Enhancing environmental flows of Putah Creek for Chinook salmon reproductive requirements

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Abstract:
Putah creek, like many of California's rivers and streams, is highly altered by anthropogenic actions and historically supported large populations of resident and anadromous native fish species. Now its ecosystem dynamics have changed drastically with the Monticello dam, the Solano diversion canal and the leveeing of its banks. Over time the creek has found a balance of habitats for native and non-native fish species that is mainly dictated by species-preferred temperature tolerances (Keirman *et. al.* 2012). Cooler temperatures and faster flows upstream from Davis prove to be ideal habitats for native species, in particular, the federally endangered Chinook salmon, which is the most widely distributed and most numerous run occurring in the Sacramento and San Joaquin rivers and their tributaries. As water moves downstream, it becomes shallower and warmer, resulting in ideal conditions for non-native species (Winters, 2005). This report analyzes the environmental flows released into putah creek and how much salmon preferred breeding habitat is available from this flow regime based on temperature.

Introduction:

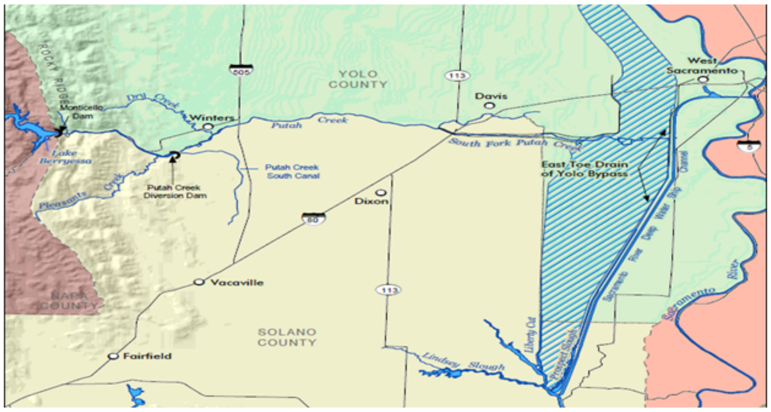

Figure 1: Teale GIS Solutions Group (1999), US Census Bureau (2002), USGS (1993) [within Winters, 2005]

The Putah Creek watershed is an important aspect in the natural, social, and economic livelihoods of the people of Yolo and Solano counties. The Putah Creek watershed begins at the highest point in Lake County, Cobb Mountain, and flows down to the Central Valley where it empties into the Yolo Bypass at near sea level. The Solano Water Project serves Solano County, and includes Lake Solano, Monticello Dam, Lake Berryessa, Putah Diversion Dam, Putah South Canal and their accompanying reservoirs. Six miles downstream from Monticello Dam on Putah Creek is the Putah Diversion Dam. The Putah South Canal breaks off from the creek and flows east for three miles, turning south, moving water from the creek thirty miles to the terminal reservoir in Solano County (USBR, 2000). The cities of Fairfield, Vacaville, Suisun, Dixon, Benicia, and Vallejo all receive their water from the Solano Project as well as Travis Air force Base, the California Medical Facility and UC Davis. It provides partial irrigation for nearly 1,000 farms, flood control for the downstream portion of Putah Creek, and recreational area around Lake Berryessa and Lake Solano. Unused water is delegated to city municipalities and industry. There is also a small hydroelectric power plant at the Monticello Dam that has an output of 11,500 kilowatts (Winters, 2005).

The Solano Project affects the habitat of many native fish species, particularly the endangered Sacramento River Chinook salmon, which historically occurred upstream as far as the headwater reaches in the Upper Sacramento, Pit, McCloud, Calaveras Rivers and even Putah Creek. However, damming of these rivers now limit the range of Chinook salmon by over 80% (USBR, 2000). The limited release flows from the diversion drastically alters the hydraulic regime that natives species have adapted their lifestyles to. Fall run Chinook salmon require one of the highest velocities of salmon, 2.44m/s (Bjornn and Reiser, 1991). Dams have negatively altered the timing of historic high flow events that trigger salmon upstream and make the river conditions unsuitable for many native species. This altered hydraulic regime results in increased stream temperatures and sedimentation downstream of the dam (Lessard, 2000). Releases from the dam contain no sediment and the water is exceptionally cold coming from the bottom of the reservoir, meaning that higher release flows result in a colder creek further downstream from the dam. Water flows slower and warmer the further downstream from the dam as it travels, creating drastically different habitat conditions available for fish, many of which are ideal for non-native species (Torgersen *et. al.* 1999). Temperature regimes of a given river affect fish in their biochemical processes, physiology, and life strategies (Beitinger *et. al.* 2000). Temperatures that are unfavorable to chinook salmon can alter the timing of their migration and accelerate or retard maturation. The habitable temperature range for the fall Chinook salmon is 10.6-19.4 degrees Celsius (Bjornn and Reiser, 1991). This makes water temperature the main limiting factor on fish distribution downstream from dams.

