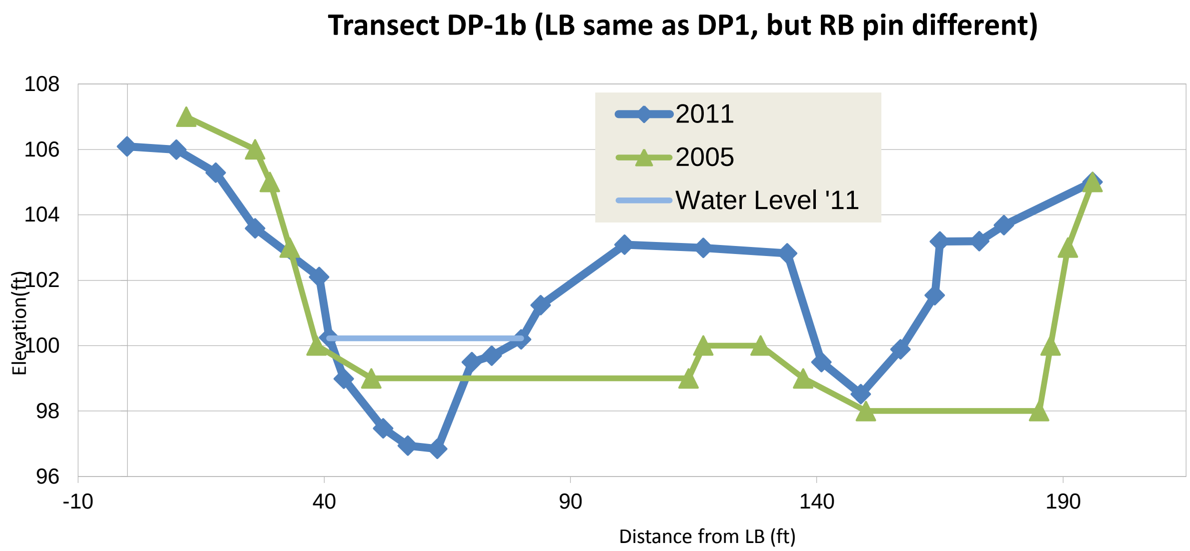


Figure 13. Elevation along transect 1, starting with 0at the left bank (LB) pin. We were unable to locate the right bank pin for the original transect DP1, so this transect deviates from DP1 as shown in figure 9. There were a lot of trees along this transect, meaning the tape could not be stretched perfectly straight and thus the distance measurements may be off, but this gives a general picture of the new channel form at the confluence. It is unclear how much of the deposition in the middle of the transect is from restoration actions taken after the LiDAR survey (soil moved with a tractor) and how much is from stream deposition.

Figure 14. Standing in Dry Creek looking south across Putah Creek at waypoint 136. Photo by Gabrielle Boisramé.

Figure 15. Looking downstream at *Arundo*, waypoint 152 (left). Looking downstream from right bank at *Arundo* stand over steep bank, waypoint 155 (right). Photos by David Pope.

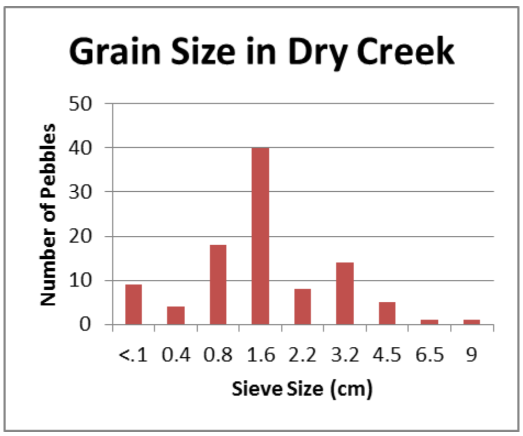


Figure 16. Results from pebble count in dry creek. Median grain size is 1.6cm.

Figure 17. The fish on the left were raised in enclosures within a river channel, while those on the right were raised in an inundated floodplain. The difference in size demonstrates the advantages of young fish being able to access floodplain habitat. Source: Opperman et.al. 2010.

Figure 18. Fresh sand deposits on the banks of Putah Creek after a flood in 2008, showing that floodwaters inundated at least a portion of the floodplain.
Source: <http://www.watershedportal.net/gallery/Dry-Creek-Putah-Creek-Confluence-Project>

Figure 19. Channel Migration. Aerial photo from 2005 (pre-project). The solid shape overlay is the channel in 2007, and the outlined shape shows the channel in 2009. This shows that the channel did not change its course drastically between 2007 and 2009, and has not recaptured any portions of the 2005 channel. Image source: Google Earth.

