TECHNICAL MEMORANDUM

FEASIBILITY OF FISH PASSAGE AT CALAVERAS DAM

Prepared for

San Francisco Public Utilities Commission

June 2009

URS HDR

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Appendices

Tables

Figures

List of Acronyms

ACDD	Alameda Creek Diversion Dam
ACDT	Alameda Creek Diversion Tunnel
ACFCWCD	Alameda County Flood Control and Water Conservation District
ACFRW	Alameda Creek Fisheries Restoration Workgroup
ACWD	Alameda County Water District
AF	acre-feet
CCC	Central California Coast
CDFG	California Department of Fish and Game
CDRP	Calaveras Dam Replacement Project
cfs	cubic feet per second
CRF	Capital Recovery Factor
DPS	distinct population segment
DSOD	Division of Safety of Dams
EBRPD	East Bay Regional Parks District
ETJV	EDAW-Turnstone Joint Venture
HDR	HDR Engineering, Inc.
HDR|SWRI	HDR Engineering, Inc.|Surface Water Resources, Inc.
MOU	Memorandum of Understanding
NMFS	National Marine Fisheries Service
O&F	Overhead and Fee
PG&E	Pacific Gas and Electric Company
SFPD	San Francisco Planning Department
SFPUC	San Francisco Public Utilities Commission
SFWD	San Francisco Water Department
SVWC	Spring Valley Water Company
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife
WSIP	Water System Improvement Program

EXECUTIVE SUMMARY

This technical memorandum describes the general design criteria for identification of conceptual-level passage components for steelhead (*Oncorhynchus mykiss*) at the replacement Calaveras Dam and assesses the feasibility and potential biological benefit of implementing these components.

The San Francisco Public Utilities Commission (SFPUC) owns and operates Calaveras Reservoir, which is located within the Alameda Creek Watershed, upstream of San Francisco Bay. The existing Calaveras Dam is located at the northern end of Calaveras Reservoir, about 1 mile upstream of the confluence of Calaveras Creek with Alameda Creek. In response to safety concerns about the seismic stability of the dam, and after consultation with the California Department of Water Resources, Division of Safety of Dams (DSOD), the SFPUC lowered water levels in the reservoir to approximately 40 percent of the normal total water storage capacity beginning in the winter of 2001. The DSOD authorized this interim operating level while SFPUC pursues an aggressive schedule to replace the dam and eliminate seismic safety concerns.

The proposed Calaveras Dam Replacement Project (CDRP) would include a replacement dam of equal height that would be built immediately adjacent to the downstream face of the existing dam. The spillway crest of the proposed dam would be approximately 200 feet above the spillway exit to Calaveras Creek, which is comparable to the dimensions of the existing dam.

Calaveras Reservoir is one of three major reservoirs in the Alameda Creek Watershed. The Alameda Creek Watershed drains interior hills and valleys of the Diablo Range before draining into San Francisco Bay near Fremont. There is no winter accumulation of snowpack in Alameda Creek Watershed, and most tributaries only convey water during the wet season and are intermittent during the dry season. Calaveras Reservoir is located in the Upper Alameda Creek Sub-Watershed, which is composed of five basins. The reservoir is located at the confluence of two of these basins, Calaveras Creek and Arroyo Hondo.

STEELHEAD IN THE ALAMEDA CREEK WATERSHED

The Central California Coast steelhead Distinct Population Segment (DPS) is listed as a threatened species under the federal Endangered Species Act (ESA). Steelhead historically had access to the Alameda Creek Watershed. Upstream migration to the Alameda Creek Watershed from the San Francisco Bay and the Pacific Ocean has been blocked for decades by a number of artificial barriers. Federally ESA-listed adult steelhead immigrating from the ocean to spawn in fresh water are present in low numbers below the BART weir (the first complete barrier to upstream migration into the Alameda Creek Watershed).

Resident rainbow trout (*O. mykiss*) and steelhead are the same species. Rainbow trout spend their entire life-cycle in fresh water, while steelhead have an anadromous life history. Rainbow trout occur in the Alameda Creek Watershed and are not listed under the federal or state endangered species acts.

The SFPUC is a member of the Alameda Creek Fisheries Restoration Workgroup, which is working to restore steelhead to the Alameda Creek Watershed. The Alameda Creek Fisheries Restoration Workgroup also includes representatives from the National Marine Fisheries Service (NMFS) and the California Department of Fish and Game (CDFG). In conjunction with other fisheries enhancement activities, the SFPUC removed Niles and Sunol dams from Alameda Creek in 2006.

ANALYSIS OF FISH PASSAGE AT CALAVERAS DAM

Industry standards for fish passage devices, methods used at other dams, and resource agency guidelines were reviewed and evaluated to determine the feasibility of fish passage at Calaveras Dam. Literature on fish physiological responses to handling, behavioral responses to devices, steelhead reproductive success, steelhead life history characteristics, and general fish passage concepts were also considered. In the analysis, design features (*design components*) for fish immigration and emigration were identified and evaluated, then analyzed in complete immigration and emigration combinations (*options*).

For adult immigration, the following design components were considered:

- Fish lifts (navigation locks, fish elevators, and fish locks)
- Fish ladders (pool and weir design, vertical slot design, and weir and orifice design)
- Trap and haul (Oak Ridge, Calaveras, and Corral Point haul routes)

Fish lifts were determined to be unsuitable as the primary means of passage because the 200-foot elevation change and other site constraints at Calaveras Dam preclude reasonable engineering solutions.

Calaveras Dam is a water supply and storage reservoir with fluctuating water surface elevations that would constrain the design of passage via a fish ladder. A fish ladder on the downstream face of the dam would lead to the dam crest, but with this design component a lift would be required on the upstream face of the dam to lower the fish to the reservoir water surface elevation, preventing adult immigration from being volitional.

The analysis of adult immigration in this technical memorandum identifies that provision of volitional passage for adult steelhead immigration is not feasible at Calaveras Dam. A fish ladder on the downstream face of the dam in conjunction with a fish lift on the upstream face of the dam could be used to provide nonvolitional passage for steelhead immigration. Trap and haul of immigrating adults collected at a facility below Calaveras Dam and trucked to a suitable release site above the dam was found to be relatively feasible compared to the other design components evaluated in the first tier of the analysis. For adult immigration, a fish ladder with a lift and trap and haul design components were retained for second tier analysis.

Next, design components that would provide passage for emigrating steelhead were evaluated. No design component identified would allow for volitional emigration of juveniles. Therefore, the juvenile emigration design consists of two steps: the first step would be to collect the juvenile steelhead somewhere above Calaveras Dam, and the second step would be to transport the fish to a location downstream of the dam. Although most steelhead die after spawning, as much as 20 or 30 percent of an annual steelhead run may be composed of repeat spawners or "kelts." Requirements for re-capturing and transporting post-spawn adult steelhead are particularly problematic. There is no precedent for capturing and transporting post-spawn adult steelhead, and no feasible design components that successfully capture post-spawn, adult steelhead were identified.

Juvenile collection design components evaluated as part of a trap and haul solution for juvenile emigration included:

- In-channel fish screens and capture in Arroyo Hondo
- A surface bypass collector at the dam
- Off-channel fish screens and capture in Arroyo Hondo
- A surface flow collector in the reservoir

Construction of in-channel fish screens was rejected because it would not effectively capture sufficient numbers of emigrating juvenile steelhead. The surface bypass collector was rejected because it was determined to be suitable only for passage at dams with minimal storage capacity (i.e., run-of-the-river type dams). The off-channel fish screen facility and the surface flow collector design components both emerged from the initial screening as technologically feasible for collection of emigrating juveniles, and were retained for further evaluation.

The following juvenile transport design components were evaluated, as the second part of a trap and haul solution for juvenile emigration:

- Tanker truck transport
- Canal or pipeline transport
- Bypass tunnel transport

The tanker truck transport design component was retained for further consideration, but canals, pipelines, and bypass tunnels were rejected from further consideration because the survival of the fish was likely to be lower, and these design components had substantially greater engineering challenges and costs. Trapping juvenile fish and hauling them to a suitable release location below Calaveras Dam was the only combination of juvenile emigration design components retained for further analysis.

Those design components, described above, that were retained through the preliminary screening were further evaluated on the basis of capital and operating costs. The order-of-magnitude cost of providing fish passage via a combination of a fish ladder for immigrating adult steelhead and trap and haul for emigrating juvenile steelhead, annualized over 30 years, and including estimated water costs to operate a fish ladder was estimated at approximately $7 million per year. The annual cost of passage via trap and haul for both immigrating adults and emigrating juveniles was estimated at approximately $1.4 million per year.

The remaining design components were evaluated based on the amount of habitat that would become accessible to steelhead. Although the Arroyo Hondo Basin is relatively large, the presence of an upstream fish migration barrier 1.8 miles above Calaveras Reservoir would severely limit the spawning and rearing habitat available to steelhead once they are transported above Calaveras Dam. Therefore, habitat availability was identified as an important limiting factor for fish passage at Calaveras Dam. The fish passage option retained for final analysis was trap and haul, with fish capture facilities on Calaveras Creek and Arroyo Hondo.

CONCLUSIONS

Given the high cost of providing fish passage via a fish ladder at Calaveras Dam, the inability to provide volitional passage with a fish ladder, and the multiple stages at which handling would be involved in the fish ladder passage option, trap and haul for both immigrating adult and emigrating juvenile steelhead is the only potentially feasible option for fish passage at Calaveras Dam. Facilitating steelhead passage via trap and haul from a location below the dam would provide access to a limited amount of spawning and rearing habitat above Calaveras Dam. However, based on this preliminary analysis, an effort to reestablish a viable population of steelhead in the 1.8-mile reach of Arroyo Hondo, in and of itself, has a low probability of success. This finding rests largely on the inability to provide volitional passage, and limitations on the quantity of accessible habitat available directly above Calaveras Dam.

The integrative value of habitat above Calaveras Dam to a steelhead metapopulation could be evaluated in conjunction with other efforts to restore steelhead to the Alameda Creek Watershed, as well as broader efforts to recover the Central California Coast steelhead DPS. However, given the inability to provide volitional passage, the cost of passage, and the limited spawning and rearing habitat that would be made accessible, alternative measures in support of Central California Coast steelhead recovery that have a greater benefit-to-cost ratio should be investigated prior to implementation of fish passage at Calaveras Dam.

1 INTRODUCTION

1.1 BACKGROUND INFORMATION

The San Francisco Public Utilities Commission (SFPUC) owns and operates Calaveras Reservoir, which is located within the Alameda Creek Watershed, approximately 24 river miles[1] upstream of San Francisco Bay (Figure 1-1). Surface water storage at Calaveras Reservoir, located on Calaveras Creek, began in 1916 by the Spring Valley Water Company (SVWC). The dam at Calaveras Reservoir was rebuilt between 1918 and 1925 following a slide that occurred during construction of the hydraulic filled embankment on the upstream side of the dam. Construction of the Alameda Creek Diversion Dam and Tunnel began in 1925 to secure additional sources of water from the Upper Alameda Creek Sub-Watershed for impoundment into Calaveras Reservoir. The Calaveras Dam and associated facilities were purchased from the SVWC by the City of San Francisco in 1930. The SFPUC began diverting water from upper Alameda Creek with the completion of the diversion dam and tunnel in 1931 (SFPUC, 2004). Calaveras Reservoir is designed to retain approximately 96,850 acre-feet of run-off from Alameda Creek, Calaveras Creek, and Arroyo Hondo. The existing dam at Calaveras Reservoir presents an impassable barrier to upstream fish migration.

The SFPUC initiated studies in 1998 to evaluate the structural stability and performance of the dam during projected large earthquakes. The studies indicated that the existing dam does not meet current safety standards for large seismic events. After consultation with the California Department of Water Resources, Division of Safety of Dams (DSOD), the SFPUC lowered water levels in the reservoir to approximately 40 percent of the normal total water storage capacity beginning in the winter of 2001. The elevation of the lowered water level corresponds to about 38,100 acre-feet (AF) of storage, which is approximately 60 percent less than the previous normal total water storage capacity. DSOD has indicated that it is allowing this interim operating level to accommodate a small portion of the water storage needs with the understanding that the SFPUC is pursuing an aggressive schedule to rebuild the dam in order to eliminate the seismic safety concerns associated with the original dam. That effort has been termed the Calaveras Dam Replacement Project (CDRP).

The purpose of the proposed CDRP is to replace the existing dam with a new dam to accommodate a public water supply reservoir of the same size as the original and meet current seismic safety design requirements, and to support water system reliability, including provision of supply during periods of maintenance to the Hetch Hetchy System, as well as during unanticipated interruptions in supply and droughts. When the proposed replacement dam is completed, DSOD restrictions would be lifted and the original reservoir pool could be restored.

CDRP includes provision of water releases in accordance with a Memorandum of Understanding (MOU) with the California Department of Fish and Game (CDFG) (CDFG, 1997). The flow compliance point for this instream flow schedule is immediately below the confluence of Calaveras and Alameda creeks. To maximize aquatic habitat under future CDRP operations, SFPUC will provide bypass flows from the Alameda Creek Diversion Dam whenever flows are available and supplement flows, as needed, with releases from the replacement Calaveras Dam to meet the requirements of the MOU (SFPUC, 2008a). The SFPUC has also proposed an instream flow schedule for future populations of steelhead (SFPUC, 2009). The SFPUC-proposed instream flow schedule would provide differing amounts of flow depending on annual hydrologic conditions (dry, normal, or wet), as summarized in Table 1-1 and illustrated in Figure 1-2. For the purposes of this technical memorandum, it is assumed that the SFPUC-proposed instream flow schedule would be provided as bypass flows at ACDD whenever such flows are naturally present.

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[1] A river mile is standard terminology for a measure of distance in miles along a river from its mouth. All streams in the Alameda Creek Watershed are in fact creeks, not rivers.

Table 1-1
SFPUC Proposed Instream Flow Schedule

Flow Schedule Decision Date	Flow Schedule Application Period	Wet (Schedule A)		Normal (Schedule B)		Dry (Schedule C[1])	
		Cumulated Flows for Water Year Classification (MG)	Flow Requirement (cfs)	Cumulated Flows for Water Year Classification (MG)	Flow Requirement (cfs)	Cumulated Flows for Water Year Classification (MG)	Flow Requirement (cfs)
N/A	October	N/A	7	N/A	7	N/A	7
N/A	Nov. – Jan. 11	N/A	5	N/A	5	N/A	5
Jan. 11	Jan. 12 – Jan. 31	> 3,660	42*	1,166 – 3,660	20*	< 1,166	20*
Jan. 31	Feb. 1 – Feb. 28	> 6,882	42	2,597 – 6,882	20	< 2,597	20
Feb. 28	Mar. 1 – Mar. 31	> 11,859	42*	5,721 – 11,859	20*	< 5,721	20*
March 31	Apr. 1 – Apr. 30	>17,449	32 – 18*	6,563 – 17,449	15*	< 6,563	7*
April 30	May 1 – May 31	> 18,211	15	7,246 – 18,211	15	< 7,246	7
May 31	June 1 – June 30	> 18,551	15	7,838 – 18,551	15	< 7,838	7
June 30	July 1 – Sept. 30	> 18,693	15	7,948 – 18,693	15	< 7,948	7

Notes:

The new flow schedule would be implemented after passage at the BART weir has been provided and National Marine Fisheries Service has confirmed steelhead occurrence upstream of the BART weir through a letter to San Francisco Public Utilities Commission.

The flow schedule also includes provision of year-round base flows of 2 cfs in Calaveras Creek below Calaveras Dam.

[1] Flow Schedule C is equivalent to the flows detailed in the CDFG MOU.