Objective:

Although the lower Putah Creek riparian corridor represents one of the largest remaining tracts of high-quality wildlife habitat in Yolo and Solano Counties and is home to unique assemblages of fish and wildlife species native to the Central Valley, it suffers from numerous invasive species, eroding banks, habitat loss and degradation, flood-related impacts, and nonpoint source pollution problems. The objective of this project is to provide a description of existing and historical natural resources in the Putah Creek watershed, create goals for natural resource management and restoration, and to implement actions that are consistent with landowner interests to restore ecosystem processes and enhance aquatic and terrestrial habitats in the watershed by assessing release flow from the Putah Diversion Dam and its effect on Chinook Salmon spawning ability.

Hypothesis

We hypothesize that the aquatic habitat preferred by salmon for spawning with ideal temperatures will be within a few kilometers of the diversion dam. With the water temperature increasing as it flows downstream, we expect that conditions favorable for non-native species will increase as distance from the dam increases.

Methods and Assumptions:

Resources used for this assessment include written reports, anecdotal information, and field surveys. A number of written reports are available that collectively provide descriptive information on the complex hydrologic, geomorphic, and water quality conditions of Putah Creek. However, no single comprehensive hydraulic evaluation currently exists. A few investigations have been completed (Yates, 2003; Jones, 2002; USACE, 1995) that provide analyses of specific elements useful to the historical and current understanding of hydraulic/geomorphic conditions in Putah Creek. In addition, researchers at UC Davis have also examined certain elements and regions of the stream channel to understand and address ecological issues such as restoration opportunities for potential fisheries analyses.

Routine collection of water quality samples in lower Putah is limited to two programs at the U.S. Bureau of Reclamation and UC Davis. Since 1975, Reclamation has conducted routine monitoring on a monthly basis for selected chemical constituents in selected regions upstream of Lake Berryssa, in the interdam reach of Putah Creek (the region in Figure 1, just east of Putah Diversion Dam), and in the Putah South Canal terminal reservoir (Yates, 2003). Solano County Water Agency (SCWA) operates the Putah Diversion Dam (PDD) and has monitored Putah South Canal twice per year since 1981 for physical characteristics, minerals, and trace inorganic and organic compounds for toxicological significance. Located downstream from the PDD, UC Davis collects samples from Putah Creek upstream and downstream of the university waste-water treatment plant outfall for a full suite of chemical analyses (UC Davis, 2003). SCWA and UC Davis have also deployed automated temperature loggers infrequently during several years for several months at a time and in several locations along lower Putah Creek (Jones and Stokes, 1996).

Our main data source comes from the *Lower Putah Creek Watershed Management Action Plan.* This study was conducted to address the improvement of environmental flows to lower Putah creek in order to meet the needs of native species and increase the connectivity of the creek to the Yolo Bypass for anadromous species like the Chinook salmon. This data is particularly useful because it has more extensive measurements of temperatures at multiple intervals downstream of the PDD over several years, taken with different release rates each year. The *Lower Putah Creek Watershed Management Action Plan* also has ideal data on fish distributions throughout the creek from extensive sampling over a five year period. These data sets are what we need to determine what the effects will be of increased release flow rates, the temperature regime of Putah creek, and how much of the stream will be available for salmon spawning based on temperature alone.