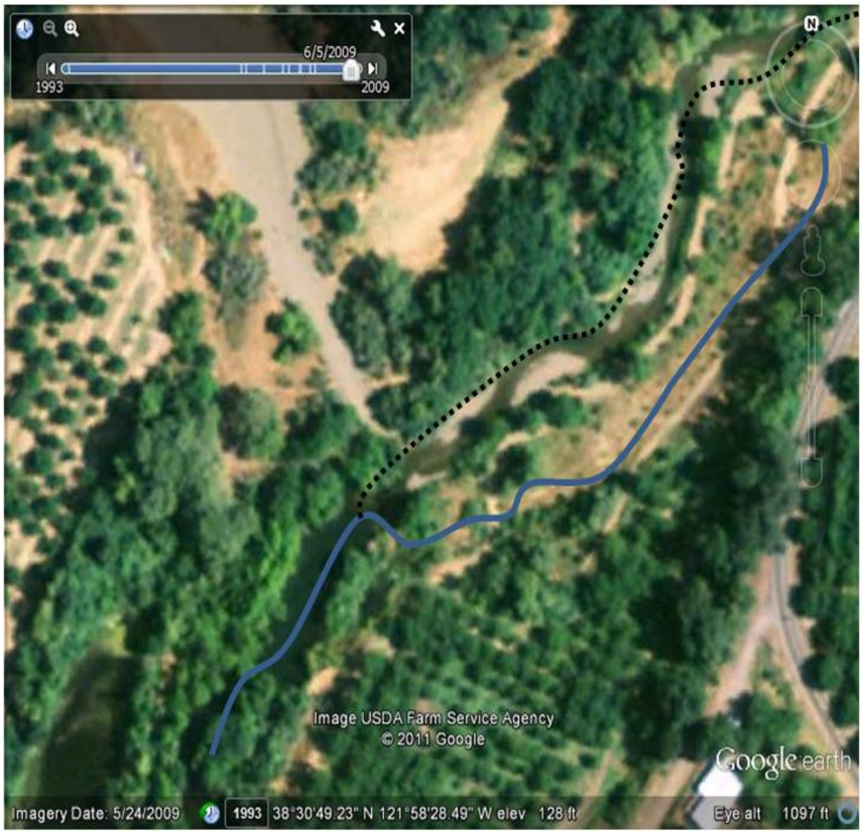


Figure 20. Meanders in restored channel. Solid blue line shows approximate location of 2005 (pre-project) channel. Black dotted line shows approximate location of 2006 (post-project) channel. Although the meanders have migrated somewhat, there does not appear to be large change in channel path between 2006 and 2009. Most importantly, the creek has not recaptured the 2005 channel.

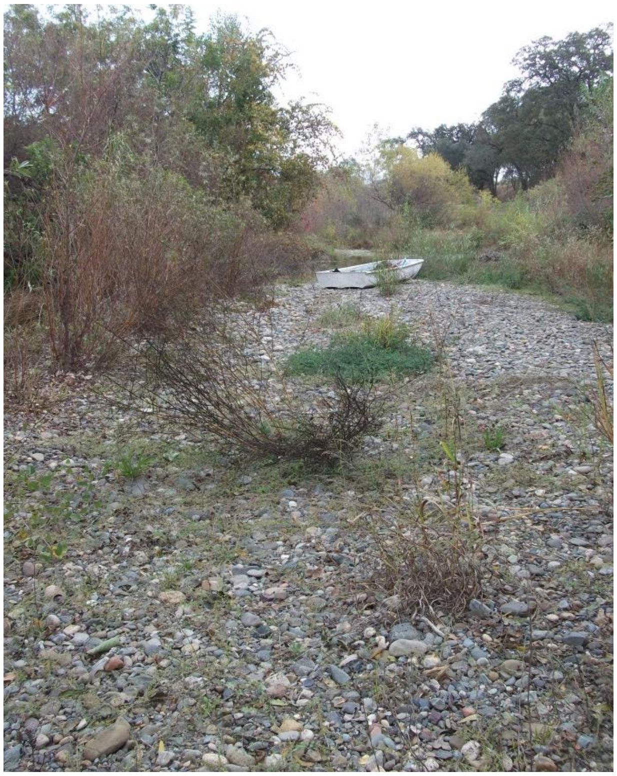


Figure 21. Gravel bar with small rowboat in background for scale. Photo taken at waypoint 141 by Gabrielle Boisramé.