* Daily ramping schedule applies

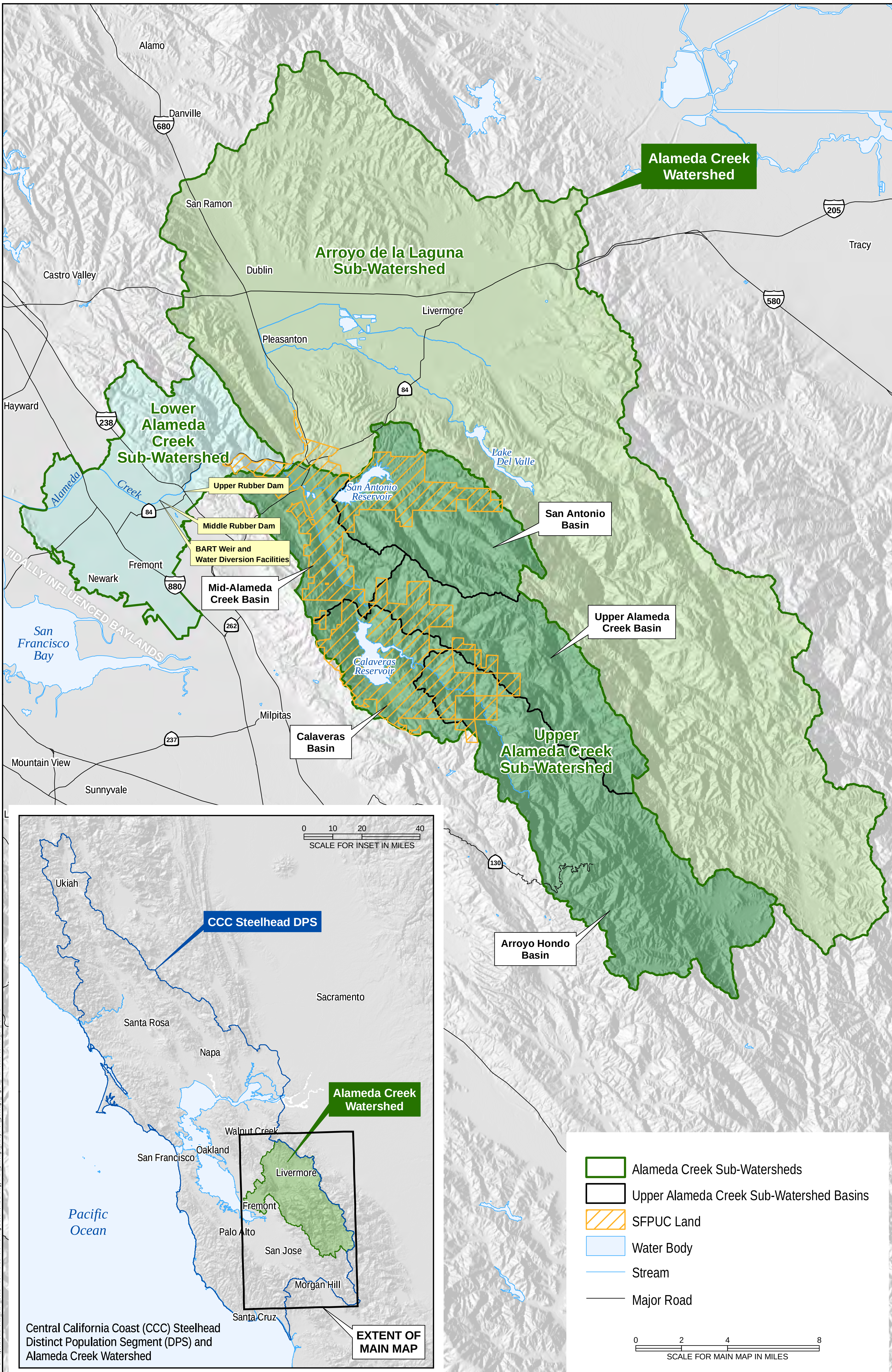
cfs = cubic feet per second

MG = million gallons

N/A = not applicable

Restoring the dam at Calaveras Reservoir is needed as part of the Water System Improvement Program (WSIP), which was adopted by SFPUC in order to improve the regional system with respect to water quality, seismic response, water delivery, and water supply to meet water delivery needs in the service area through the year 2018. The WSIP establishes level of service goals and system performance objectives (SFPUC, 2008b).

SFPUC has been working with other stakeholders since the late 1980s to restore steelhead to the Alameda Creek Watershed (TAC, 1989). Below natural and manmade impassable barriers, Central California Coast (CCC) distinct population segment (DPS) naturally spawned anadromous steelhead (*Oncorhynchus mykiss*) are listed as threatened under the federal Endangered Species Act (NMFS, 2006). Steelhead access to the Alameda Creek Watershed from the ocean has been blocked by various water development and other projects in Alameda Creek (TAC, 1989; ETJV and ESA-Orion Joint Venture, 2008; SFPUC, 2008a), but resident, native rainbow trout (*O. mykiss*) still occur in the upper watershed. Rainbow trout above the BART weir (Figure 1-1), an impassable fish migration barrier in the Lower Alameda Creek Sub-Watershed, are not listed or proposed for listing under the federal or state endangered species acts. However, federally listed adult steelhead migrating from the ocean to spawn in freshwater are sometimes present in low numbers below the BART weir (see Section 2.4, Steelhead Presence in the Alameda Creek Watershed).



Alameda Creek Watershed

Feasibility of Fish Passage at Calaveras Dam
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Figure 1-1

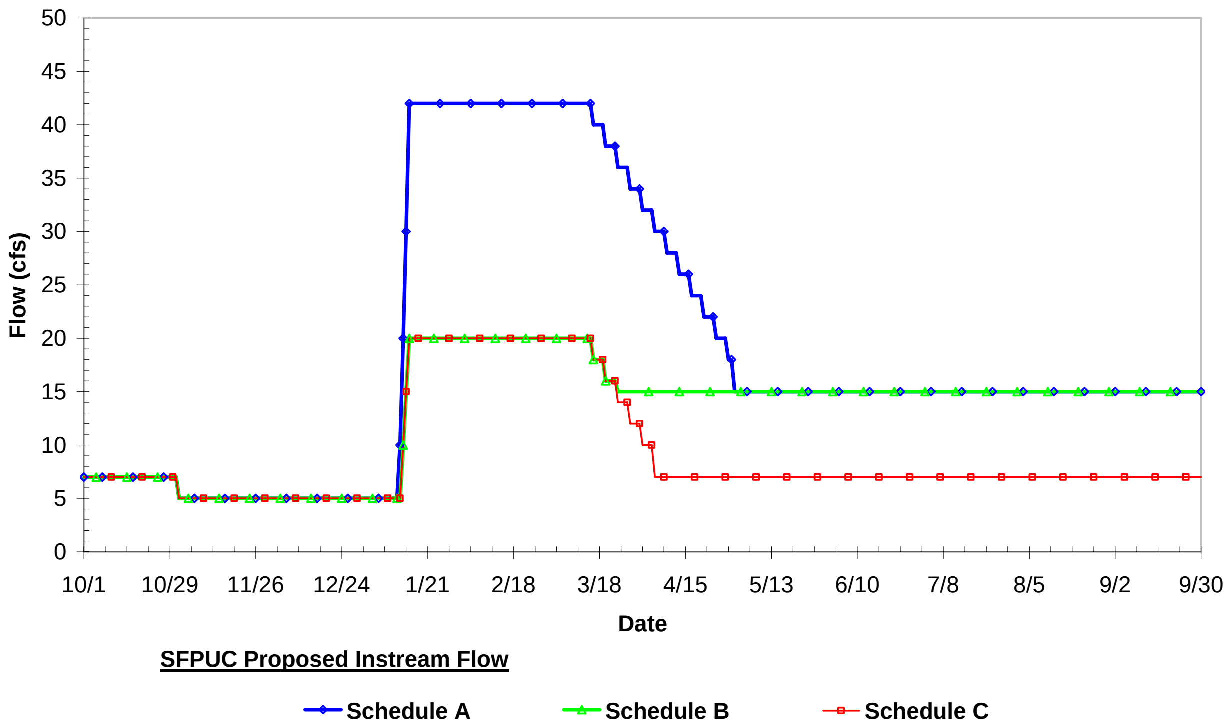


Figure 1-2 SFPUC-Proposed Instream Flow Schedule

1.2 PURPOSE

The SFPUC has retained URS Corporation and HDR (HDR|SWRI and HDR|FishPro) to provide professional fisheries and engineering services to evaluate the feasibility of providing fish passage for anadromous steelhead at the proposed replacement Calaveras Dam. In conjunction with ongoing efforts to remedy the barriers to passage, it is anticipated that a run of anadromous steelhead will be restored to the Alameda Creek Watershed (ETJV and ESA-Orion Joint Venture, 2008). This technical memorandum describes the general design criteria, evaluates conceptual-level options, and assesses the feasibility of providing passage for adult steelhead above the proposed CDRP and subsequent downstream passage for juveniles and post-spawn adults.

1.3 SCOPE

The scope of work for this effort includes examining the feasibility of moving anadromous steelhead past Calaveras Dam during both adult immigration and juvenile emigration life stage periods. The evaluation of fish passage includes the construction of fish ladders, fish lifts, trap and haul, and other possible options for fish passage at the replacement Calaveras Dam. This evaluation includes consideration of the feasibility, cost, and benefits of providing fish passage.

Three other technical memoranda, which are in preparation, examine passage conditions at natural barriers in the stream reaches in the Upper Alameda Creek Sub-Watershed; study and estimate steelhead migration flows in the reach of Alameda Creek at the Sunol quarries; and assess the technical feasibility of providing passage at SFPUC's ACDD.

1.4 ORGANIZATION OF TECHNICAL MEMORANDUM

The organization of the Feasibility of Fish Passage at Calaveras Dam Technical Memorandum is as follows:

- Section 1 provides background information and introduces the CDRP and the purpose and scope of this technical memorandum.
- Section 2 describes existing hydrology and historic and existing steelhead presence in the Alameda Creek Watershed, and defines the study area for this technical memorandum.
- Section 3 describes the methodology used in this technical memorandum.
- Section 4 describes and analyzes the design components and operational constraints that would be part of fish passage at Calaveras Dam.
- Section 5 identifies a potential fish passage option and provides an analysis of the potential for fish passage at Calaveras Dam to meet specific passage goals.
- Section 6 presents the conclusions reached in this technical memorandum.
- Section 7 lists the preparers of this technical memorandum.
- Section 8 lists the references used in preparation of this technical memorandum.
- Appendix A provides technical information about fish ladders. Appendix B provides cost backup calculations. Appendix C describes the hydrologic model selection process and provides detailed flow data. Appendix D presents information on viable population size for salmonids.

2 ENVIRONMENTAL SETTING

Calaveras Reservoir is one of three major reservoirs in the Alameda Creek Watershed, as shown on Figure 1-1. Table 2-1 lists the approximate acreages of the Alameda Creek Watershed, its sub-watersheds, and the basins within the Upper Alameda Creek Sub-Watershed, which comprise the environmental setting for this technical memorandum.

Table 2-1
Approximate Acreage[2] Within the Alameda Creek Watershed, its Three Sub-Watersheds, and the Five Basins in the Upper Alameda Creek Sub-Watershed

Watershed	Sub-Watershed	Basin	Acreage
Alameda Creek			440,000
	Arroyo de la Laguna		270,000
	Upper Alameda Creek		130,000
		Arroyo Hondo	51,000
		Upper Alameda Creek	26,000
		San Antonio	25,000
		Mid-Alameda Creek	15,000
		Calaveras	13,000
	Lower Alameda Creek		40,000

2.1 ALAMEDA CREEK WATERSHED

Calaveras Reservoir is one of three major reservoirs (including San Antonio and Del Valle) in the approximately 440,000-acre Alameda Creek Watershed (Figure 1-1), the largest tributary to the South San Francisco Bay Estuary. It drains the interior hills and valleys east of San Francisco Bay, including the northwestern slopes of the Diablo Range and the Livermore-Amador and Sunol valleys, before cutting through the East Bay hills via Niles Canyon and flowing across its largely developed alluvial fan and floodplain. Alameda Creek, the stream for which the watershed is named, flows approximately 39 miles before draining into the southeastern portion of San Francisco Bay, just north of the Highway 84 Bridge.

Average annual rainfall in the watershed varies from 24 inches on Mount Hamilton, the highest peak in the watershed at an elevation of 4,400 feet above sea level, to 15 inches near the Bay margin in Fremont. Unlike California watersheds that originate high in the Sierra Nevada Mountains, Alameda Creek Watershed does not accumulate snowpack in winter, so many of its streams are ephemeral, drying completely or to a series of intermittent pools before they are refilled by winter rains.

Alameda Creek Watershed has been modified extensively for purposes of flood control and water supply. Roughly 3,000,000 residents of the Bay Area rely on Alameda Creek for clean drinking water (SFEI, 2009). In addition to the growing urban area of Livermore, Dublin, Pleasanton, and

[2] Acreages reported for watersheds in this technical memorandum are based on CalWater data, available at http://cain.ice.ucdavis.edu/calwater/caldata.html.

Fremont, the watershed is managed for grazing, equestrian facilities, nurseries, and, more recently, vineyards.

Alameda Creek Watershed is composed of three sub-watersheds (Figure 1-1). The largest sub-watershed is the Arroyo de la Laguna Sub-Watershed, which at approximately 270,000 acres drains more than 60 percent of the total watershed and contains the major reservoir, Lake Del Valle. The Arroyo de la Laguna Sub-Watershed would not be directly influenced by fish passage at Calaveras Dam.

The Upper Alameda Creek Sub-Watershed is the second largest of the three sub-watersheds, which at approximately 130,000 acres drains just less than 30 percent of Alameda Creek Watershed. The Upper Alameda Creek Sub-Watershed contains Calaveras Reservoir and Calaveras Dam, the subject of this fish passage technical memorandum, and it also contains San Antonio Reservoir (Figure 1-1).

The Lower Alameda Creek Sub-Watershed is the smallest sub-watershed; it drains approximately the lower 40,000 acres, or 10 percent of the area of the entire Alameda Creek Watershed.

2.2 UPPER ALAMEDA CREEK SUB-WATERSHED

Calaveras Reservoir is in the Upper Alameda Creek Sub-Watershed, which is composed of five basins (Figure 1-1). The reservoir is located at the confluence of two of these basins, Calaveras Creek and Arroyo Hondo. Calaveras Creek, an intermittent stream, drains the Calaveras Basin. It is the smallest basin in the sub-watershed, consisting of approximately 13,000 acres. Arroyo Hondo, a perennial stream, drains the approximately 51,000-acre Arroyo Hondo Basin, the largest basin in the sub-watershed. Because of their location above Calaveras Dam, these two basins could be directly affected by fish passage at Calaveras Dam.

The second largest basin in the sub-watershed is the approximately 26,000-acre Upper Alameda Creek Basin, which contains the uppermost reaches of Alameda Creek (Figure 1-1; Table 2-1). Despite being the namesake of the entire Alameda Creek Watershed, this portion of Alameda Creek typically does not have perennial flow, but rather is an intermittent stream that dries to a series of isolated pools and sections of wetted channel during the dry season (Hagar and Paine 2008). Although Alameda Creek does not flow into Calaveras Reservoir, wet season flows from the Upper Alameda Creek Basin are diverted to Calaveras Reservoir. This basin, however, would not be influenced by fish passage at Calaveras Dam.

The Upper Alameda Creek Sub-Watershed also contains the approximately 25,000-acre San Antonio Basin, which drains into San Antonio Reservoir, and the approximately 15,000-acre Mid-Alameda Creek Basin, which is below both the Calaveras and San Antonio reservoirs (Figure 1-1; Table 2-1). Neither of these basins would be directly influenced by fish passage at Calaveras Dam.

2.3 STUDY AREA

The focus of this technical memorandum is to evaluate the feasibility and benefit of providing fish passage at Calaveras Dam (specifically steelhead, see Section 1.1). Of primary interest are the streams and facilities that could be directly affected by fish passage at the replacement Calaveras Dam, all of which lie within the Upper Alameda Creek Sub-Watershed.