Calculations/Results:

The Solano Project was built to substitute surface water for groundwater and reduce long-term groundwater deficits. All facilities built under this project (Monticello Dam, PDD, and Putah South Canal) were completed in 1957, resulting in the current highly regulated streamflow regime. Construction and operation of Monticello Dam dramatically altered the natural high stream-flow and flood regime along the stream. In December 2002, a total of 13 inches of rain fell within 4 days during this event, resulting in 90,000 cfs entering Lake Berryssa while regulated outflows remained at 200 cfs (Yates 2003). Without the dam, the cities of Winters and Davis would have been flooded. Following construction of the Solano Project, releases from the PDD to the lower reaches of Putah Creek were initially made under a “live stream” operating rule. Releases were set to equal the in-flow to Lake Berryssa, or the amount of release required to maintain a flow of 5 cfs at Old Davis Road, whichever was less. Figure 2 shows a summary of median flows at or near the PDD before and after construction of the Solano Project. Median flows are shown to increase during August and September months since operation began. It also shows the basic required flow regime as prescribed for “normal” and “drought” conditions. In 2000, the Putah Creek Water Accord was implemented, which required streamflow to always be present from the PDD to the Yolo Bypass. The purpose of the Accord was to create as natural a flow regime as feasible as well as the protection and enhancement of native resident and anadromous fish populations and maintenance of riparian vegetation.

Summary of Flows at or Near Putah Diversion Dam Before and After Construction of the Solano Project

Variable	Flow (cfs)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pre-Project (1934–1956) [1]												
Max	3,957	6,468	3,506	2,729	452	156	64	32	21	45	807	5,110
Med	794	1,075	736	281	125	42	7	5	6	6	37	296
Min	45	67	151	50	17	7	2	0	2	1	3	9
Post Project (1971–1981, 1985–1990) [1]												
Max	1,239	2,239	3,403	2,020	51	43	43	34	36	20	50	85
Med	38	41	33	46	43	43	43	34	20	20	25	25
Min	25	18	26	45	33	33	33	26	16	15	26	25
Putah Creek Accord Release Schedule [2]												
Normal Year – PDD [3,4,5]	25	16	26	46	43	43	43	34	20	20	25	25
Normal Year – I-80 [3, 4, 5]	15	15	25	30	20	15	15	10	5	5	10	10
Drought Year – PDD [6]	25	16	26	46	33	33	33	26	15	15	25	25
Drought Year – I-80 [6]	2	2	2	2	2	2	2	2	2	2	2	2

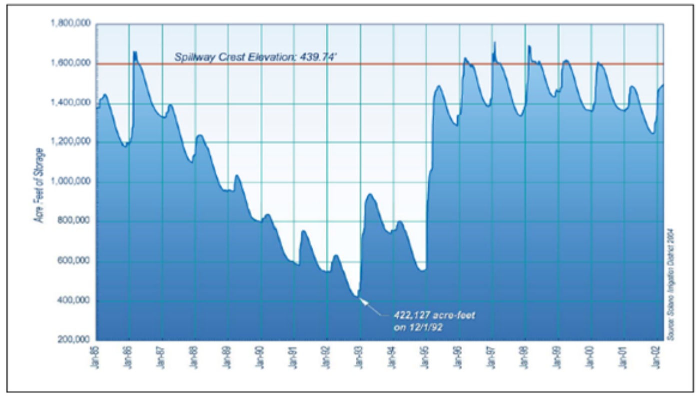

Figure 2: [Winters, 2005]

Figure 3: Lake Berryssa Water Storage, 1985-2002 [Winters, 2005]

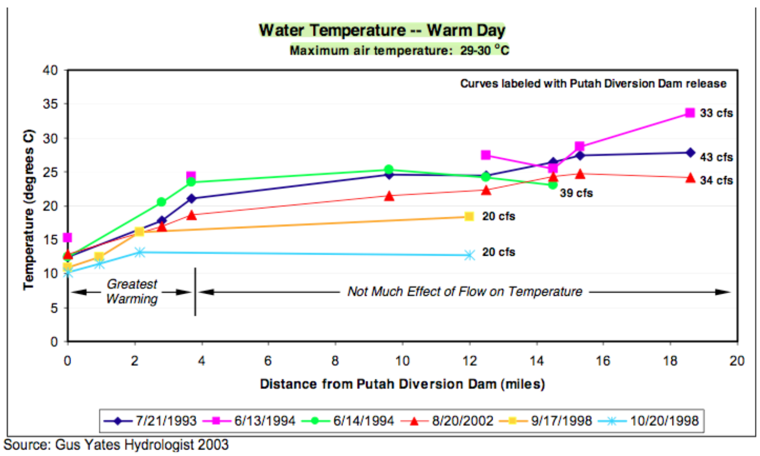

Figure 4: Temp. of creek with distance from dam [Winters, 2005]