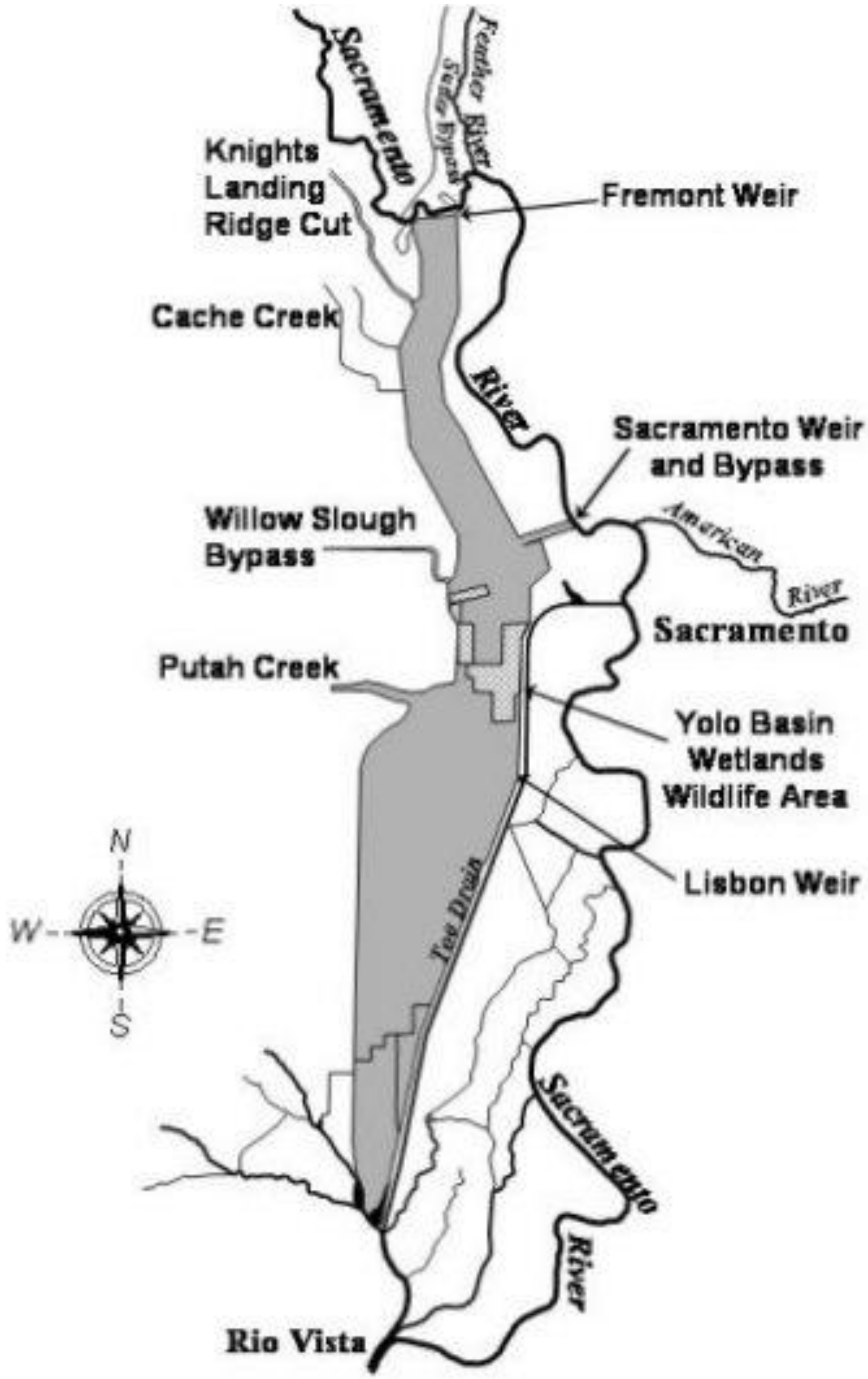
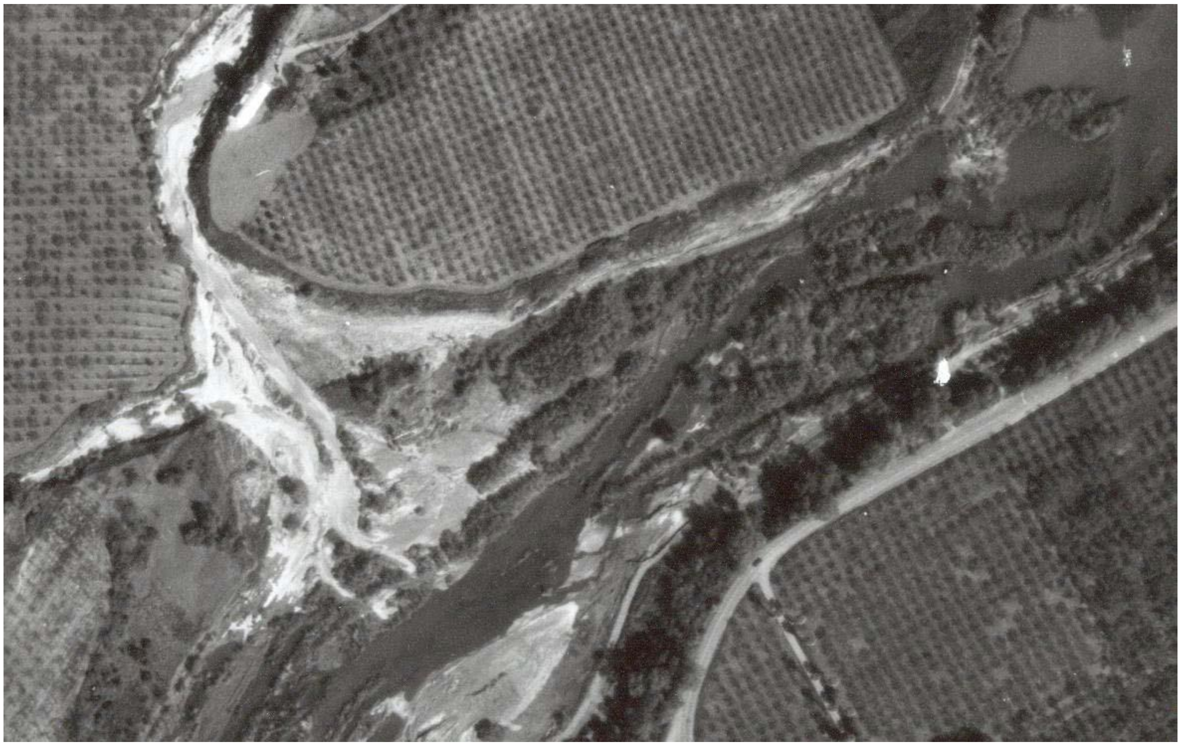


Figure 22. Yolo Bypass Wildlife Area. Source : <http://www.water.ca.gov/aes/yolo/>

Appendices

Appendix A: Photos

In-stream pictures were taken by David Pope and Gabrielle Boisramé. Aerial photos are from Google Earth unless otherwise noted.



A.1. Dry Creek/ Putah Creek Confluence 1970. (photo courtesy of StreamWise)

A.2. Looking upstream. Pool below beaver dam at confluence of Putah and Dry Creeks.

A.3. Tape stretched across pool at confluence for transect 1.

A.4. Standing mid-creek looking at South bank 000-100ft. of survey area
Undercutting erosion of South bank building up sediment bar downstream.

A.5. Looking downsream at black walnut tree growing out of cut bank.

A.6. Looking upstream. Large pool downstream of same black walnut as previous picture. Steep cut bank. (Waypoint 143)

A.7. Looking downstream. Channel narrows to a riffle between gravel bar and beaver dam. (Waypoint 144).