Calaveras Reservoir receives runoff directly from Calaveras and Arroyo Hondo basins, with a combined area of approximately 64,000 acres. Additionally, during the wet season, flows from the

Upper Alameda Creek Basin are diverted to Calaveras Reservoir from the ACDD[3] (Figure 2-1) via the Alameda Creek Diversion Tunnel (ACDT), with peak flows passing over ACDD. ACDD and ACDT would not be directly affected by fish passage at Calaveras Dam, and are therefore not considered part of the study area for this technical memorandum. Features that could potentially be directly affected by fish passage at Calaveras Dam and described in the following sections include:

- Arroyo Hondo
- Calaveras Creek
- Calaveras Dam

2.3.1 ARROYO HONDO

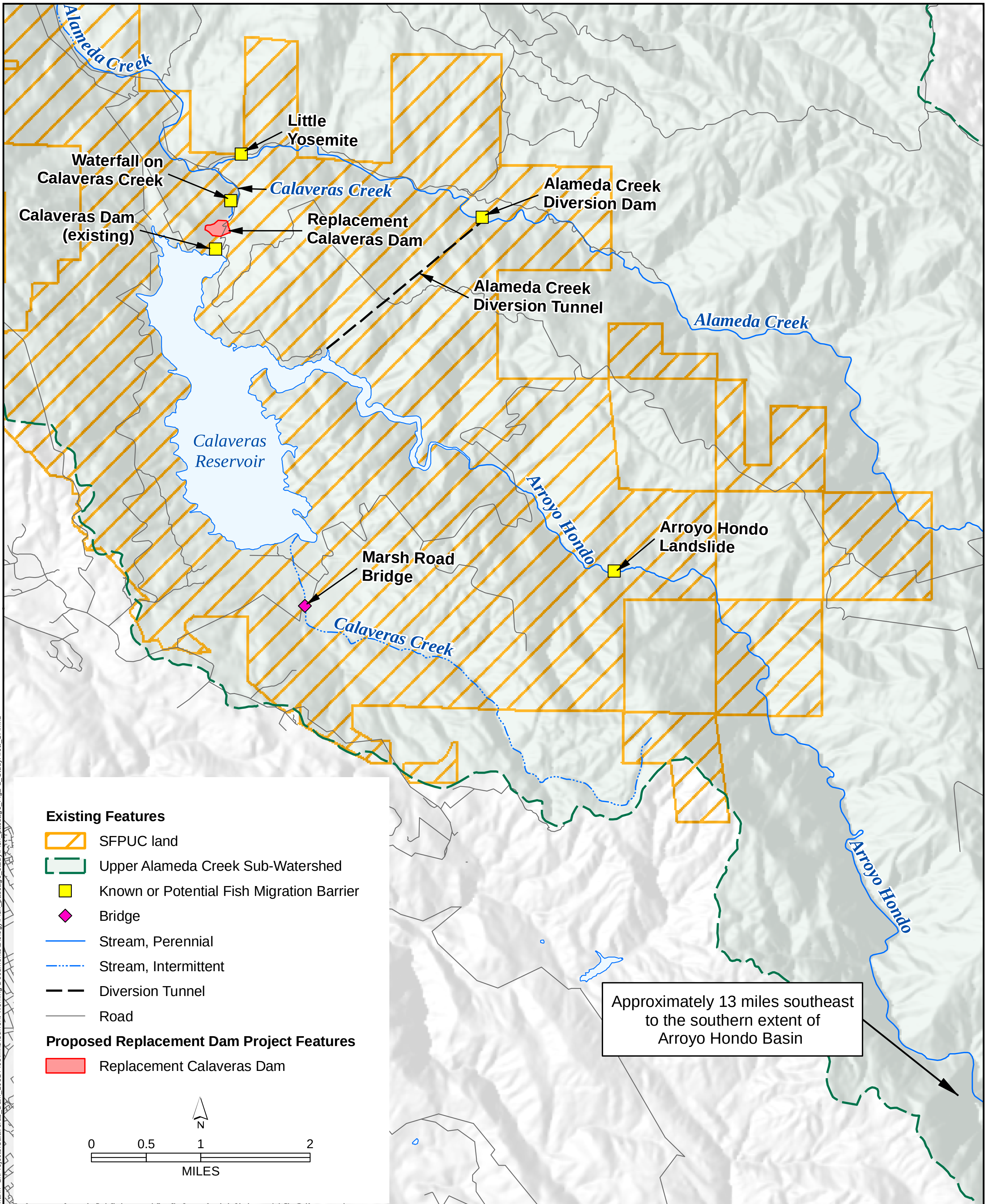
Arroyo Hondo is an approximately 10-mile-long perennial stream that supports one of the largest stands of white alder riparian forest in the Alameda Creek Watershed (SFPD, 2007). Arroyo Hondo and its tributaries drain approximately 51,000 acres, and Arroyo Hondo is the largest contributor of water to Calaveras Reservoir. Flows in Arroyo Hondo are not impeded by any major dams, and range from around 1 cubic foot per second (cfs) during the dry season to well over 1,000 cfs during significant precipitation events (USGS, 2009) (see Figure 4-7).

Two landslides converge at Arroyo Hondo approximately 1.8 miles upstream from its confluence with the average high water level of Calaveras Reservoir (Figure 2-1), and upstream fish passage at this location is obstructed. The larger landslide, which extends up the north wall of the canyon for approximately 2,000 feet, shows signs of recent activity over most of its length and is unstable (URS, 2009). While many of the large boulders resting in the creek channel at this location were likely originally part of these landslide masses, the two largest "boulders" create an approximately 15-foot waterfall and may be bedrock outcrops. The waterfall was identified in a separate study, using a methodology modified from Powers and Orsborn (1985), as an impassable barrier to immigrating adult steelhead at most flows (URS and HDR, 2009). Based on a March 3, 2009 URS site visit, when flows in the creek ranged from 700 to 800 cfs, the passability of this feature is no different at 800 cfs than at the flows evaluated by URS and HDR (2009). There is a low probability that this feature is passable at extremely high flows that occur on occasion in this tributary, but passability under these unobserved conditions is speculative.

2.3.2 CALAVERAS CREEK

Calaveras Creek is a roughly 5-mile-long intermittent stream that drains directly into Calaveras Reservoir (Figure 2-1). The middle and upper reaches of the stream are characterized by low to no flow in the summer, and flashy flow in winter months. The average width of the stream is approximately 4 feet (Hagar and Payne, 2008). There is no stream flow gage on Calaveras Creek, but based on a recent modeling study, flows at a location roughly 0.6 mile upstream from the confluence of Calaveras Creek and the reservoir full pool elevation are strongly linked to precipitation events (ETJV and Hydroconsult Engineers, Inc., 2008). Large, single-day spikes in discharge quickly drop within one or two days (see Figure 2-2). Flows of 10 cfs or greater are expected to occur on approximately 24 days in an average year. For all years studied, the monthly average flow at the Marsh Road bridge (Figure 2-1) was expected to be above 5 cfs only during the months of January, February, and March.

[3] This technical memorandum is concerned with SFPUC's Calaveras Dam, which has a structural height (foundation to crest) of 230 feet and is scheduled for replacement due to seismic safety requirements. SFPUC's Alameda Creek Diversion Dam, which has a structural height of approximately 31 feet and requires no seismic upgrade, is only noted in this report as it relates to the provision of flows to Calaveras Reservoir. Feasibility of providing fish passage at ACDD is being studied separately and the results of that analysis are reported in a separate technical memorandum.



Study Area and Vicinity

Feasibility of Fish Passage at Calaveras Dam
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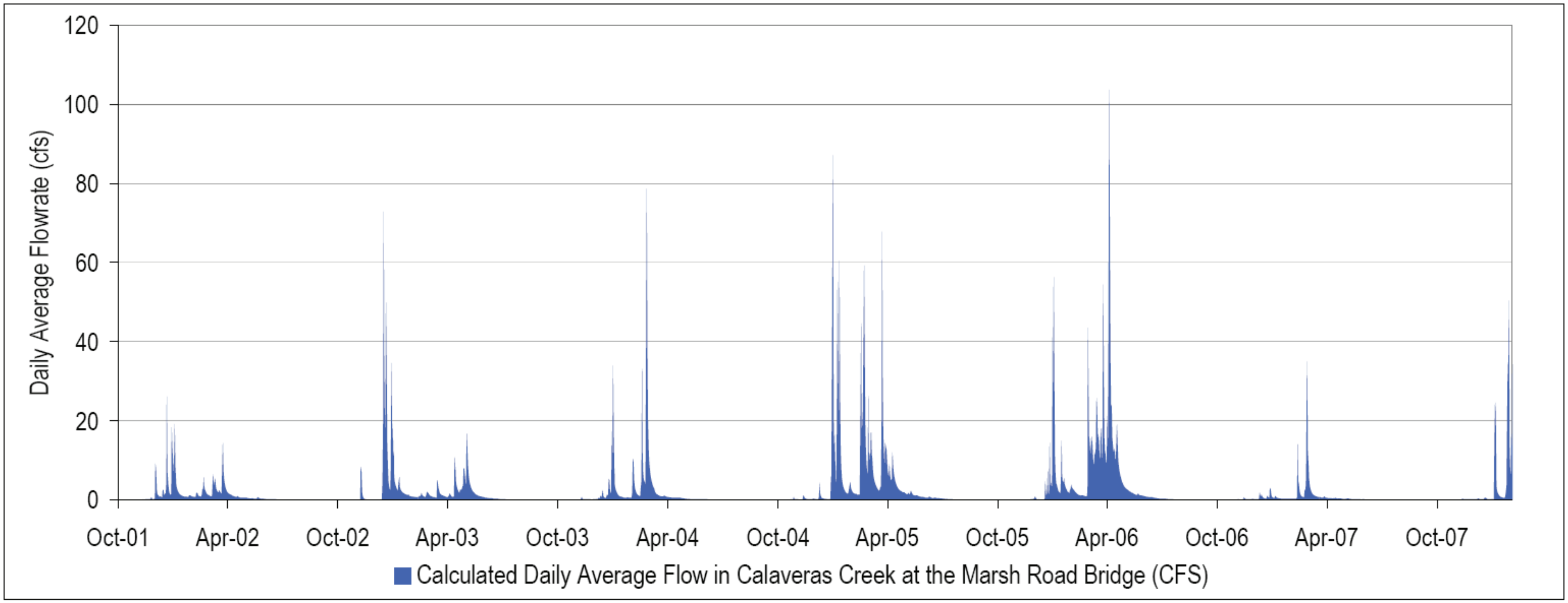
Figure 2-1



Source: ETJV and Hydroconsult Engineers, Inc. 2008

Calaveras Creek Discharge

Feasibility of Fish Passage at Calaveras Dam
Technical Memorandum

June 2009

Figure 2-2

Although the upper portion of Calaveras Creek does support a small population of resident rainbow trout, there is little potential for migration from Calaveras Reservoir into upper Calaveras Creek due to the nature of the stream between Marsh Road and the reservoir (Hagar and Payne, 2008). Immediately below Marsh Road there is a well defined, albeit typically dry, stream channel (see photograph [a] on Figure 2-3). Downstream from Marsh Road the channel has been significantly altered by past human attempts to contain and channelize flow (ETJV and Hydroconsult Engineers, Inc., 2008). In this reach, the channel becomes increasingly braided and less distinct (see photograph [b] on Figure 2-3). Approximately 2,900 feet below the Marsh Road bridge, the channel is no longer evident (Hagar and Payne, 2008). As it nears the average highest water surface elevation of Calaveras Reservoir, the ground surface is generally quite flat, with a gentle slope towards the reservoir. Overland flow takes multiple paths, floods low-lying areas, infiltrates into the ground, and likely changes flow paths frequently (see photograph [c] on Figure 2-3) (ETJV and Hydroconsult Engineers, Inc., 2008). Due to the lack of flow conditions suitable for steelhead migration, Calaveras Creek above Calaveras Reservoir is not considered suitable for steelhead spawning or juvenile rearing.

Also of note is the short reach of Calaveras Creek between Calaveras Reservoir and Alameda Creek (Figure 2-1), where flows are determined almost entirely by operation of Calaveras Dam. Installation of fish passage infrastructure could alter flow regimes here, potentially affecting fish passage both upstream and downstream. Perhaps more important is the presence in this reach of a 0.4-mile-long field of boulder debris located approximately 500 feet below the CDRP. A 12-foot waterfall located within this reach is identified in a separate technical memorandum, using a methodology modified from Powers and Orsborn (1985), as an impassible barrier to adult steelhead immigration under the current flow regime (URS and HDR, 2009). The 12-foot vertical step that creates the waterfall is formed where boulders have wedged into a jointed portion of bedrock eroded by stream flow (URS, 2009). Spills down the spillway at Calaveras Dam happen infrequently, and the passability of the waterfall, with flows of that magnitude, is unknown. Due to the presence of this barrier, the adult steelhead immigration design components evaluated in this memorandum begin below the debris field.

2.3.3 CALAVERAS DAM

Calaveras Dam (Figure 2-4) is located at the northern end of Calaveras Reservoir, which transects the border between Alameda and Santa Clara counties. The dam is about one mile upstream of the confluence of Calaveras Creek and Alameda Creek. Calaveras Reservoir is the largest reservoir in the SFPUC's Bay Area water system.

The proposed CDRP includes a replacement dam (Figure 2-5) that would be built immediately downstream of the existing dam. The dam would be a zoned earth and rock fill dam built to withstand the maximum credible earthquake originating on the Calaveras Fault. It would restore the reservoir's historical capacity of approximately 96,850 acre-feet.

2.4 STEELHEAD PRESENCE IN THE ALAMEDA CREEK WATERSHED

Historic population estimates of steelhead in the Alameda Creek Watershed are unavailable, but steelhead were historically present (Leidy, 2007). Based on various anecdotal accounts of steelhead presence in the watershed from as early as the 1930s, the size of the watershed, the presence of perennial streams, and various *O. mykiss* records from surveys since the 1930s, it is likely that in the past this watershed supported a large steelhead run, relative to other San Francisco Estuary streams (Leidy et al., 2005). Rainbow trout are currently present in the upper reaches of the Alameda Creek

(a)

(b)

(c)

Photos of Calaveras Creek on January 22, 2009 from (a) just below Marsh Road Bridge, (b) between Marsh Road and Calaveras Reservoir full pool elevation, and (c) just above Calaveras Reservoir full pool elevation, demonstrating how the channel disappears as it approaches the reservoir.

Photos of the Calaveras Creek Channel, Below Marsh Road

Existing Calaveras Dam

Feasibility of Fish Passage at Calaveras Dam
Technical Memorandum

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Figure 2-4

Proposed Calaveras Replacement Dam

Feasibility of Fish Passage at Calaveras Dam
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Figure 2-5

Watershed, and there are well-documented reports of steelhead in the lower Alameda Creek channel below the BART weir (located approximately 10 miles upstream of San Francisco Bay and approximately 16 miles downstream of Calaveras Dam; Figure 1-1). This weir currently presents an impassable upstream migration barrier (Gunther et al., 2000; Hayes, 2001). Small numbers of adult steelhead have been observed attempting to pass the BART weir (Gunther et al., 2000), some of which have been relocated above the weir and subsequently tracked to Stonybrook Creek (located approximately 13 miles upstream of San Francisco Bay and approximately 13 miles downstream of Calaveras Dam) where they were observed spawning (San Jose Mercury News, 2008). Additional structures and natural cascades are located upstream of the BART weir that also present obstacles for upstream movement of fishes (Gunther et al., 2000).