We found that with an average of 30cfs of release from the dam (1cfs=450gallons/minute) in from the post Solano measurements (Figure 2) , approximately 21,775 acre feet of water is released from below the diversion dam each year. Over some of these years, lake Berryessa retained 1.5 million acre feet or more, meaning that a mere <1.5% of the reservoirs storage was sacrificed for the environmental flows of Putah creek. On average about 200,000 acre feet of the reservoir is released per year. This shows that the majority of the water is diverted for human use.

The graph above (Winters, 2005) displays stream temperature measurements from 1993,1994, 1998 & 2002. There is little obvious change in temperature after 4 kilometers past the dam, largely because of the fact that stream temperature is dictated by surrounding air temperature after this distance due to the low volume of the creek. With ideal temperatures for salmon eggs being 10-14 degrees C, only the first 2 km of the creek is available for salmon to breed for all flow regimes (Sykes *et. al.* 2009). It is important to note that this is projected from periods before the salmon migrate upstream prior to winter. There could be a variable increase in the distance salmon egg prefered temperatures extend downstream of the diversion canal, based on the variation in winter temperatures from year to year and how much this influences stream temperature.

Conclusions:

We have found that there are many external factors that dictate temperature beyond just the flow rate of the creek and release from the Solano diversion dam. Putah Creek's low flows do not have enough volume to retain cold temperatures for a considerable distance past the diversion dam. If the flow were doubled, only an extra 2 km would be provided for the salmon, with all external factors influencing stream temperature not considered (Brown & Ford 2002, Keirman *et. al.* 2012). Every extra kilometer of creek that salmon eggs can survive in is valuable habitat, but will require a substantial flow increase to achieve these conditions. There are also many other variables that need to be considered with increasing flow, particularly flood risk and erosion. If any increases in flow were to be released into the creek, it would be best to commit them to keeping winter flows high during December and January. This would keep full connectivity to the Yolo Bypass and have a strong enough streamflow for salmon to recognize and swim upstream. It is equally important to keep summer flows high enough to ensure connectivity to the bypass for the migrating salmon fry (Keirman *et. al.* 2012, Marchetti & Moyle 2001, Sykes *et. al.* 2009). This can be achieved with the summer flows that have been administered since 2002, but with the cost that there will be many non-native predators waiting downstream.

Recommendations/Limitations:

While the long-term problem of protecting lower Putah Creek remains to be solved, flow rates have been preserved by efforts of a citizen's group, the Putah Creek Council. In a successful court trial (*Putah Creek Council v. Solano Irrigation District*)l, the Council cited the Fish and Game Code section 5937, which states that "the owner of any dam shall allow sufficient water at all times.. .to pass over, around or through the dam, to keep in good condition any fish that may be planted or exist below the dam" (Smith 2012). There is no question of the importance of quantity and timing of instream flows towards maintaining fish populations, as regulated rivers provide information necessary to develop different methods and models to determine how much water is needed to be left in a particular stream. However, within the overall approach to restore native stream conditions and fish populations, these methods tend to focus on a single species. The focus of our modeling is the Chinook salmon, which relies on a specific set of physical parameters (temperature, depth) that affect its spawning, distribution, and abundance. Efforts to rejuvenate all native aquatic species (fish, plants, invertebrates) rely not only on the increase in stream inflow, but seasonal fluctuations as well (Keirman *et. al.* 2012). Increased flows would provide all-around benefits to the ecosystem, but at the risk of jeopardizing the water storage security of the Berryessa reservoir. We recommend the creation of an adaptive management plan to adjust the flow regime of Putah creek during wet years. This would likely entail increasing the flows of putah creek by ⅓ in the years where there are above average precipitation, only reducing the storage of Berryessa by about 8,000 acre feet during these wet years (UC Davis, 2003). During dry years, the normal average flow should be released to ensure the integrity of the creek's vulnerable ecosystem.