A.8. Looking downstream. Close-up of same riffle (Waypoint 144)

A.9. Looking Downstream. Waypoint 147

A.10. Looking downstream at deep pool under cut bank with Arundo. (Waypoint 151 is across creek from the Arundo)

A.11. Clay bottom. (Waypoint 151)

A.12. Looking downstream at Arundo. (Waypoint 152)

A.13. Looking downstream from right bank. Creek narrows to about 15 ft. wide. Arundo hanging over cut left bank. Dirty gravel bottom. (Waypoint 155)

Appendix B: Other Restoration Sites Along Putah Creek

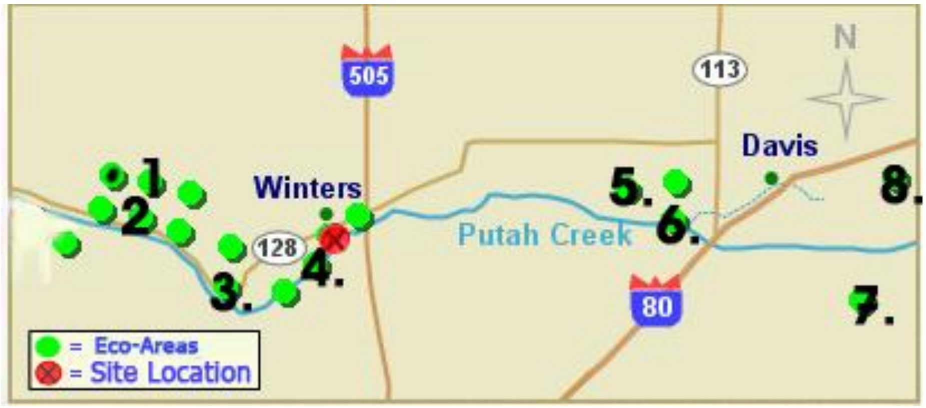


Figure B7. Ecologically Important areas along Putah Creek. Map from the "Putah Creek Explorer Book" published online by the Putah Creek Council. Numbered dots show:

1. The Yolo County Parks and Resources Department is currently renovating the fishing access sites, including new trails, educational panels, access road improvements and parking areas.
2. The New Zealand Mudsnail (NZMS) can choke out other native snails and insects, deprive fish of their main sources of food, multiply rapidly, and can damage fisheries and native habitats. The Putah Creek biomonitoring group, surveys sites to inventory track the spread of NZMS.
3. Lake Solano formed from the Putah Diversion Dam. Approximately 200,000 acre-feet of Putah Creek water per year is diverted.
4. The Winters Nature Park and Community Center is a part of a four stage restoration project recently undertaken in 2011. Future plans include trails along the creek, restoring connection of the creek to its floodplains, removal of invasive species, native grass and tree restoration, and other recreational amenities.
5. A Riparian Reserve established by UC Davis in 1983 to preserve creek side habitat on campus property for research, teaching and wildlife habitat protection. Also used by bird watching and picnicking visitors.
6. An active channel water-flow, outside of the neighboring closed systems. An area of nest boxes placed by UC Davis researchers studying small birds, wood ducks, gray squirrels, western lizards and jackrabbits.
7. The City of Davis has restored 120 acres of riparian woodland and grassland habitat along the South Fork of Putah Creek. The South Fork Preserve supports wildlife habitat, managed public access, commercial agriculture and flood control facilities.
8. The Yolo Wildlife Area (YWA) is the largest wetlands restoration project west of the Florida Everglades. The property is managed for flood control, wildlife habitat protection, and recreational activities (Putah Creek Council).

Appendix C: Rich Marovich Interview

To gain further understanding of the objectives beyond the project proposal, we spoke with Rich Marovich, a streamkeeper for the Solano County Water Agency who has been involved with planning and monitoring of the project. Outside of the orchard considerations and protection of the roadside bank, he stated that the efforts of the restoration were guided by three goals: gravel for spawning, habitat diversity, and cooler water temperatures, especially by providing more shade. In regards to fulfillment of the proposal implementation, he noted that although the gully was filled in, that terraces were utilized over a true facilitation of a natural floodplain. He also noted that areas were worked into the channel design to preserve several exposed willow roots which provide exceptional habitat for the trout spawning in the cooler waters up-stream and the native fish predominant down to Steven's Bridge. In other terms of success, he speculated that the creek would never leave the new channel outside of a removal or major release from Monticello Dam, which regulates the water-flow of this system.

For the Post-Project Survey, Marovich described the initial results as "Beautiful" confirming that gravel movement from the Dry Creek Bed was in process. Upon return for a later survey however, gravels were found to be covered by fines due to the down-cutting of Pleasant Creek, creating a steeper grading due to the higher than peak flows in tributaries during the flood event of January 3, 2006 (the second highest in over thirty years) and the erosion from turbidity events on Pleasant Creek having increased ten-fold over the last fifty years because of hydrological changes from the dams creating fines.

As for Post-Project monitoring, though it was planned to include three years of follow-up, he would have liked to have seen more monitoring and the utilization of the floodplain services. He also advocated for more Willow planting, noting that abundant Black Walnut tree volunteers were decreasing the bird diversity. Follow-Up Maintenance however does continue both through the community element included in the proposal and by the city to control the invasive Arundo. As he explained the most efficient control as spraying while wild grapes were dormant, he also remarked on recent EPA restrictions of spraying over water areas to conflict with that method. Among the most valuable post-project information that could be gathered, he recommended a longitudinal profile to evaluate the success of gravel movement from Dry Creek (Rich Marovich, Solano County Water Agency, California, personal communication, 05 Nov 2011).