A number of existing facilities under the jurisdiction of Alameda County Water District (ACWD), Alameda County Flood Control and Water Conservation District (ACFCWCD), California Department of Water Resources, SFPUC, and Zone 7 Water Agency, among others, strongly affect hydrological and fisheries habitat conditions in the Alameda Creek Watershed adjacent to and downstream of the proposed CDRP. Many of these structures and facilities have been in existence for well over 80 years, and have resulted in substantial changes to the natural conditions that existed before the twentieth century when a steelhead run is presumed to have been present throughout the basin. Although built in the past, these existing facilities and influences continue to operate and affect habitat conditions for steelhead in the Alameda Creek Watershed. Some of these are direct barriers to fish migration; others pose various degrees of control/influence over habitat conditions (Gunther et al., 2000). Major facilities (separated by sub-watershed) include the following:

In the Arroyo de la Laguna Sub-Watershed:

- Del Valle Dam and Reservoir/South Bay Aqueduct, including State Water Project releases;
- Quarry lakes recharge facilities;
- Various channelized and culverted stream segments; and
- Expanding urban development of the Tri-Valley Area.

In the Upper Alameda Creek Sub-Watershed:

- Calaveras Reservoir and Dam;
- Alameda Creek Diversion Dam and Tunnel;
- Sunol Valley aggregate mining operations and quarries;
- Turner Dam and San Antonio Reservoir;
- Sunol infiltration galleries; and
- Pacific Gas and Electric Company (PG&E) pipeline crossing protection covering (drop structure).

In the Lower Alameda Creek Sub-Watershed:

- ACWD's upper, middle, and lower inflatable dams and quarry pits recharge facilities;
- BART weir; and
- ACFCWCD channelization project.

All of these facilities, combined with urbanization and other land use activities, have resulted in substantial alteration of habitat conditions for steelhead in the watershed. It is worth noting that two historic structures (the Nile and Sunol dams, both on Alameda Creek below the Sunol quarries) were removed in 2006 by the SFPUC. The East Bay Regional Parks District (EBRPD) also recently removed two small barriers from Sunol Wilderness Regional Preserve.

Nielson (2003) examined mitochondrial DNA and 14 microsatellite loci of rainbow trout from Alameda Creek and found that trout from Arroyo Hondo, upper Alameda Creek, and San Antonio Reservoir are more closely related to steelhead captured in Alameda Creek below the BART weir than they are to any other wild or hatchery population of *O. mykiss* examined in the study. These trout were also found to be similar to populations from other creeks within the CCC steelhead DPS. A more recent analysis of the genetic diversity and population structure of *O. mykiss* in nearby streams of the Santa Clara Valley examined 18 microsatellite loci and found that populations of trout from above dams in the Guadalupe, Pajaro, and Permanente/Stevens basins are all of recent steelhead ancestry (Garza and Pearse, 2008). Future genetic studies would be necessary if it was determined that information was needed on the precise evolutionary origin of steelhead attempting to immigrate into the Alameda Creek Watershed.

On January 5, 2006, the CCC DPS, including all naturally spawned anadromous steelhead (*O. mykiss*) populations below natural and manmade impassable barriers, were listed as threatened under the federal Endangered Species Act by the Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NMFS) (NMFS, 2006). The geographic extent of this DPS includes coastal drainages from Soquel Creek in Santa Cruz County (inclusive), north to the Russian River in Sonoma County (inclusive), and the drainages of San Francisco, San Pablo, and Suisun Bays east of Chipps Island at the confluence of the Sacramento and San Joaquin River Systems (inset box, Figure 1-1). Steelhead that spawn in the Sacramento-San Joaquin River Basin are within a separate DPS. In the Final Endangered Species Act Listing Determination, NMFS concluded that the resident rainbow trout population in Alameda Creek is not considered part of the DPS (NMFS, 2006), in part due to their reproductive isolation resulting from man-made barriers. When steelhead (CCC DPS) are successfully re-established in the Alameda Creek Watershed via the removal or modification of passage barriers, all rainbow trout (*O. mykiss*) in areas made accessible from the ocean will be considered as part of the same population regardless of their realized life history character (i.e., anadromous, fluvial, or adfluvial).

The historic steelhead population of the Alameda Creek Watershed can be referred to as a metapopulation. NMFS (2005) defines metapopulations as "spatially structured populations in which populations or subpopulations occupy habitat patches, connected by some low-to-moderate stray rates." Low-to-moderate levels of straying result in regular genetic exchange among populations, creating genetic similarities among populations in adjacent watersheds or sub-watersheds. Metapopulation theory and the ecology of steelhead suggest that management efforts that increase the rate of colonization of presently unoccupied habitats may promote the recovery and persistence of Pacific salmon stocks, including steelhead (Young, 1999).

Efforts are currently underway to restore the migration of adult steelhead into the Alameda Creek Watershed. In 1999, the Alameda Creek Fisheries Restoration Workgroup (ACFRW) was established (CEMAR, 2002). The workgroup has generated a report that assesses the potential for a viable steelhead population to exist in Alameda Creek (i.e., Gunther et al., 2000). Efforts to restore steelhead populations to Alameda Creek have targeted the elimination of fish migration barriers, particularly those in the lower reaches (Gunther et al., 2000; Wood Rogers, 2007).

A number of future projects could potentially affect conditions for steelhead in the Upper and Lower Alameda Creek sub-watersheds, and affect the ability of steelhead to immigrate to Calaveras Dam. These projects include several that are in various stages of planning and implementation by public agencies, citizens' groups, and quarry operators. They include removing/modifying dams, weirs, culverts, and pipelines that block fish passage, installation of positive barrier fish screen at water diversions, restoring and protecting habitat, and providing instream flows. Of particular importance to this analysis is the existence of several fish migration barriers in the watershed and associated future projects to address passage. These obstructions include the ACFCWCD's grade control structure (also known as the BART weir) located about 9.5 miles upstream from the creek's confluence with San Francisco Bay (Figure 1-1); ACWD rubber dams (ranging in location from about 2 miles upstream of the Bay to just below Niles Canyon); and the PG&E concrete drop structure in the Sunol Valley. The SFPUC removed aboveground portions of two relict diversion dams on the creek (Sunol Dam and Niles Dam) in September 2006. ACWD intends to remove its lowermost rubber dam during 2009 (CEMAR, 2009), and construction of a fish ladder at the BART weir and a second rubber dam is anticipated for 2010. Other migration barriers along the creek are in various stages of planning to address passage. It is assumed that these projects will be completed at some point in the future, and steelhead will have access to the Upper Alameda Creek Sub-Watershed, where Calaveras Reservoir and Dam are located.

3 METHODOLOGY

3.1 BACKGROUND INFORMATION REVIEW

This evaluation is based on a review of devices and methods used at other dams that currently have fish passage operations in place, in combination with aerial photographs, site visits, and input from knowledgeable experts. Literature on fish physiological responses to handling, behavioral responses to devices, steelhead reproductive success, steelhead life history characteristics, and general fish passage concepts was also reviewed. Whenever possible, information specific to steelhead was used in the evaluation. In the absence of available steelhead data, other anadromous salmonid data were used as a surrogate. References are included in the text describing specific devices and methods, and a complete list of references is provided in Section 8.

3.2 IDENTIFICATION AND ANALYSIS OF DESIGN COMPONENTS FOR FISH PASSAGE

Identification and analysis of design components consisted of four steps:

1. Identification of fish passage design components that are technologically feasible at Calaveras Dam that would meet the basic biological needs of a steelhead population above Calaveras Dam, and elimination of design components that were identified as unsuitable for use at Calaveras Dam (Section 4.1);

2. Estimation of the economic cost of each viable component (Section 4.2);

3. Estimation of the amount of habitat that the remaining design components would make available to steelhead (Section 4.3), the ability for passage to maintain a minimum viable population size (Section 4.4), and environmental considerations related to the implementation of fish passage (Section 4.5);

4. Selection of design components most suitable for providing fish passage at Calaveras Dam based on the above considerations (Section 4.6).

Each of these four steps is described in more detail below.

The first step used to assess the feasibility of providing fish passage at Calaveras Dam was to identify fish passage design components that are technologically feasible at Calaveras Dam that would meet the biological needs of a re-established steelhead population above Calaveras Dam. There are three elements to steelhead migration: adult immigration, juvenile emigration, and post-spawn adult emigration. In general, the design components identified would not individually serve all three of these passage elements. In addition, different components of fish passage would be operational at different times of the year. Therefore, each design component is identified and analyzed in the context of the element of steelhead migration it would serve (Section 4.1). Infrastructure components and operational requirements associated with each potential method of fish passage are identified. These design components are evaluated for their ability to meet the biological needs of one or more of the steelhead migration elements, and are simultaneously screened for engineering feasibility at Calaveras Dam. Based on these considerations, a determination was made as to whether each design component should be retained for further consideration in subsequent analyses or rejected.

The design components that passed the initial screening were next evaluated based on their relative cost (Section 4.2). Order-of-magnitude capital, operations, and maintenance costs were developed, and where design components serve and achieve identical purposes at different costs, the more expensive component was rejected.

The next step in the analysis was to estimate the amount of habitat that the remaining design components would make available to steelhead (Section 4.3). Considering the amount of habitat available, the potential for success was evaluated (Section 4.4) in terms of the ability for passage to maintain a minimum viable population size. Environmental considerations related to the implementation of fish passage are also discussed (Section 4.5), although these considerations are deferred to a later stage of planning when an impact determination would be more appropriate, and do not weigh heavily on the feasibility evaluation.

The last step in this first stage of the feasibility evaluation was to evaluate the remaining design components in light of all of all the above considerations, and select the design components most suitable for providing fish passage at Calaveras Dam (Section 4.6). Once the preferred design components were selected, a potential fish passage option for Calaveras Dam was evaluated for its potential to meet specific fish passage goals, as described below.

3.3 EVALUATION OF A POTENTIAL PASSAGE OPTION TO MEET SPECIFIC PASSAGE GOALS

While providing fish passage is almost always “technologically” feasible (that is, it is almost always possible to catch some fish and relocate them somewhere else), simply moving the fish does not accomplish the goals of fish passage. For the purposes of this analysis, the following goals have been identified for fish passage:

- To provide access to additional quantity of habitat to increase natural production;
- To contribute to species recovery through increased overall natural production;
- To provide access to historical habitat;
- To protect or enhance the genetic integrity and/or distinctness of stocks; and
- To reduce risk of extinction through increased natural production and creation of additional independent populations.

The final step in this feasibility evaluation was to examine the potential fish passage option at Calaveras Dam, and evaluate its ability or likelihood to meet these goals (Section 5.2). Following these primarily qualitative evaluations, the potential for success of steelhead passage at the replacement Calaveras Dam was rated as low, medium, or high.

4 FISH PASSAGE DESIGN COMPONENTS AND ANALYSIS

This section describes and evaluates the design components that could potentially be used to provide fish passage over Calaveras Dam that were identified during the review of the literature and existing fish passage projects.

In addition to steelhead, volitional passage (if available) could also benefit anadromous lamprey that occur in portions of the Alameda Creek Watershed. Resident stream fishes might also benefit from volitional passage, which could have positive effects on their population genetic fitness (Campbell et al., 1999) and ability to recolonize areas from which they have been extirpated (Begon et al., 1996). The biological benefits and technical requirements associated with providing passage for non-salmonid fishes, however, are not as well understood as for anadromous steelhead and salmon. As described in the following sections, true volitional fish passage is not feasible at Calaveras Dam because Calaveras Reservoir is a water supply and storage reservoir that has a fluctuating water surface elevation level, so the surface elevation of the reservoir would often be below the spillway crest elevation. Due to the difficulty and expense associated with highly managed, non-volitional passage, it is unlikely to be implemented for species without a compelling need to regularly pass the dam, such as an anadromous life history. Additionally, non-volitional passage designed to benefit steelhead would not simultaneously accommodate other species, due to differences in life history, habitat requirements, size, and swimming ability. Although Chinook salmon (*Oncorhynchus tshawytscha*) have been observed in Alameda Creek below the BART weir (Leidy, 2007), it is uncertain whether they are native to the Alameda Creek Watershed. Chinook salmon spawning runs in nearby Guadalupe River and Coyote Creek are of hatchery origin (Moyle, 2002; Leidy, 2007), and the origin of this species in many San Francisco Bay tributaries may never be conclusively demonstrated (Leidy, 2007). For these reasons, this technical memorandum addresses the feasibility of providing passage for steelhead only.

4.1 IDENTIFICATION OF DESIGN COMPONENTS AND PRELIMINARY ANALYSIS

As mentioned in Section 3, the three passage elements to be addressed for steelhead at Calaveras Dam are:

- adult immigration;
- juvenile emigration;
- post-spawn adult emigration.

Table 4-1 summarizes the steelhead life stage time periods when each passage element would be required to be operational. The time periods presented in the table are based upon the literature review, survey data collected in the Upper Alameda Creek Sub-Watershed and personal communications with individuals familiar with the watershed. Migrations are typically expected to occur as described here, but are ultimately dependent upon the rainfall pattern in a given year, which determines when flows suitable for migration are available. A flow duration analysis and a storm peaking analysis would be recommended if additional study of passage at Calaveras Dam is requested; these analyses would further define the flows under which steelhead are most likely to migrate. Key design requirements for any passage features would come directly from this analysis.

Table 4-1
Steelhead Passage Element Timing

Passage Element	Month											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Adult Immigration[a]			■	■	■	■	■					
Juvenile Emigration[b]						■	■	■	■			
Post-spawn Adult Emigration[c]				■	■	■	■	■	■			

[a] Gunther et al., 2000; Moyle, 2002
[b] Gunther et al., 2000; Brian Sak, pers. comm., 2009; SFPUC, 2004
[c] Gunther et al., 2000

Due to temporal differences in when design components addressing each of these passage elements would be operational, as well as differences in the size of the fish and direction of travel, the individual design components reviewed are generally not suitable for all three passage elements. Therefore, the following subsections introducing the design components reviewed are organized by the passage elements they address.

4.1.1 ADULT IMMIGRATION

Depending on annual hydrological conditions, adult steelhead immigration in the Alameda Creek Watershed is expected to occur from December through April. Design components to facilitate adult immigration to spawning habitats above Calaveras Dam are discussed in Sections 4.1.1.1 Fish Ladder, 4.1.1.2 Fish Lift, and 4.1.1.3 Trap and Haul.

4.1.1.1 FISH LADDER

In this section, fish ladders are evaluated as a specific design component for providing passage to immigrating adult steelhead. Following the analysis, this design component is retained for consideration later in this document.

A fish ladder is a structure used to facilitate passage of fish over or around an obstacle, typically a dam or other migration barrier (Figure 4-1). Specifically, as defined by NMFS, the fish ladder is the component of a fish passage facility that dissipates hydraulic potential energy into discrete pools or into a baffled chute to provide passage for upstream migrants (NMFS, 2003). Fish ladders are the method most commonly used for allowing upstream fish migration past in-stream barriers. Although design criteria for fish ladders are primarily based on adult fish immigration, when operating, some fish ladders also can provide for downstream emigration of juvenile anadromous species.

Typically, fish ladders consist of a series of ascending pools that must be "climbed" or jumped by the fish. A series of pools contained within the water passage acts to incrementally divide the height of the passage and to dissipate the energy in the water, thereby enabling fish to gradually climb the height required to pass over the obstacle. The number of pools contained within the fish ladder depends on the climb required to pass over the obstacle. Although the incremental drop between pools may vary depending on the leaping capabilities of the species that need to pass through the ladder, a drop of one foot is most commonly used for adult life stages and a drop ranging from 0.5 to 0.8 foot may be required for juvenile passage. Fish move up the ladder by leaping from one pool to the next in an upstream direction. After ascending the ladder, individuals can be collected in confined pools or tanks at the top of the ladder or, in some cases, released directly into the body of water above the obstacle (Larinier, 2000; USACE, 1996).

(a) A view of Pelton Dam on the Deschutes River in Oregon with fish ladder visible where it meets the dam on the left.

(b) The North Fork Dam fish ladder on the Clackamas River in Oregon, the longest (1.9-mile) operating fish ladder in the world.