There are a variety of other restoration methods that could improve the habitat quality of Putah Creek. In particular, the most effective restoration method would involve gravel augmentation projects below the diversion dam. Much of this area, while within the ideal temperature range of salmon eggs, do not have adequate gravel for salmon to create their redds and deposit their eggs. With temperatures being the primary limiting factor, lack of adequate gravel is easily the second limiting factor of salmon spawning success (Sykes *et. al.* 2009).

References:

Beitinger, Thomas L., Wayne A. Bennett, and Robert W. McCauley. (2000)"Temperature Tolerances of North American Freshwater Fishes Exposed to Dynamic Changes in Temperature." *Environmental Biology of Fishes* 58 : 237-75. Print.

Brown, L.R. and Ford, T. (2002) Effects of flow on the fish communities of a regulated California river: Implications for managing native fishes. River Research and Applications 18(4), 331-342.

Bjornn, T. C. and Reiser, D. W. 1991. Habitat Requirements of Salmonids in Streams. Influences of Forest and Rangelands Management on Salmon and their Habitat. American Fisheries Society Special Publication 19. http://205.225.207.106/water_issues/programs/tmdl/docs/303d_policydocs/165.pdf

City of Winters. Lower Putah Creek Coordinating Committee. *Lower Putah Creek Watershed Management Action Plan*. By Rich Marovich. N.p.: n.p., n.d. Dec. 2005. Web. <http://www.cityofwinters.org/pdf/putahcreek/Lower%20Putah%20WMAP%20Vol%20I%2012-05.pdf>.

Kiernan, J.D., Moyle, P.B. and Crain, P.K. (2012) Restoring native fish assemblages to a regulated California stream using the natural flow regime concept. Ecological Applications 22(5), 1472-1482.

Lessard, Joanna L. *Temperature Effects of Dams on Cold-water Fish and Macroinvertebrate Communities in Michigan*. Diss. Michigan State University, 2000. Michigan Dept. of Resources, 2000. Print. <http://www.michigandnr.com/PUBLICATIONS/PDFS/ifr/ifrlibra/research/reports/2058rr.pdf>

Marchetti, M.P. and Moyle, P.B. (2001) Effects of flow regime on fish assemblages in a regulated California stream. Ecological Applications 11(2), 530-539.

Moyle, Peter B., and Michae P. Marchetti. "Fish Health and Diversity: Justifying Flows for a California Stream." *Middle Fork American River Project Relicensing*. Placer County Water Agency,July 1998. Web. 30 Nov. 2013. <http://relicensing.pcwa.net/Documents/Resource_Agencies_PMEs/USFS%20-%20August%205,%202011/04_Enclosure%20III/FS_lit%20cited_1/20110805-5072(26145279).pdf>.

UC Davis, 2003 Long Range Development Plan Draft EIR (UC Davis 2003). <http://sustainability.ucdavis.edu/progress/commitment/planning/lrdp.html>.

United States. Bureau of Reclamation. *Usbr.gov*. By Zachary Redmond. United States Bureau of Reclamation, 05 June 2000. Web. <http://www.usbr.gov/projects//ImageServer?imgName=Doc_1305643072566.pdf>.

Smith, Matthew J. "Protecting Putah Creek." *Middle Fork American River Project Relicensing*. Placer County Water Agency, 9 Mar. 2012. Web. 30 Nov. 2013. <http://relicensing.pcwa.net/Documents/Resource_Agencies_PMEs/USFS%20-%20August%205,%202011/04_Enclosure%20III/FS_lit%20cited_1/20110805-5072(26145279).pdf>.

Sykes, G.E., Johnson, C.J. and Shrimpton, J.M. (2009) Temperature and Flow Effects on Migration Timing of Chinook Salmon Smolts. Transactions of the American Fisheries Society 138(6), 1252-1265.

Torgersen, C.E., Price, D.M., Li, H.W. and McIntosh, B.A. (1999) Multiscale thermal refugia and stream habitat associations of chinook salmon in northeastern Oregon. Ecological Applications 9(1), 301-319.

Yates, G., "Gravel and Temperature Surveys of Lower Putah Creek," prepared for Lower Putah Creek Coordinating Committee, Vacaville, CA, 2003. Print.