Appendix D: Field Notes

GPS Waypoint Notes

The following notes match up with the waypoints in figure A.1. GPS locations are in the WGS84 datum and are accurate to within ten feet. These are the same notes that are attached to the waypoints corresponding to each ID number.

ID	LAT	LONG	ALT	NOTES
136	38.51357	-21.975	36	Confluence
137	38.51324	-121.975	41	R.bank end of transect 1 (approx location of DP1 end, could not find pin)
138	38.51332	-121.974	37	bottom of abandoned channel
139	38.51366	-121.974	35	riffle, clean gravel below sm. beaver dam
140	38.5138	-121.974	33	pool, about 2ft above arundo patch
141	38.51389	-121.974	33	middle of gravel bar
142	38.51395	-121.974	33	deep pool w/ eroding left bank
143	38.51389	-121.974	32	near cut bank
144	38.51396	-121.974	32	narriwm ruffkesm diwbstream of cattails and buried logs
145	38.51412	-121.973	29	outside edge of L. rurning bank, 12' wide, just upstream of waist deep pool

146	38.51426	-121.973	29	5' deep pool w/ sandy bottom
147	38.51438	-121.973	29	side pool in abandoned channel. Some arundo
148	38.51442	-121.973	28	riffle, pool, clean gravel
149	38.51464	-121.973	27	shallow stream, gravel under 3 inches
150	38.51473	-121.973	26	Inside of R. turning bend. Arundo on L. bank. sandy bottom. bank ~15' from planted willow row
151	38.51483	-121.973	25	sandy pool approx 6' deep. Cut bank on L. Blue clay covering gravel
152	38.51504	-121.972	23	4 clumps of Arundo (~25' wide total) on R. bank. Deep pool on L. silty bottom over gravel
153	38.51506	-121.973	22	approx 3' deep sand pool w/ gravel bar on L. bank
154	38.51533	-121.972	22	sharp bend, sm. arundo patch. Near bottom of road to Bertenoia's
155	38.51514	-121.972	28	riffle, approx 15' wide, arundo over L. cut bank, dirty gravel bottom
156	38.51513	-121.972	28	arundo, sedges, & sm. tree in middle of creek. sandy bar on R. bank w/ plants
157	38.51507	-121.972	27	remnant channel

158	38.51545	-121.972	26	riffle at sharp turn, approx 10' wide
159	38.51535	-121.972	26	flagged rebar
160	38.51554	-121.971	25	end of sharp turn, 2' thalweg, fast flowing
161	38.51358	-121.973	9	DP3 r. bank pin, edge of orchard
162	38.5132	-121.974	11	DP2 r. bank pin, just W. of oak trees
163	38.51348	-121.974	28	riffle along DP2
164	38.51516	-121.972	23	Bottom of 1000' reach
165	38.51516	-121.973	21	900' mark
166	38.51495	-121.973	21	800' mark
167	38.51482	-121.973	22	700' mark
168	38.51466	-121.973	22	600'
169	38.51439	-121.973	22	500'
170	38.5141	-121.973	22	400'
171	38.51387	-121.974	23	300'
172	38.51386	-121.974	22	200'
173	38.51366	-121.974	23	100'

174	38.51354	-121.975	21	start of reach

Notes and maps by David Pope (This is only a sample of our field notes. Complete notes are available online).

We have divided Putah Creek project area into 100 foot sections going downstream starting at the Dry Creek confluence. Measurements begin at the west bank side of Dry Creek where the largest beaver dam is attached.