Photos of Example Fish Ladders

Feasibility of Fish Passage at Calaveras Dam
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There are a variety of fish ladder designs; all are based on the same basic design concepts. The three most common variations on the basic fish ladder are pool and weir design, vertical slot design, and weir and orifice design. The height and length of individual ladders varies depending upon the height of the obstacle, the hydrology of the river system, and the fish species using the facility. Due to the large number and wide variety of fish ladders currently in use, a substantial body of technical information describing the species specific and physical requirements of fish ladders is available. Appendix A summarizes some of that information.

Pool and weir ladders are commonly used at artificial structures (State of Michigan Department of Natural Resources, 2004), and weir and orifice fish ladders have a long history of use at dams on the Pacific Coast of North America, mostly on the Columbia River in the Pacific Northwest. Additionally, weir and orifice ladders have successfully been used for passage of all five species of Pacific salmon, and for steelhead and sturgeon. Each of these systems has some common and some very specific hydraulic operating requirements.

USE OF A FISH LADDER AT CALAVERAS DAM

Several types of fish ladder would be appropriate for steelhead[4] at Calaveras Dam. Construction footprints and costs of the various fish ladder types are similar.

The CDRP would have a height of 200 feet from spillway outlet water surface to spillway crest; therefore, the ladder would have to ascend at least this height. A fish ladder channel that begins in Calaveras Creek below the boulder debris field (described as a steelhead immigration barrier in Section 2.3.2) would have to be at least 90 feet taller, so a fish ladder at Calaveras Dam would likely have a height of more than 290 feet, making it taller than any fish ladder identified in the review conducted for this analysis.

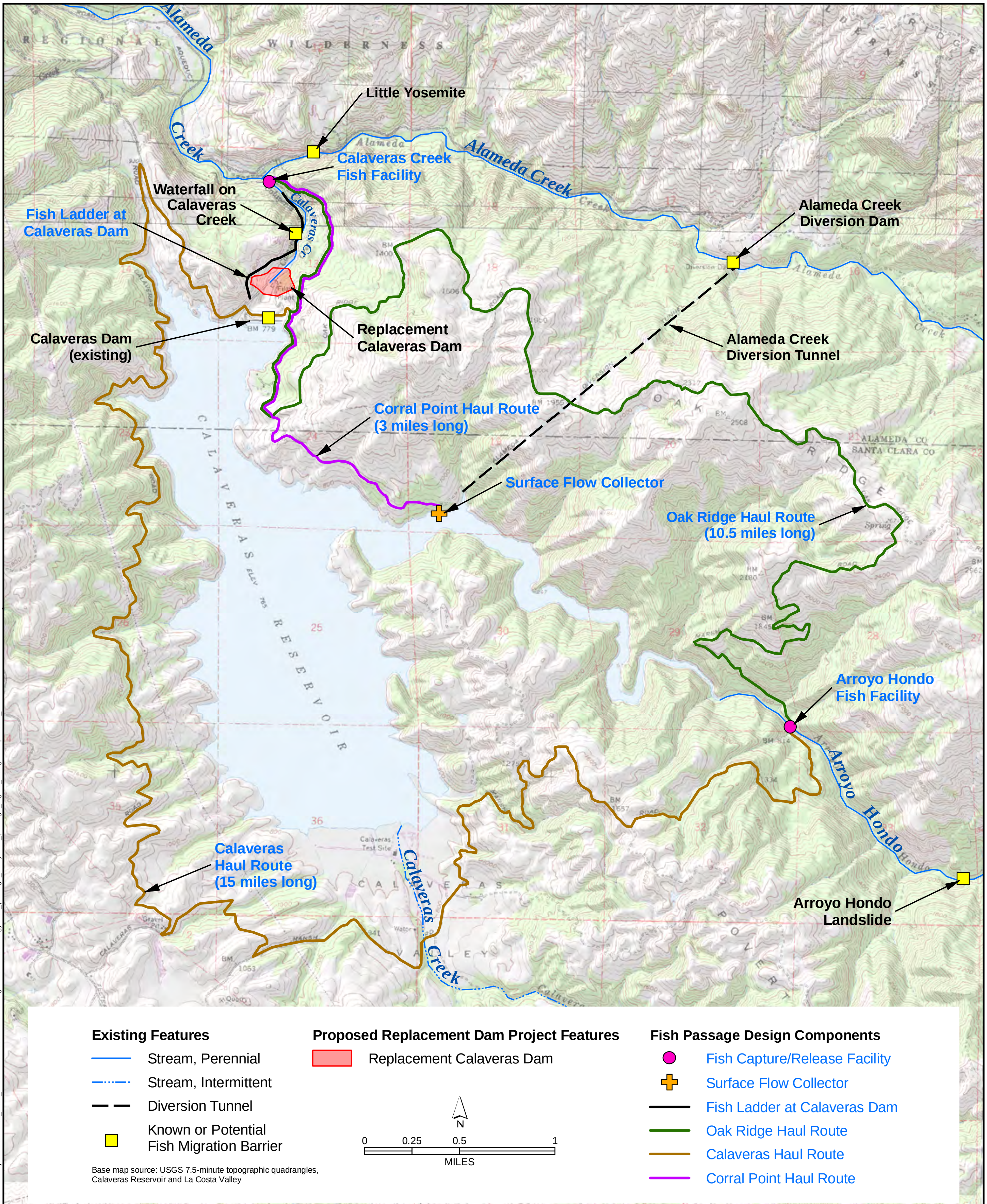
A review of literature on fish ladders and existing fish ladder projects indicates that ladders seldom exceed a vertical gain of 125 feet; however, Portland General Electric has implemented two fish ladders that are nearly 200 feet in height (Idaho Power Company, 2001). The first is at Pelton Dam in Oregon on the Deschutes River. The ladder was approximately 200 feet high with a length close to three miles and was in operation from 1958 to 1968 (see photograph [a] on Figure 4-1). While in operation the ladder experienced problems maintaining water temperatures low enough to support salmonids (Idaho Power Company, 2001). A second fish ladder in operation on the Clackamas River in Oregon ascends a height of 196 feet and is considered successful (see photograph [b] on Figure 4-1). This ladder, referred to as the North Fork Dam fish ladder, is 1.9 miles in length (Idaho Power Company, 2001). Construction of a fish ladder at Calaveras Dam would require approximately 290 pools with a drop between pools of 0.5 and 1.0 foot. The overall length of the ladder would depend on the route chosen for ladder construction. If a pool and weir type ladder were constructed with minimum pool lengths of 6 feet, a 1-foot wall between pools, a 10-foot resting pool every 100 feet, a 10-foot entrance, and a 10-foot exit, the minimum length of the required ladder would be approximately 2,260 feet. This length estimate, however, is based on a perfect topographic configuration that is not likely to exist. The actual length of the ladder may be significantly longer, as it would need to maneuver around obstacles. With the construction of a 2,260-foot fishway, water temperatures during certain migration periods may become fatal. This would need to be carefully examined in any detailed design and may drive minimum ladder operational flows.

[4] While the focus of this memorandum is passage for steelhead, it is noted that the weir and orifice variation or the vertical slot variation would work for steelhead, and lamprey may find it easier to climb these types of ladders than others, such as pool and weir.

A potential location of a fish ladder at Calaveras Dam is shown on Figure 4-2. The entrance to the fish ladder would be located downstream of potential immigration barriers on Calaveras Creek (see URS and HDR, 2009). From the entrance, the fish ladder would extend to the base of the dam, where it would ascend the dam using the proposed spillway or follow an alternate route above the spillway, as shown on Figure 4-3. If a fish ladder were constructed within the spillway, it would likely be necessary to install steel plates over the ladder to maintain the desired flow characteristics of the spillway. Because the water surface elevation would often be lower than the top of the fish ladder, water would typically need to be pumped from the reservoir into the fish ladder. Construction of a fish ladder along the hillside on the west side of the spillway would require additional excavation and geotechnical considerations.

An advantage of fish ladders compared to other fish passage methods is the minimal handling and associated stress to the fish. At Calaveras Dam, however, this advantage would not be realized to the same degree as at run-of-the-river dams, or reservoirs with static water surface elevations. Calaveras Reservoir is a water supply and storage reservoir with a fluctuating water surface elevation, which is frequently not at the dam crest or spillway elevation. At Calaveras Dam a fish ladder on the downstream face of the dam would likely lead to a holding pool near the dam crest. Water pumped from the reservoir would be discharged into the holding pool and would supply the required operational flows. A fish ladder leading from the holding pool at the crest of the dam down to the reservoir's surface would require the fish to swim downstream to the reservoir. Because the adult steelhead are on their upstream migration they would likely not swim down the ladder. Additionally, a false attraction flow would be created at the fish exit (reservoir entrance) due to the opposite orientation of hydraulics towards the reservoir, further confusing the immigrating steelhead. Thus, immigrating adult steelhead would have to be transferred to the reservoir from the holding pool through another means. Instead, adult steelhead could be transferred from the holding pool at the dam crest to the reservoir using a fish lift (see Section 4.1.1.2 for a description of fish lifts) on the upstream face of Calaveras Dam. Since the lift would have to be controlled and operated, the fish could not pass the dam of their own volition alone. The need to transfer fish from the ladder to another device, such as a fish lift, also increases handling and associated stress. While a fish ladder could work for immigrating adult steelhead, it has disadvantages relative to the use of fish ladders at some other dams. Despite these concerns, based on its ability to achieve passage for immigrating steelhead at Calaveras Dam and its successful use at many other facilities, the fish ladder design component, as described above, is retained for further consideration in this memorandum.

Another potential solution to upstream migration issues considered was a fish ladder with multiple openings at the upstream end. This type of ladder is sometimes used in situations where the forebay elevation fluctuates. Each opening is configured to operate for a narrow range of forebay fluctuations. Several openings used in conjunction with one another can provide volitional upstream passage through a range of potential forebay conditions. This approach includes the need for continual adjustment of the control gates that allow each opening to be open or closed, performed by maintenance personnel or computer-operated monitoring and control equipment, or both. The spillway elevation at the replacement Calaveras Dam will be at approximately 756 feet, and when spilling, the water surface elevation will be above the spillway elevation. Under normal operating conditions the reservoir is drawn down prior to the onset of the rainy season, and is gradually filled by runoff during the winter and spring. In a 1991 MOU with CDFG, SFPUC agreed to operate the reservoir in a manner that would typically limit draw down of the reservoir to 690 feet in elevation, when possible (SFPUC, 1991). In order for a fish ladder with multiple openings to work over the full operating range at Calaveras Dam, it would have to accommodate forebay fluctuations of up to 70 feet. This range of forebay fluctuations is far greater than the current state of the practice for fish ladders with multiple openings. Given the footprint and cost associated with construction of multiple openings, the impact that such a structure would have on the dam, and seismic concerns due to the proximity of the dam to active geologic faults (OCC, 2003; URS, 2005), a fish ladder with multiple openings was assumed to be infeasible at Calaveras Dam, and was eliminated from further consideration in this memorandum.



Fish Passage Design Components Evaluated for Calaveras Dam

Feasibility of Fish Passage at Calaveras Dam Technical Memorandum

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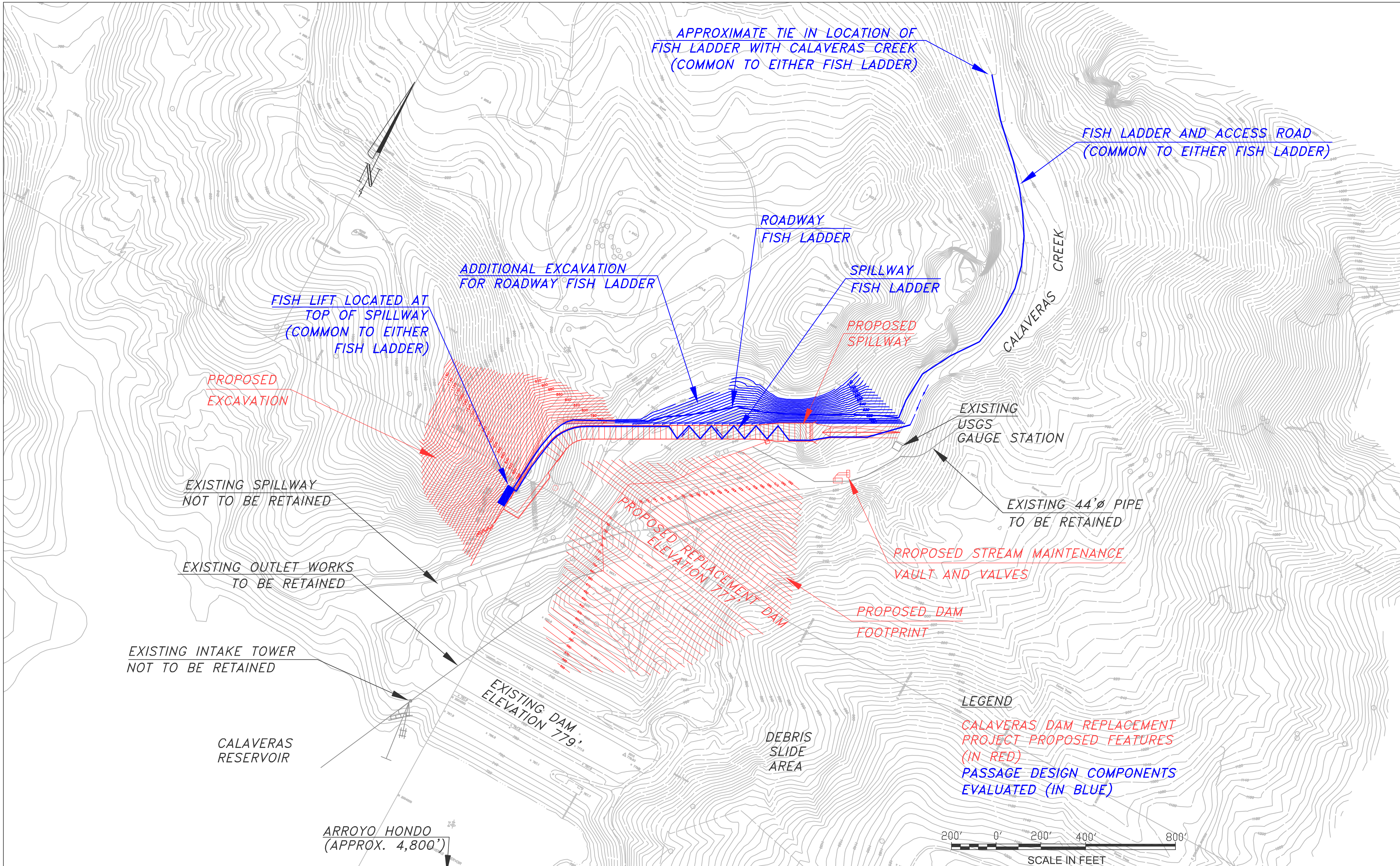
Figure 4-2

URS Corp - Oakland CA - C.Raumann L:\Projects\Calaveras_Dam_26814408\Mxd\Current Working Documents\Biology\Fish_passage_study\Fish_passage_Fig4-2_DesignComponents_SF.mxd



Feb 18, 2009 – 6:18pm
X:\x_geo\Calaveras Final Design\Fisheries Task Group W\5000_Deliverables\5100_Task_1_Passage\CADD Exhibits\Fish Ladder Alt 021809.dwg

Fish Ladder Conceptual Designs

Feasibility of Fish Passage at Calaveras Dam
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Figure 4-3

4.1.1.2 FISH LIFT

A review of available literature and existing projects indicates that three basic types of mechanical lifts are typically used for fish passage: navigation locks, fish locks, and fish elevators (collectively referred to below as "fish lifts"). This section reviews all three types of fish lifts, and makes a determination as to their applicability at the Calaveras Dam.