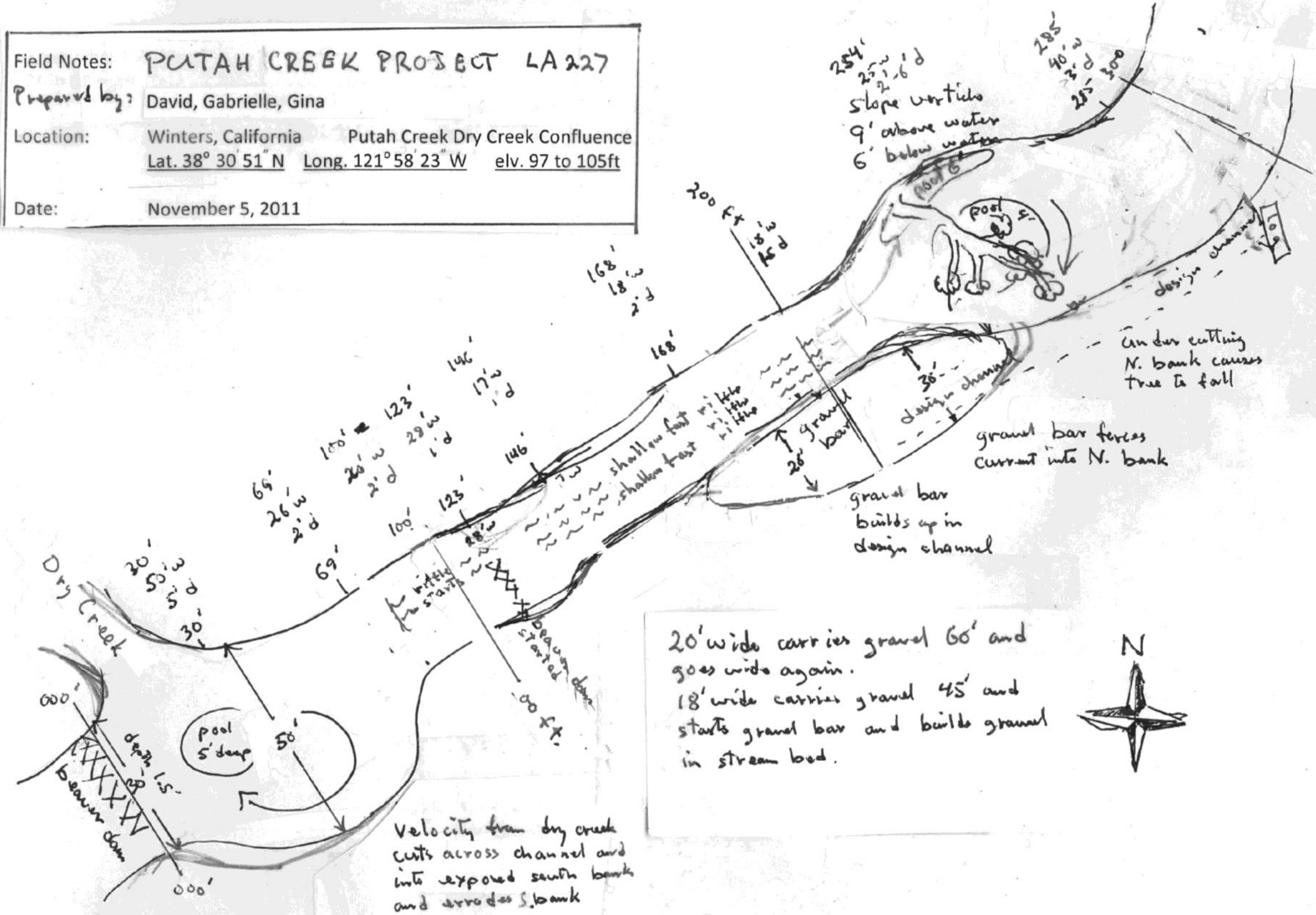
Field Notes: PUTAH CREEK PROJECT LA227

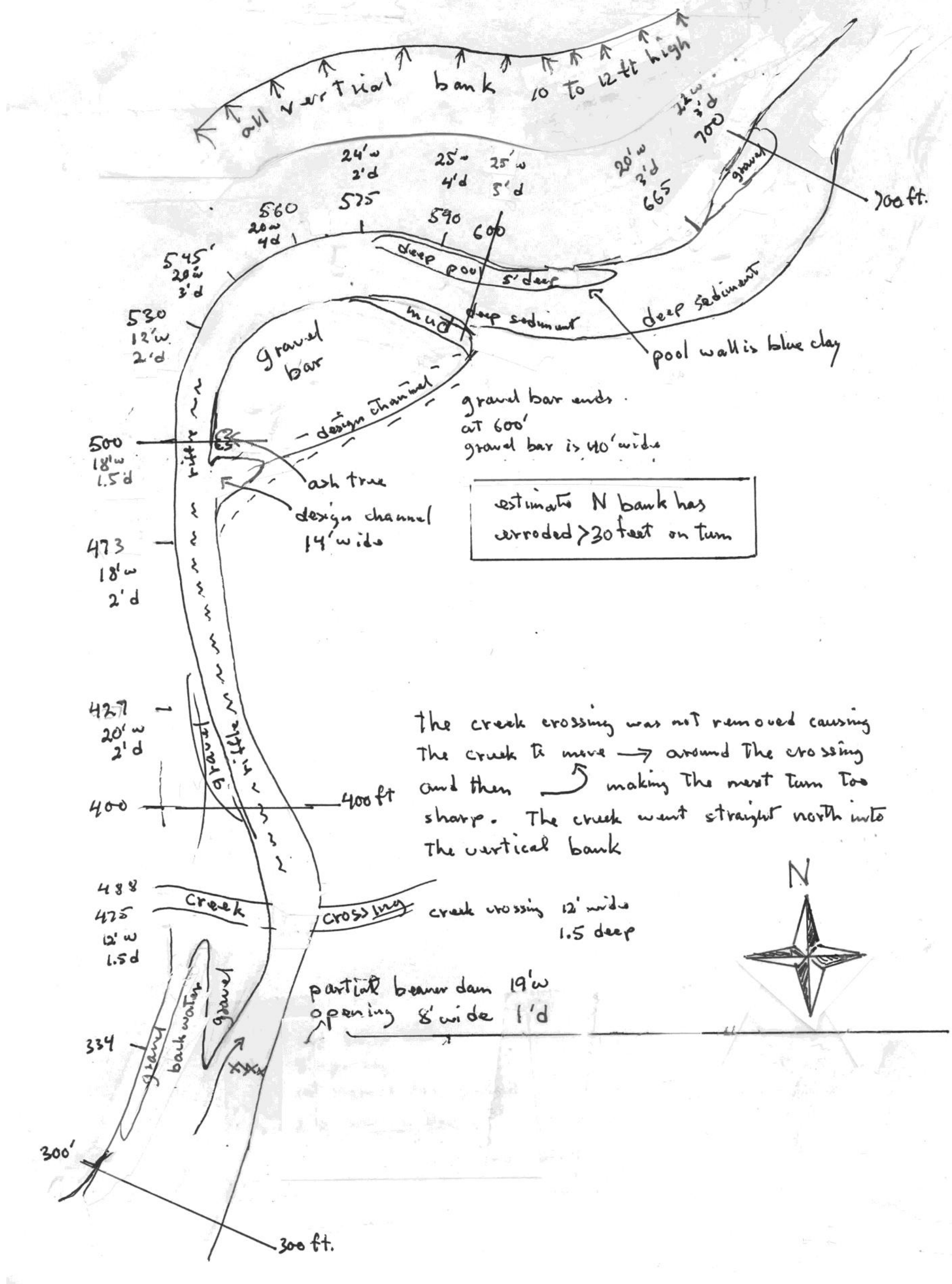
Prepared by: David, Gabrielle, Gina

Location: Winters, California Putah Creek Dry Creek Confluence

Lat. 38° 30' 51" N Long. 121° 58' 23" W elv. 97 to 105ft

Date: November 5, 2011




all vertical bank 10 to 12 ft high
24'w 2'd
25'w 4'd
25'w 5'd
20'w 3'd 665
22'w 3'd 700
gravel
700 ft.
560 20w 4d
575
590
600
545' 20'w 3'd
530 12'w 2'd
deep pool 5' deep
deep sediment
mud
deep sediment
pool wall is blue clay
gravel bar
design channel
gravel bar ends at 600'
gravel bar is 40' wide
500 18'w 1.5'd
riffle
ash tree
design channel 14' wide
estimate N bank has erroded >30 feet on turn
473 18'w 2'd
427 20'w 2'd
gravel
riffle
400
400 ft
The creek crossing was not removed causing The creek to move → around The crossing and then ⤴ making The next turn Too sharp. The creek went straight north into The vertical bank
N
488
475 12'w 1.5d
Creek crossing
creek crossing 12' wide 1.5 deep
partial beaver dam 19'w opening 8' wide 1'd
334
gravel
back water
gravel
300'
300 ft.

Field Notes: **PUTAH CREEK PROJECT for LA 227** David, Gabrielle, Gina

Page 1 of 10

Location: Winters, California Putah Creek Dry Creek Confluence

Lat. 38° 30′ 51″ N Long. 121° 58′ 23″ W elv. 97 to 105ft

Date: November 5, 2011

Link for Pictures: [photos creek 11-5-2011\0-100ft]

000 ft GPS = WP - 174	Distance downstream from confluence of Dry Creek and Putah Creek measured from west bank of Dry Creek						100 ft GPS = WP - 173
North bank	Confluence of Dry Creek Sloped bank , willows, no undercut --------- ----→						
Distance (ft) downstream	000		30		69		100
Width (ft)	30		50		26		26
Depth (ft)	1.5		5		2		2
Channel bottom	gravel		deep pool center mud shallow south bank		I------riffle dirty gravel------→		
South bank	Beaver dam under construction		Vertical bank 3ft high Large cut (20ft) into south bank				

Notes:

- Measurements begin at the west side bank of Dry Creek at the beaver dam.
- Dry Creek is cutting straight across the Putah Creek channel into its prior gravel deposit and has made a 5ft deep pool in the middle of the stream just below the beaver dam.
- The creek has cut 20ft into the south bank directly across from the confluence. This makes a shallow muddy shelf with slow upstream circulation. The south bank is unprotected from further erosion. It is only 3ft high but needlessly muddying the gravel downstream and will continue to erode if not protected.