NAVIGATION LOCK

A navigation lock (see photograph [a] on Figure 4-4) is mainly used to raise and lower boats between stretches of water at different elevations. This type of lock consists of a fixed water-tight chamber within which the water level can be raised and lowered. Gates at either end of the chamber can be opened to allow vessels to pass, and lock gears control the water level. The typical rise for navigation locks varies from 7 to 15 feet, with 20 feet being an exceptionally large rise. Where larger rises are needed, especially at steep gradients, a flight of locks or staircase navigation locks are used.

The location within Calaveras Creek under consideration for potential fish capture (Figure 4-2) would not physically accommodate a navigation lock. Additionally, navigation locks are generally only suitable for run-of-the-river dams and require fish access to the base of the dam. Therefore, navigation locks were eliminated from consideration as a potential fish passage design component in this analysis.

FISH LOCK

A fish lock (see photograph [b] on Figure 4-4) consists of holding chambers at the upstream and downstream sides of a dam linked by a sloping or vertical shaft. Automated control gates are fitted at the extremities of the upstream and downstream chambers. The fish lock moves immigrating fish over the dam by attracting fish into the downstream holding chamber, which is subsequently closed and filled with water, along with the entire shaft. Fish exit the upstream chamber through the opened gate. Flow is typically established within the shaft through a bypass in the downstream chamber to encourage the immigrating fish to leave the lock. As with a fish ladder or other mechanical lifts considered in this analysis, some means of transport would be required to move the fish from the top of the lock at the Calaveras Dam crest, to the fluctuating reservoir surface elevation. The efficiency of such a fish facility depends mainly on the behavior of the fish, which must remain in the downstream pool during the whole of the attraction phase, follow the rising water during the filling stage, and leave the lock before it empties. The use of fish locks as the primary means of passage at Calaveras Dam is evaluated further below, under "Use of a Fish Lift at Calaveras Dam."

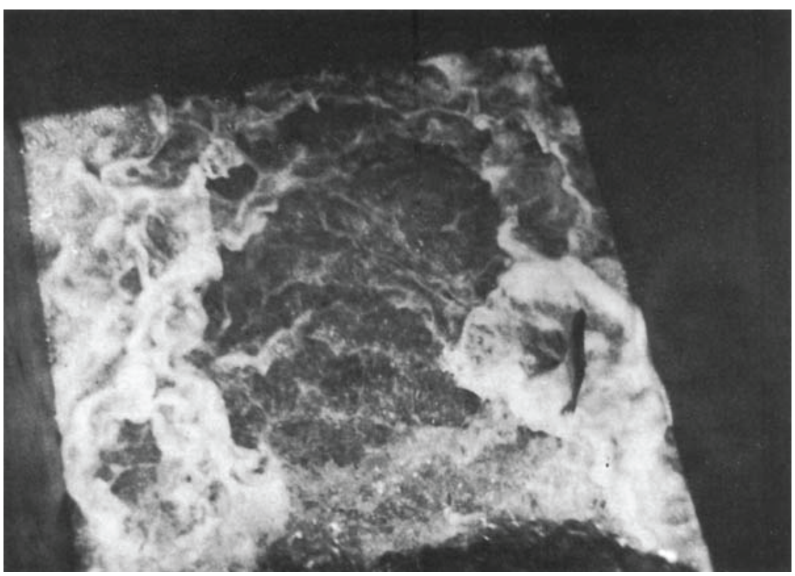
FISH ELEVATOR

A fish elevator (see photograph [c] on Figure 4-4) works by luring fish with rushing water to a compartment at the base of the dam. The fish swim into the compartment and then are unable to find their way out. The compartment is then lifted like an elevator until it reaches a holding pen or flume where the fish are released into a reservoir or river above the dam. The use of a fish elevator as the primary means of passage at Calaveras Dam is evaluated further below, under "Use of a Fish Lift at Calaveras Dam."

USE OF FISH LIFTS

Clay (1995) reports that fish lifts are capable of lifting fish over dams up to 200 feet in height. However, a review of the fisheries literature and existing passage projects did not indicate existing fish lifts approaching this height. Clay (1995) does report on a fish lift installed at Baker Dam in Washington that lifted fish close to 300 feet over Baker Dam. The lift was replaced by trap and haul passage (at considerable cost) because of dissatisfaction with results. The most successful and well-publicized use of fish lifts in the United States occurs on the east coast, particularly on the

(a) A view of the navigation lock at the Beaucaire power plant on the Rhone River in France.



(b) A photograph of a Borland type fish lock filling and fish leaping out of water at Salto Grande hydroelectric plant in Argentina.

(c) A view of the fish elevator on the Connecticut River in Holyoke, Massachusetts.

Photos of Example Fish Lifts

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Connecticut River. A successful lift operation was installed at Hadley Falls that lifts fish approximately 52 feet over the Holyoke Dam on the Connecticut River (Ducheney et al., 2006). No examples could be located of fish lifts currently in operation on the west coast.

Fish lifts are used more frequently in Europe than in the United States. They are typically used to raise fish no more than 30 feet, and problems have been report with their operation. For example, Larinier (2007) reports that fish lifts suffer the following disadvantages compared to ladders: higher operating and maintenance costs, more chance of breaking down, and a higher risk of damage to fish.

Fish lifts require the use of screens, or gates which move through the water to crowd or isolate the fish into the lock or hopper; these devices are susceptible to deterioration, fouling, jamming, and other problems associated with machinery operating in water or wet environments. Fish lifts, by their mechanical nature, have higher operating and maintenance costs than fish ladders. While fish lifts are designed to operate untended, the environment in which the equipment operates and the debris transported in the flows results in greater personnel costs in maintaining the lifts than for ladders (ASCE, 2007).

USE OF A FISH LIFT AT CALAVERAS DAM

The use of a fish lift as primary means of providing fish passage over Calaveras Dam was eliminated from further consideration for the following reasons:

- Engineering and construction challenges, particularly in a seismically active area, would likely be formidable. A fish lift on the downstream face of Calaveras Dam would only achieve passage if it was paired with a downstream ladder, because the waterfall within the boulder debris field in Calaveras Creek (see Section 2.3.2) would otherwise prevent immigrating steelhead from reaching the base of the dam, and the entrance to the lift. The most likely installation would involve construction of a fish ladder from near the confluence of Calaveras and Alameda creeks to the base of the dam. At the base of the dam, a structure well in excess of 200 feet in height would be necessary to house the lift. A horizontal bridge from the top of the structure to the top of the dam would then have to be constructed to allow a flume from the top of the lift to a lock structure at the dam's crest, which would be required to lower the fish down the upstream face of the dam, from the crest to the reservoir's water surface elevation. Water would have to be pumped from the reservoir across the bridge to the top of the lift to allow a return flow in the flume.

- Fish lifts are expensive and complex. As stated above, Larinier (2007) reports that fish lifts have the following disadvantages compared to ladders: higher operating and maintenance costs, more chance of breaking down and a higher risk of damage to fish. Fish lifts, by their mechanical nature, have higher operating and maintenance costs than fish ladders.

- Of the fish lift installations determined to be successful, none appear to be over 60 feet in height.

Although a fish lift on the downstream face was eliminated from consideration as the primary means of passage over Calaveras Dam, it is retained in subsequent analysis in this memo on the upstream face of the dam, as part of a passage combination with a fish ladder on the dam's downstream face (presented in Section 4.1.1.1).

4.1.1.3 TRAP AND HAUL

Information on the capture and transportation of immigrating adult steelhead is presented in this section. First, either a facility for collecting immigrating adults would need to be constructed or some sort of manual trapping (e.g., fish traps or nets) would be required downstream of Calaveras Dam.

Second, a method would be required to transport the captured fish to a location upstream of Calaveras Dam. Similarly, if barriers to downstream emigration exist, methods or facilities for capturing and transporting emigrating juveniles are necessary (Section 4.1.2, Juvenile Emigration). Unlike most Pacific salmon, steelhead present a third trap and haul requirement, post-spawning adult emigration, because not all steelhead die after spawning (Section 4.1.3, Post-Spawn Adult Emigration).

COLLECTION OF IMMIGRATING ADULT FISH (TRAP)

This design component would need to capture upstream migrating adult steelhead while minimizing mortality due to stress associated with handling and transport. Collection of adult immigrating steelhead would involve construction of a seasonally deployed instream barrier, a small fish ladder leading to a trap, and a holding pool of sufficient size to accommodate a significant number of adult steelhead prior to transporting the adults to an upstream location.

NMFS (2003) describes criteria for holding pools and fish trapping systems. The NMFS handling guidelines indicate specific requirements for holding pool conditions, including a minimum holding pool volume of 5 cubic feet per fish. The criteria indicate that water must be supplied to the holding pools at a rate of 2 gallons per minute per adult fish. Additionally, methods to be employed to minimize stress upon fish associated with human activity in the vicinity include providing water spray across the entire pool surface or use of a pool cover to prevent fish agitation from nearby human activities. NMFS (2003) also recommends controlling water surface elevation in the holding pools through the use of an exit overflow weir, and that separate water supply and drain systems should be incorporated into the designs of holding pools. Due to the likelihood of fish jumping within the holding pools, soft netting, surface spray systems, or darkening of the area over the pool should be provided to minimize fish injury.

The location of the adult collection facility would be based on physical site characteristics. Requisite site characteristics include accessibility of the facility for upstream migrating adult steelhead and sufficient attraction flows to draw fish into the facility. Additionally, the site must have road access for the tanker truck used in the transport process.

ADULT FISH TRANSPORT (HAUL)

A survey of fish transportation equipment and techniques used by hatcheries, private producers, Indian reservations, and research laboratories conducted by Carmichael and Tomasso (1988) revealed that among survey respondents, truck-mounted tanks were more common than trailer-mounted tanks and a majority of transport vehicles carried only one tank. More than half of the loading volumes were reported to be between 60 and 500 gallons of water (see photograph [a] on Figure 4-5) with between 501 and 1,000 gallons of water (see photograph [b] on Figure 4-5) being the second most common loading volume class reported. The survey also revealed that fiberglass tanks were the most common type of tank used among respondents and that tanks typically contained some type of insulation. Ice was most commonly used for water temperature maintenance rather than refrigeration units, and air venting or infusion of bottled oxygen directly into the water is necessary to maintain oxygen levels sufficient for the fish (Carmichael and Tomasso, 1988). Respondents to the survey reported using tank trucks for transporting a number of salmonid species, including rainbow trout, brown trout, brook trout, coho salmon, and Chinook salmon. Survival rates for adult fish transport are reportedly typically more than 99 percent if fish are in good condition at capture, holding conditions and duration are appropriate, and transport equipment is in good condition and operated appropriately. In some cases, particularly where access is limited, helicopters may also be appropriate for transporting migratory fish around barriers.

(a) A pickup truck adapted for hauling fish, with an approximately 210-gallon aluminum tank.

(b) Large Department of Fish and Game fish transport truck used to stock trout at Lake Davis, California.

Photos of Example Fish Transport Trucks

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IMMIGRATING ADULT TRAP AND HAUL AT CALAVERAS DAM

With this design component, immigrating adult steelhead would be captured below Calaveras Dam on Calaveras Creek, transported around the dam, and released at a location above Calaveras Dam. The best location to capture immigrating adult steelhead would be below the potential passage barriers on Calaveras Creek approximately 0.2 mile upstream of the confluence with Alameda Creek (see Calaveras Creek Fish Facility on Figure 4-2). Pending the completion of more detailed hydraulic studies, the capture facility would likely consist of a seasonally deployed instream barrier and a short fish ladder leading to a fyke trap (a trap that consists of a mesh net with a live box attached to one end) and a holding pool. For the ladder at Calaveras Creek Fish Facility, a pipe could be used to divert gravity flow from upstream on Calaveras Creek to the fish trap and ladder. Requirements for the capture location include road access and adequate flow regimes in Calaveras Creek to provide attraction flows.

Adult fish would be transported from a holding facility below Calaveras Dam to upstream tributaries or Calaveras Reservoir. While helicopter transport may be appropriate in some cases, in this case due to the proximity of Calaveras Dam to the Sunol Regional Wilderness and the tendency for noise-sensitive wildlife (including bald eagles [*Haliaeetus leucocephalus*]) to nest around the reservoir, transport via truck is more suitable than helicopter. Transfer from the holding facilities to the transport trucks would likely be conducted by water-to-water transfer. Water-to-water transfer requires the fish holding tanks to be elevated above the loading station for the transport truck, and the holding tank drains into the transport truck to transfer the fish without handling injury or related stress. Truck tanks use automatic quick-release gates for subsequent release of adult fish. Releasing adult fish from trucks requires very little infrastructure other than direct access to the water's edge; therefore, the requirements for adult fish release facilities are minimal (e.g., a boat ramp).

For the purposes of this analysis, it is assumed that a truck-mounted tank would be sufficient to transport the fish.

Three potential transportation routes are shown on Figure 4-2.

- Oak Ridge Haul Route – 10.5 miles from the Calaveras Creek Fish Facility to the Arroyo Hondo Fish Facility
- Calaveras Haul Route – 15 miles from the Calaveras Creek Fish Facility to the Arroyo Hondo Fish Facility
- Corral Point Haul Route – 3 miles from the Calaveras Creek Fish Facility to the Surface Flow Collector location

All three routes connect a potential adult capture location (Calaveras Creek Fish Facility) with potential juvenile capture locations (the Arroyo Hondo Fish Facility and the Surface Flow Collector location, discussed in more detail in Section 4.1.2.1) that are also potential adult release locations. Most of these roadways are not paved, and paving would be required at many locations to accommodate frequent trips by a heavy truck during the rainy season, and to minimize erosion, the potential for sediment to increase stream turbidity, and potential sediment accretion in the watershed.

The lower segment of the haul route (from the dam crest to the potential Calaveras Creek Fish Facility location) would be common to all three identified routes and currently exists. However, this unimproved road would require substantial upgrades to support frequent travel by the fish transport tank truck. Improvements for any of the haul routes chosen would include paving the roadway from the dam crest to the Calaveras Creek Fish Facility, providing a truck turnaround at the capture location, and drainage and safety improvements (i.e., guardrail, bollards, etc.) along the roadway where needed.

Oak Ridge Haul Route, which is 10.5 miles long and connects the Calaveras Creek and Arroyo Hondo Fish Facilities (Figure 4-2), requires the most extensive improvements of the three haul routes considered. Construction of a second paved turnaround would be required at Arroyo Hondo and paving would be necessary along nearly the entire length of the roadway, as it is currently dirt and gravel. Drainage improvements would also be required at various locations. Visibility concerns, due to periodic winter fog at the high elevations of the roadway, necessitate a guard rail along a portion of the haul route as well as vehicle speed restrictions. It is assumed that the one-way duration of the Oak Ridge Haul Route is approximately 90 minutes, which provides for the longest haul of the three options. Finally, Oak Ridge Road is an SFPUC-owned road that is not maintained by the county. Therefore, operation and maintenance costs could be potentially greater than the other two haul routes.

Calaveras Haul Route is 15 miles long and also connects the Calaveras Creek and Arroyo Hondo fish facilities. Similar to the Oak Ridge Haul Route, construction of a second paved turnaround for fish release is necessary at the Marsh Road crossing of Arroyo Hondo. Calaveras Haul Route uses Calaveras and Marsh roads, which are both county-maintained roads. Paving is only necessary along this haul route on Marsh Road from the bridge over Calaveras Creek to Arroyo Hondo. Drainage and safety improvements would also need to be addressed along the same stretch of road. Calaveras Haul Route one-way duration is approximately 80 minutes.

Corral Point Haul Route provides a connection between the Calaveras Creek Fish Facility and the Surface Flow Collector at Arroyo Hondo. This is the shortest of the haul routes, totaling 3 miles, but it would only be used if the surface flow collector design component was implemented for the juvenile collection phase of passage (described in Section 4.1.2.1). Approximately two-thirds of the route requires paving, along with associated drainage and safety improvements. Like the other two routes, a truck turnaround is also needed at the Surface Flow Collector location.

Based on its ability to effectively move adult steelhead over Calaveras Dam, its engineering simplicity, and the fact that hauling fish is a common means of moving them from place to place, the trap and haul design component is retained for further consideration in this memorandum. Section 4.2 discusses the order-of-magnitude capital, operations, and maintenance for this design component.

4.1.2 JUVENILE EMIGRATION

Juvenile steelhead emigration naturally occurs simultaneously with the smoltification process when physiological changes occur that adapt the juvenile fish to life in the ocean. While the location at which smolts would be collected depends on the design component selected, juvenile fish collection would begin after a period of rearing upon the start of juvenile steelhead emigration from the upstream tributaries of Calaveras Reservoir. In the Alameda Creek Watershed, depending on annual hydrological conditions, emigrating steelhead smolts are expected to migrate downstream between March and June with older fish (ages 2 and 3 years) generally migrating earlier (March and April) and younger fish (age 1 year) migrating later (May and June) (Gunther et al., 2000). The design component that serves the juvenile emigration passage element should be designed to minimize juvenile fish mortality due to stress from handling and/or environmental conditions while maximizing target species capture efficiency.

Fish ladders can provide volitional passage for emigrating fish at run-of-the river sites with static water surface elevations where the upstream terminus of the ladder is accessible to the fish; however, volitional passage for emigrating juveniles is not feasible at Calaveras Dam. While a lift on the upstream face of the dam could be used at Calaveras Dam to transport immigrating steelhead between the top of the fish ladder and the reservoir (as described in Section 4.1.1.1), the fish lift would not attract emigrating fish, and therefore could not be used for downstream passage. Volitional passage down a fish ladder at Calaveras Dam is not feasible, nor is it feasible to provide passage (e.g., bypass pipe) through earthen dam facilities without compromising the structural integrity of the dam. If fish were collected and placed into the top of the fish ladder, they could then move downstream, but if emigrating steelhead are to be collected and placed into a truck (or lift), it is probably more practical to release them below the dam (as described in Tanker Truck Transport, in Section 4.1.2.2, Juvenile Fish Transport). The feasibility of providing volitional downstream passage in conjunction with spills over the dam crest was also considered. Spilling does not occur at Calaveras Dam during most years, thus the infrequency of spills would prevent any emigration design component associated with reservoir spilling from being effective. Accordingly, the juvenile steelhead emigration element of fish passage would require non-volitional components designed to collect juveniles and transport them to a location below Calaveras Dam.

The design components evaluated for collecting emigrating juveniles include tributary fish screen capture via an in-stream or off-channel fish screen facility in Arroyo Hondo (Section 4.1.2.1), and reservoir fish capture via a surface flow collector (Section 4.1.2.2) installed in the arm of the reservoir leading to Arroyo Hondo. A surface bypass flow collector is also considered, but determined to be inappropriate for passage at Calaveras Dam (Section 4.1.2.1).

A second design component would be required to move the juvenile fish from the point of capture and holding to a release point below Calaveras Dam. For juvenile fish transport, tanker truck transport is considered first, and appears to be the most feasible design component for this element of passage (Section 4.1.2.2). Canal or pipeline transport is also evaluated, but rejected (Section 4.1.2.2). Other transport options reviewed and rejected included boat transport and a bypass tunnel (Section 4.1.2.2).

4.1.2.1 COLLECTION OF EMIGRATING JUVENILE FISH

TRIBUTARY FISH CAPTURE SCREENS

Juvenile fish capture could be accomplished in the Arroyo Hondo tributary of Calaveras Reservoir with either an instream fish screen or an off-channel flow diversion fish screen facility.

The in-stream fish screen is an inexpensive removable fish screen that is placed in the stream channel. However, its effectiveness would be limited by the nature of flows in Arroyo Hondo, as described in more detail below. The second, and preferred fish screen design component is a full-flow diversion to an off-channel fish screen facility. The off-channel flow diversion fish screen facility is more expensive than the removable screens, but can be designed to meet the range of flows in Arroyo Hondo during the juvenile steelhead emigration period. Both screen types require daily maintenance during the capture and transport period for removal of debris that may affect screen capture efficiency. Additionally, if heavy debris transport results in clogging, portable trash racks may be required upstream of the diversion facility or screens to help keep the screens debris free.

Regardless of which screen type is used, after juveniles have been collected in Arroyo Hondo, they would be transported from the collection facility to a downstream release point. Current NMFS criteria state that fish should not be held more than 48 hours prior to transport (Idaho Power Company, 2001). It has been shown that juvenile fish transport by truck has no significant effect on survival or subsequent homing (immigration) (Idaho Power Company, 2001), unless they have not completed the smolting process.

Site selection criteria for an upstream tributary fish screen facility include:

- Adequate road access
- Appropriate stream channel cross section and velocity characteristics

- Location that maximizes potential upstream rearing habitat
- Location that minimizes the variability of flow regimes

Off-Channel Fish Screening Facility

An off-channel fish screening facility would operate using the same basic principles as instream screens without the limitation of requiring relatively low velocities. An off-channel fish screen facility is designed to divert all flows up to the design flow capacity through fish screens that separate the fish into holding tanks. Off-channel trapping of emigrating juveniles can be accomplished using a low-head diversion structure and trapping system. The low-head diversion structure could be composed of an Obermyer, inflatable, or concrete dam that spans the width of the main stream channel. This dam would be adjusted to deflect a range of in-stream flows off-channel and into the proposed trapping facility. Flows outside of the targeted trapping range would be allowed to flow over the top of the constructed dam. Even when peak flows reach ranges that are above the design capacity of the fish screens, all of the flow except the amount above the design limit would continue to be screened. In contrast, the instream screen must be removed from the tributary when flows exceed the design capacity and all capture opportunities for peak juvenile emigration on pulse flows are lost.

When tributary flow would be diverted into the off-channel screen facility, it would begin traveling within a canal with an appropriate width and gradient to allow water velocity to decrease sufficiently to be screened, but not substantially enough to create a backwater effect in the main tributary channel. The trapping facility would include a series of fixed vertical plate screens that allow access water to pass through but bypassing water and fish. The access water is diverted back to the main channel while the bypass water and fish are routed to a holding tank. Bypass water would continue to circulate through the holding tank and would be discharged back into the main stream channel. After screening, all flow not being used to maintain the captured juveniles within the holding tanks would be diverted back into the tributary channel. Fish would remain within the holding tank until collection and transport occurs.

An off-channel screening system could be designed in a variety of configurations, as is the case with diversion screening, and is dependant upon the range of flows anticipated to occur during juvenile out-migration as well as the available footprint area available for construction. In general, the fixed-plate vertical screens would be oriented in a “V”-type configuration where access water is screened out to both sides and the fish and bypass water are directed towards the middle. At the end of the screens, a bypass pipe or channel sweeps fish and water to the holding tank. The holding tank would contain guide slots and stop logs so that a range of hydraulic conditions could be accommodated. The holding tank would also process a crowding system that would facilitate concentration of the fish prior to collection and transport.

Vertical Screen

The most likely design for a removable, in-channel fish screen/juvenile capture facility is a vertical screen (see Figure 4-6). Vertical screens are typically installed in a “V” or “W” configuration, depending on stream channel width, with the opening of the “V” or “W” upstream and the junction of the arms of the “V” or “W” at the most downstream end of the screening unit. The “V” or “W” shape of the screening unit limits impingement of individuals by altering the angle at which juveniles approach the screens. Screens using this general design are commonly referred to as stationary panel fixed screens, vertical fixed plate screens, and when associated with a pipe and holding box, the general term “smolt trap” often is used (WDFW, 2000; Office Technology Assessment, 1995; Murphy, 2002; USACE, 2000).

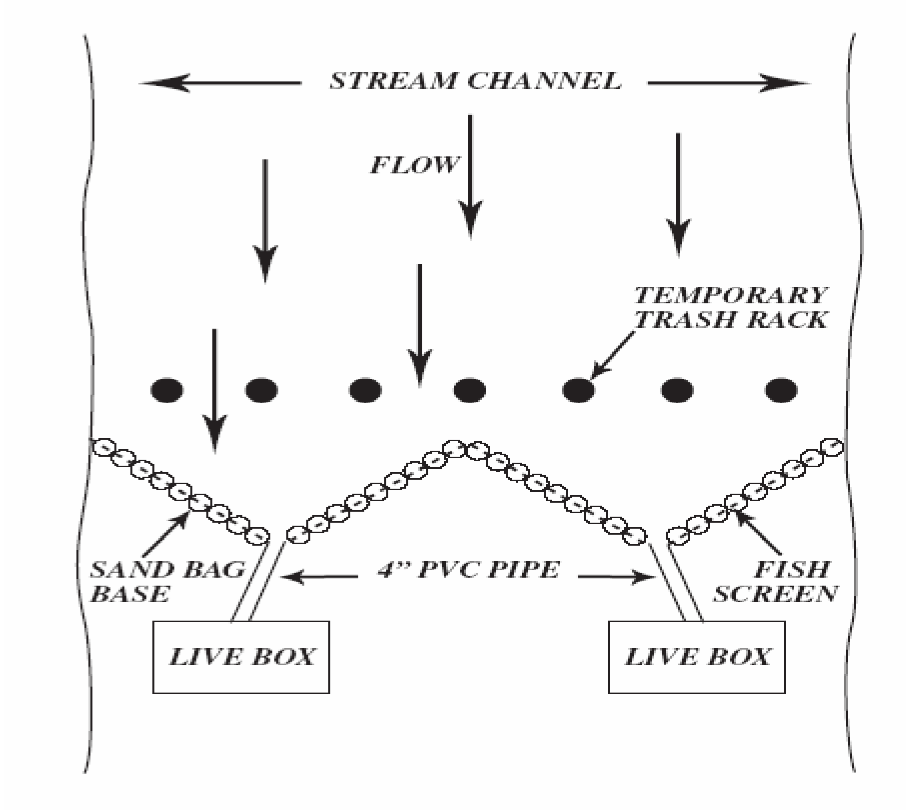


Figure 4-6 Removable Instream Fish Screen and Juvenile Fish Trapping Facility

These types of installations are relatively inexpensive. The screens are generally panels of 1/4- or 3/8-inch screen affixed to a frame of 2-by-4-inch wood. The screens are held in place by metal stakes driven into the stream bed. Sandbags are used at the base of the screen to seal the bottom and provide a level base. A 4-inch PVC pipe is built into the apex of the fence to transport the fish to a live box for temporary holding. The live box generally would contain a sectioned compartment of galvanized mesh that is sized to allow juveniles (fry and parr sized) to pass through the first compartment into a smaller compartment that larger fish cannot enter, if larger predators become trapped in the holding box (Murphy, 2002).

USE OF INSTREAM OR OFF-CHANNEL SCREENS OR TRAPS AT CALAVERAS DAM

Although considered up to this point in the analysis, the relatively flashy flow regime in the Alameda Creek Watershed would limit the use of instream screens during the juvenile downstream migration period. Arroyo Hondo has a base flow in autumn of just 0.5 to 2 cfs, but during winter and spring precipitation events flows can quickly rise upwards of 1,000 cfs (USGS, 2009, Figure 4-7). Smolt trapping studies conducted in Arroyo Hondo (using 1-inch by 2-inch wire screens, lined with ¼-inch hardware cloth, supported by standard T-posts and braces) have revealed that they can only effectively be operated when flows are less than roughly 140 cfs, and must be removed from the creek before it swells to a size greater than that (Brian Sak, pers. comm., 2009). Additionally, exact flows cannot be predicted; a very cautious approach to managing the screens would mean removing them in anticipation of high flows that might not materialize, and a less cautious approach would likely result in occasional damage to or destruction of the apparatus. Flashy, high flows following

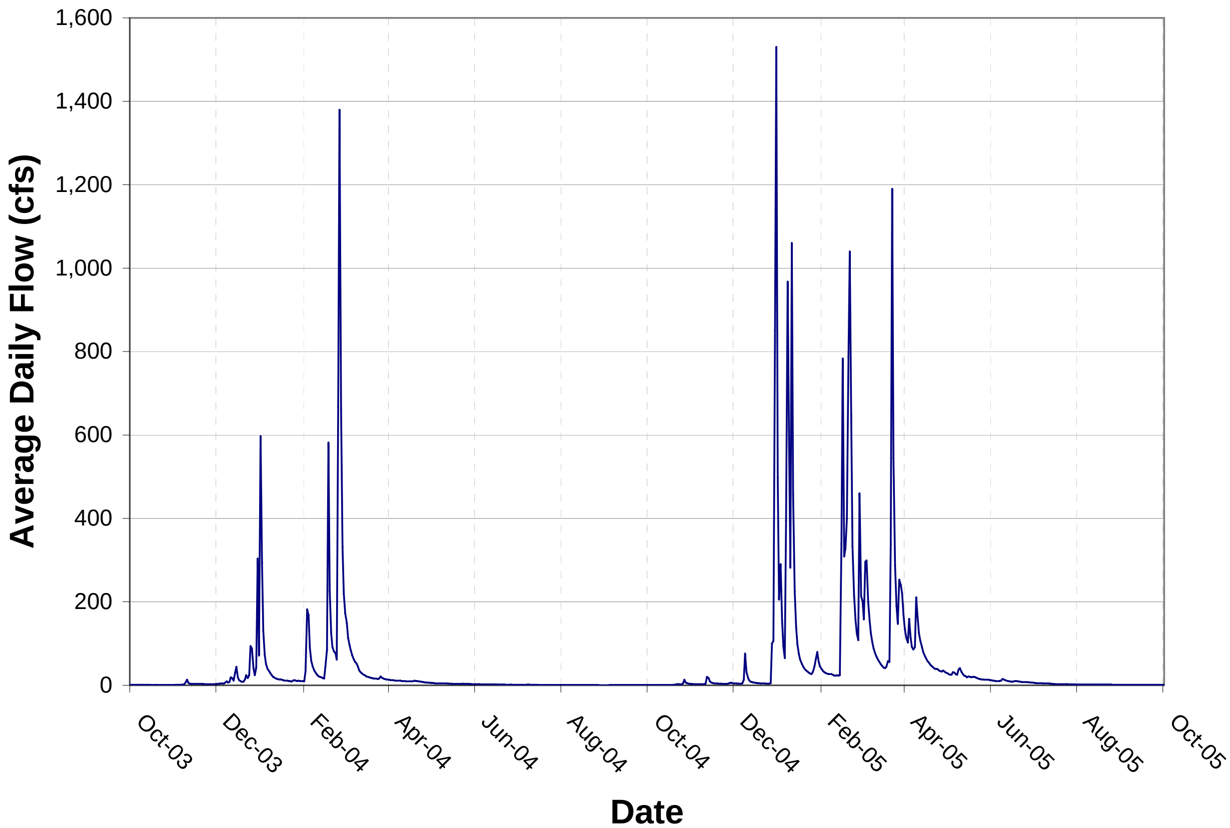


Figure 4-7 Average Daily Flow at the USGS Gage on Arroyo Hondo for 2004 and 2005 Water Years

precipitation events confined within relatively narrow stream channels create prohibitively high water velocities for instream screen use. Because removal of the screens during high flows would mean allowing a majority of emigrating steelhead to pass by without being captured, an unacceptable scenario in terms of the overall biological goals of providing fish passage, instream screens are eliminated from further evaluation for capturing juvenile steelhead in this technical memorandum.

An off-channel screen would be more effective in Arroyo Hondo. A potential location for an off-channel screen is shown in Figure 4-2 (Arroyo Hondo Fish Facility). Because it is impossible to tell the difference between juvenile steelhead and resident rainbow trout juveniles, all captured juveniles would have to be treated as steelhead. If the traps operate at a high level of efficiency and a significant proportion of emigrating juveniles are captured and transported below Calaveras Dam, the resident population of rainbow trout in the reservoir could be negatively impacted. Non-salmonid species (e.g., Sacramento sucker) would also be captured, but would be released immediately downstream of the trap. Traps would only be operational during the spring months when juvenile steelhead would be emigrating; therefore, it is not anticipated that upstream migrants would be significantly affected. An off-channel fish screen is retained as a viable design component for further analysis in subsequent sections of this technical memorandum.