- The beaver dam is currently destroyed each year for fish passage.

Recommendation:

- Plant cattails in the shallow mud at the base of the south bank in the turn.
- Do not destroy the beaver dams. Slow water behind beaver dams removes fine sediment and provides clean water downstream. A downstream gradient is needed for spawning.

Field Notes: **PUTAH CREEK PROJECT for LA 227**
David, Gabrielle, Gina

Location: Winters, California Putah Creek Dry Creek Confluence
Lat. 38° 30′ 51″ N Long. 121° 58′ 23″ W elv. 97 to 105ft

Date: November 5, 2011

Link for Pictures: photos creek 11-5-2011\100-200ft

100 ft GPS = WP - 173	Distance downstream from confluence of Dry Creek and Putah Creek measured from west bank of Dry Creek								200 ft GPS = WP - 172
North bank	Vertical bank with undercut →								
Distance (ft) downstream	100		123		146		168		200
Width (ft)	26		28		17		18		18
Depth (ft)	2		1		1		2		1.5
Channel bottom	I------riffle, gravel is clean in center of stream where water is faster →								
South bank	Gravel bar ---------------------→								

Notes:

- Vertical north bank is cutting and needs to be turned and toe slope built before bank cuts more.

Cause of Problem:

- The gravel is dirty because of the bank erosion upstream at 30 feet across from dry Creek.
- The rifle starts at 69 feet and starts depositing gravel at 168 feet. The width of 18 feet is too narrow to carry the gravel, so the creek started to unload it and made a gravel bar.

Recommendation:

- First, place 3" dia. willow or cottonwood posts pounded into creek bottom at beginning of turn about 2 or 3 ft. out from bank and at an angle to turn the water. These should be in groups of 3 or 4 posts and the groups spaced 6 to 8 ft. apart. The object is not to stop the water but to reduce the velocity so the creek leaves a deposit behind the posts and creates a toe. If you try and make a toe mechanically it will wash.
- Willow brush tails can be tied to posts below water line with heavy duty twine to better reduce velocity and increase the rate of sediment deposit.
- Second, remove growth on gravel bar and widen it some on top so no more gravel is caught and the gravel bar will shrink as the toe slope builds and the channel moves back south.

Field Notes: **PUTAH CREEK PROJECT for LA 227** David, Gabrielle, Gina

Location: Winters, California Putah Creek Dry Creek Confluence

Lat. 38° 30′ 51″ N Long. 121° 58′ 23″ W elv. 97 to 105ft

Date: November 5, 2011

Link for pictures: photos creek 11-5-2011\200-300ft

200 ft GPS = WP - 172	Distance downstream from confluence of Dry Creek and Putah Creek measured from west bank of Dry Creek						300 ft GPS = WP - 171
North bank	Vertical bank 9ft height, undercut, 6ft deep pool Black walnut fallen across creek at 254 -260ft						
Distance (ft) downstream	200		254		285		300
Width (ft)	18		25		40		40
Depth (ft)	1.5		4		3		3
Channel bottom	15” of Sediment in creek bottom on top of ½” to 1 ½”gravel						
South bank	------------- End of gravel bar →I						

Notes:

- Willow cuttings and a 3 foot diameter log buried sloping downward now high and dry at 290 ft. show the existing channel has moved north 10 to 35 feet from the design channel at this point.
- Channel bottom at 285 ft. is 18 in. of sediment covering fine gravel ½” to 1 ½’ dia. The sediment deposit is from the bank cut just upstream at 254 ft.
- The north bank is vertical and the cut is aggravated by a large black walnut tree falling into the stream.

Cause of Problem:

- The cut into the bank at 254 feet is caused by the channel narrowing at 140 feet and being forced to carry too much gravel which it quickly drops starting at 168 feet. The design channel was placed too close to the north bank so when the creek goes around the gravel deposit it runs into the vertical north bank and starts to cut into the bank because it ills soft.
- The location of the design channel should have left more room to turn.

Recommendation:

- On the north bank continue the recommendations from the previous reach. It is the same turn.
- Cut the walnut and remove it.
- On the south bank at 285 ft. where it is 40 ft. wide and the eddy is cutting into the bank, stabilize the bank with sedge or some other plant whose roots will grow under water. The roots of creeping wild rye, which is what was planted, stop at the water table.

Appendix E: Floodplain Context

The Putah-Cache Bioregion Project summed up a report from 1994-1998 of a life-cycle fish sampling through the UC Davis, selecting eight sites within the lower 23 miles of Putah Creek which included the confluence with Dry Creek. Although Chinook Salmon was observed, the native species were predominately Sacramento pikeminnow, Sacramento sucker and prickly sculpin, with an increase in smallmouth bass abundance. For their findings of native larval fish, the Dry Creek site had 1-2 orders of magnitude more native larval fish than the others sampled, suggesting a native preference for spawning and rearing at the Dry Creek site (UC Davis 1998). "Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale" by authors Opperman, Luster, McKenney, Roberts, and Meadows, describe the benefits of opening up historically inundated floodplains to include empirically observed higher growth rates of fish, known as the ‘‘flood pulse advantage". This advantage is a feature of floodplains which opens up the river system to greater and more diverse food resources, also providing shelters for hiding, increasing the successes of native fish survival against predators and other environmental circumstances. Along with supporting the largest fisheries, floodplain rivers also host greater diversity along with the services of surface water filtration, groundwater recharge, recreation, fish, timber and other plant resources with flood-management for low maintenance costs. Opperman et al. continues by defining the activation of the flood-pulse to be dependent on "magnitude, frequency, duration, rates of change, and seasonality" of flow regimes (Opperman et.al 2010).

The regulated flows of the Monticello Dam may restrict this ability to activate the designed floodplain. Comparing a flood frequency analysis of pre- and post- dam flows from USGS.gov, the reduction of these flows to less than 25% of the pre-dam cfs is apparent, meaning little likelihood of functional floodplain inundation and a decrease in the maximum bedload carrying capacity of Putah Creek (Figure 5). (Toby Minear 2011). Such conditions have been identified to create the “hungry waters” described in “The Effects of Dams and Gravel Mining on River Channels” by Mathias Kondolf. This involves the increased build-up of energy in sediment-starved flows from dam obstructions that increase erosional incision while the movement of sediment and other gravels is cut-off from replacement sources upstream of the dams (Kondolf 1997). The trapping of large-grained bed load sediment by the Monticello and Solano Dams, promotes progressive streambed scour, leaving Putah Creek with no other source of gravels upstream from the Dry Creek confluence. Along with the implications this may lead to for habitat values, seeking the more low-land conditions for floodplain activation, may be the most beneficial for the native larval fish, naturally promoted in this area.

Other projects around the site evaluated offer the potential for ecological health by creating nodes of habitat that adapt to land ownerships challenges (Figure *B7. Ecologically Important areas along Putah Creek).* One of the largest restoration projects is the Yolo Bypass Wildlife Area between Davis and Sacramento, encompassing 16,000 acres, 3,700-acres of which as floodway land. (Figure 22). The Natural Heritage Institute et.al, included the lower reach of Putah Creek as a water-source scenario in their 2002 “Habitat Improvement for Native Fish in the Yolo Bypass” project. This report identifies low-land floodplain regions along the bypass, with Putah Creek as a possible water source to provide for thirty days of inundation during the months of April-June annually. Alternative combinations from dam removal to demonstration-level projects varying from small ponds to a large one, to a four-mile long channel connecting existing riparian habitat en route to the Yolo floodplain. After assessing costs, potential impacts, and ability to meet project criteria, the recommendation of a smaller scale floodplain inundation program along the third alternative route created from “a new alignment of Putah Creek through lowlands to the southeast”, as this path would offer the flood-pulse advantage to the greatest low-land floodplain region (up to 1,100 acres). By including local floodplain inundation in the scenarios described, the report sought to take advantage of the wide temperature variations and shallow vegetated waters along the creek to support the rearing and spawning of a diverse assemblage of fish. The recommended channel design alternative was also selected to deal with the flow level limitations of drought and non-drought year flow set regulations (Natural Heritage Institute et. al. 2002). Though this proposed scenario would seek to activate the low-land floodplains of the Yolo Bypass through channelization to bypass the regulated flow restrictions, it would provide premium habitat conditions in the Yolo Bypass, but may compromise any smaller floodplain systems upstream of it.