RESERVOIR SURFACE FLOW COLLECTOR

A surface flow collector, also called a gulper, is a floating barge that uses an attraction flow to guide fish towards the device, and often is associated with an additional guidance device such as a physical or behavioral barrier to lure emigrating juveniles into a trap located within the barge.

The Baker River Fish Passage Project, Washington, is the most thoroughly documented installation of a gulper as the primary method of juvenile salmonid collection (PSE, 2002a; Wayne Jr., 1961; Whitney et al., 1997). The Baker River Fish Passage project uses two gulper systems (one in Baker Lake at the Upper Baker River Facilities and one in Lake Shannon at the lower Baker River Facilities) that were assumed to be representative of a typical fish gulper system that could be constructed for use in a potential fish passage project at Calaveras Reservoir. Both gulper systems use similar gulpers and guidance net devices (PSE, 2002b). Figure 4-8 shows a picture of the gulper system used in the Baker River Fish Passage Project.

Figure 4-8 Gulper System in Use at the Baker River Fish Passage Project

The surface collection barge in use at Baker Lake is a rectangular barge measuring 36 feet by 70 feet attached to steel floatation tanks that allow for adjustable buoyancy. The entrance channel to the collection barge is 12 feet wide by 35 feet long and attached to the steel trusses of the barge. The channel contains a sloping timber louver and two pumps that draw water through the louver. Immediately past the louver is a smaller flume that leads to a gravity flow pipe connected to a fish trap. The trap measures 62 feet by 54 feet and is constructed of concrete floatation modules and a submersible steel box, which has a ballast that is compartmentalized into four raceway channels for holding and sorting fish (PSE, 2002b).

The surface collection barge at Baker Lake draws water from immediately below the reservoir surface and generates a flow designed to aid attraction of emigrating juveniles into the barge entrance channel. The attraction flow through the entrance channel reportedly acts to facilitate the movement of fish toward the timber louver and into a smaller flume and subsequent trap (PSE, 2002b). The louver was designed to funnel fish into the flume, while the reduction in size from the louver to the flume was designed to create velocities that prohibit juveniles from swimming against the current, thus avoiding the trap and re-entering the reservoir. The guide net, which spans across the forebay, acts to form a complete migration barrier preventing fish from moving farther into the reservoir while directing them toward the surface collector (PSE 2002b, 2002c).

Several investigations have been made into the efficacy of surface flow collectors. During a study conducted at the Upper Baker Lake fish gulper in 2002 acoustic tags were used to track the behavior of Coho and sockeye salmon as they moved through the forebay of the reservoir toward the gulper. Only 21 percent of the tagged juvenile salmon were collected by the gulper[5] (PSE, 2002c). Earlier studies at the same location used fixed location hydroacoustics to determine that between 67 and 79 percent of the tagged fish found the gulper (FERC, 1993). Based on these studies between 21 and 79 percent of juvenile steelhead might be expected to be captured by a gulper. Survival associated with fish gulpers is assumed to be high but limited information is available regarding injury related to the use of gulpers to guide and capture fish. Of those fish that are captured by the gulper, some additional, perhaps small, percentage may be injured or killed during capture. Uncaptured or severely injured juvenile fish would not have the opportunity to contribute to the productivity of the re-established steelhead population, and the capture efficiency of this design component may be one of its greatest limitations.

Use of a Surface Flow Collector at Calaveras Reservoir

Collection of juvenile steelhead in Calaveras Reservoir could potentially occur with a surface flow collector located in the Arroyo Hondo arm of the reservoir. While capture efficiency is expected to be lower than with an off-channel screen in Arroyo Hondo (for which instream screens in Arroyo Hondo were eliminated from further consideration), surface flow collection provides flexibility in the juvenile capture location not provided by either screen design component. While spawning is only expected to occur with any regularity in Arroyo Hondo, the degree of flexibility in capture location provided by use of a surface flow collector warrants retaining this design component for further analysis. See Section 2.3 for a description of these tributaries to Calaveras Reservoir, Section 4.3 for a more detailed discussion of available spawning habitat, and Figure 4-2 for an example location for a potential surface flow collector operating station. This design component would require a method to transport the fish to a location below the dam after they have been collected.

The surface flow collector design component, based on this initial analysis, is retained for further consideration in this memorandum. Section 4.2 discusses the order-of-magnitude capital and operations and maintenance for this design component.

SURFACE BYPASS COLLECTOR

Surface bypass collectors, which are used to guide juvenile salmonids away from turbines and provide safe passage past dams on the Columbia River, use attraction flows near the surface of the water to take advantage of the natural behavior of migrating juveniles. In this way surface bypass collectors are similar to gulpers used in the Baker River Fish Passage Project. The surface bypass collectors used at the Columbia and Snake river projects, however, are different from gulpers in that they attract juveniles into bypass routes, such as spillway gates, or collection devices (Nordlund and Rainey, 2000), as opposed to simply capturing them for subsequent transport via some other device.

[5] No studies specific to steelhead and use of a gulper were identified.

Use of a Surface Bypass Collector at Calaveras Dam

A surface bypass collector is inappropriate at Calaveras Dam because it is not a run-of-the-river type dam with a relatively static water surface elevation. Therefore, surface bypass collectors are eliminated from further consideration.

4.1.2.2 JUVENILE FISH TRANSPORT

TANKER TRUCK TRANSPORT

Transport of juvenile fish in a truck would be similar to the transfer of adult fish discussed in Section 4.1.1.3, and is a viable option for transporting juveniles to a location below Calaveras Dam once they have been captured. Juvenile fish transport methods via truck are well established and mortality rates are generally very low. Facilities for water-to-water transfer of captured juvenile fish from the holding tanks to the trucks would be required. Requirements for juvenile fish release location facilities are access to the water's edge and turnaround space for the trucks. The proposed location for the juvenile fish release would be at the "Calaveras Creek Fish Facility," on Calaveras Creek at the upstream end of the pool above the confluence with Alameda Creek (Figure 4-2).

The tanker truck design component, based on this initial analysis, has been retained for further consideration. Section 4.2 discusses the order-of-magnitude capital and operations and maintenance for this design component.

CANAL OR PIPELINE TRANSPORT

Another design component considered for transporting juvenile fish from the capture location to a location below Calaveras Dam was the construction of a canal or pipeline that would stretch from the Arroyo Hondo Fish Facility to the dam, and then from the dam to the Calaveras Creek Fish Facility, below the dam. One concern about this type of conveyance is that if the water moves slowly it could be warmed by ambient air temperatures, and its temperature and dissolved oxygen levels could move outside of the range required by juvenile steelhead. In order to create a gradient sufficient for water to flow through the canal or pipeline to the top of the dam quickly enough to avoid stressing the fish, the starting point of the conveyance would need to be up the Arroyo Hondo tributary to just above the Arroyo Hondo landslide, (see Section 2.3.1 for description of the landslide) resulting in a total length to the dam of 6 miles. The landslide is a major obstacle, if not a complete barrier, to fish migration (URS and HDR, 2009), and starting the conveyance above the accessible habitat reach is not functional. Therefore, this configuration was rejected.

A shorter conveyance could potentially be constructed. For example, starting at a point such as the "Arroyo Hondo Fish Facility" (Figure 4-2), the juvenile fish and water supply would need to be pumped to an elevation above the dam. Once the fish reach the top of the dam, provisions would be required for either transport of the fish downstream or a mechanism for safe passage over the dam, such as the continuation of the conveyance as described in the preceding paragraph, a juvenile bypass pipe, or a fish ladder. Nevertheless, water temperatures, dissolved oxygen, clogging, and maintenance requirements would all still be substantial concerns for the viability of this transport alternative. Little data exist on the effectiveness of any open canal or closed conduit alternatives to transport juvenile steelhead trout. In the conclusion of its *Columbia River Salmon Mitigation Analysis – Phase 1* report, the U.S. Army Corps of Engineers stated that the canal and pipeline proposals should be eliminated from further consideration because of biological concerns and uncertainties (Idaho Power Company, 2001). Similarly, in this analysis the use of a canal or pipeline for transporting emigrating juveniles is eliminated from further consideration.

OTHER TRANSPORT OPTIONS CONSIDERED BUT REJECTED

Two other transportation options, boat transport and a bypass tunnel, were considered but rejected due to the availability of more readily applicable and desirable methods of transportation.

If the surface flow collection design component is selected for juvenile steelhead capture, and it is not located at the reservoir shoreline, a potential fish transport option is to use a boat to move the fish from the surface flow collector to shore. Although it would be built upon a barge, a surface flow collector requires a large span of netting, or similar apparatus, to help guide the fish into the collection point. This would prohibit the surface flow collector from easily moving to the shore to drop off juveniles it had collected. Once brought to shore on the boat, the juveniles would still need to be moved either to a truck or to the top of the fish ladder, for transport to a location below Calaveras Dam, essentially adding an additional handling stage to the operation. A boat would not be required if the surface flow collectors are located either at the dam or at tributary anchoring stations with road access. Although technically feasible, the site conditions, distances, and access issues would be more appropriately addressed with a design component other than boat transport.

A bypass tunnel starting from near the confluence of Arroyo Hondo and the reservoir, continuing through Oak Ridge down to Calaveras Creek below the proposed location for the replacement Calaveras Dam, was also initially considered for transport of juveniles to a location below the dam. There is some uncertainty, however, about the potential biological problems that could occur with juvenile transport through a tunnel. Additionally, preliminary cost estimates indicated that a bypass tunnel would cost substantially more than other design options for transporting juvenile fish. For these reasons, a bypass tunnel was rejected from further consideration.

4.1.3 POST-SPAWN ADULT EMIGRATION

Although most steelhead die after spawning, a significant number do not. As much as 20 or 30 percent of an annual steelhead run may be composed of repeat spawners (Shapovalov, 1953; Shapovalov and Taft, 1954). Therefore, these fish would be an important component of any plan to establish and maintain a viable population of steelhead within the project area. However, requirements for re-capturing and transporting post-spawn adult steelhead are particularly problematic. As discussed in Section 4.1.2, Juvenile Emigration, volitional passage down a fish ladder at Calaveras Dam is not feasible. A review of the fisheries literature and existing passage projects was unsuccessful in identifying any steelhead-only trap and haul passage projects in the United States. Additionally, the review did not document any design options to successfully capture post-spawn, adult steelhead.

One design option considered and rejected is a removable instream fish screen, or smolt trap, similar to that described under Tributary Fish Capture Screens in Section 4.1.2.1, Collection of Emigrating Juvenile Fish. Smolt trapping studies conducted in Arroyo Hondo indicate that smolt traps are very successful in capturing adult rainbow trout if larger than normal pipes that can accommodate adults are used (Brian Sak, pers. comm., 2009), but smolt traps used to capture emigrating adults would be subject to the same limitations as described in Section 4.1.2.1 for juveniles. The flashy flows discussed in that section (Figure 4-7) would be even more problematic if instream screens were used to capture adults, because the traps would have to be in place earlier in the season than they would if they were being used to capture smolts only (Table 4-1). Therefore, instream screens are not likely to be an effective means of capturing emigrating adults.

Unlike other Pacific salmon species, not all steelhead die after spawning. No suitable means of capturing and transporting the surviving, post-spawn adult steelhead downstream of Calaveras Dam was identified. The ultimate fate of these surviving adults is unknown.

4.2 CAPITAL AND OPERATING AND MAINTENANCE COST ESTIMATES

In the previous section, a variety of design components were identified and evaluated based on their ability to meet the biological requirements of three steelhead passage elements, and screened for suitability at Calaveras Dam. The design components were either rejected because they are unlikely to meet the biological requirements of passage or because of some other easily identified flaw, or retained for further consideration. The following design components were retained through the preliminary analysis, and are evaluated in this subsection based on cost:

Adult immigration

- Fish ladder
- Trap and haul

Juvenile emigration, capture

- Off-channel fish screen
- Surface flow collector

Juvenile emigration, transport

- Tanker truck (haul)

The estimated cost of these fish passage design components is broken down in the following sections based on capital costs of construction (Section 4.2.1), estimated annual water costs (Section 4.2.2), and the total annualized cost of each design component alone and in combinations that together provide complete fish passage options (Section 4.2.3).

4.2.1 CAPITAL COSTS

The estimated cost of fish passage design components at Calaveras Dam includes both the estimated capital cost of constructing the facilities and annual operations and maintenance costs. This section describes the estimated capital costs associated with the design components retained through the initial analysis.

Capital cost estimates are provided based upon facilities at other sites where similar projects have been implemented, as well as typical industry costs and engineering judgment. Each design component was evaluated on a conceptual level, taking into consideration basic factors such as site conditions and conceptual designs. When sufficient information was available, capital costs for the design components were estimated by developing unit costs and multiplying these by estimated quantities. Unit costs were compared with historical database unit prices; vendor quotes were used, when available. Where the level of design detail was insufficient to support an estimate, lump sum allowances based on historical experience for similar projects were used. Raw capital costs were then generated for each design component. Estimated raw costs and additional assumptions are detailed in Appendix B.

Comprehensive design work has not been done for any of the design components. For purposes of this analysis, relative cost estimates were developed. Based on the limited descriptions of the design components provided in Section 4.1, assumptions regarding what the structures may consist of have been made, as shown in Appendix B, in order to develop the raw capital costs shown in Table 4-2.

Table 4-2
Capital Costs of Calaveras Passage Design Components

Design Component	Raw Cost[1]	Soft Costs and Contingency (100%)[2]	Total Capital Cost[3]
Spillway Fish Ladder	$20,880,000	$20,880,000	$41,760,000
Roadway Fish Ladder	$23,660,000	$23,660,000	$47,320,000
Calaveras Creek Fish Facility	$800,000	$800,000	$1,600,000
Arroyo Hondo Fish Facility	$1,810,000	$1,810,000	$3,620,000
Surface Flow Collector	$9,100,000	$9,100,000	$18,200,000
Calaveras Haul Route	$5,720,000	$5,720,000	$11,440,000
Oak Ridge Haul Route	$10,040,000	$10,040,000	$20,080,000
Corral Point Haul Route	$2,470,000	$2,470,000	$4,940,000

Notes:
1 Back-up for raw cost is shown in Appendix B.
2 100% factor includes the following: (a) Estimate Contingency 25%, (b) Construction Escalation 24%, (c) Construction Contingency 10%, and (d) Soft Costs 41% (SFPUC, 2006).
3 Order-of-magnitude costs are estimated based on current rates in 2009 dollars.

The SFPUC WSIP program delivery cost methodology (SFPUC, 2006) was used to determine the factor to add to the raw construction cost to develop a total estimated capital cost for each design component (Table 4-2). The total factor of 100 percent consists of an estimate contingency (25 percent), construction escalation to time of construction (24 percent), construction contingency (10 percent), and soft costs (e.g., planning, design, review management, etc.) (41 percent).

A number of limitations are associated with the estimates provided. The costs are preliminary, order-of-magnitude[6] estimates to assist in the comparison of relative costs among options. No engineering site work or calculations have been performed. Depending upon geotechnical and hydrological conditions at the site, it may not be feasible to construct certain components as assumed. In addition, environmental impact mitigation costs could be required with implementation of some or all options. These mitigation costs are not included in this estimate.

6 An order-of-magnitude cost estimate is also known as a concept Class 5 estimate (AACE, 2005). Its primary use and purpose is to screen alternatives and determine feasibility. Expected accuracy ranges from -20% to -50% on the low end, and +30% to +100% on the high end.

4.2.2 ANNUAL WATER COST

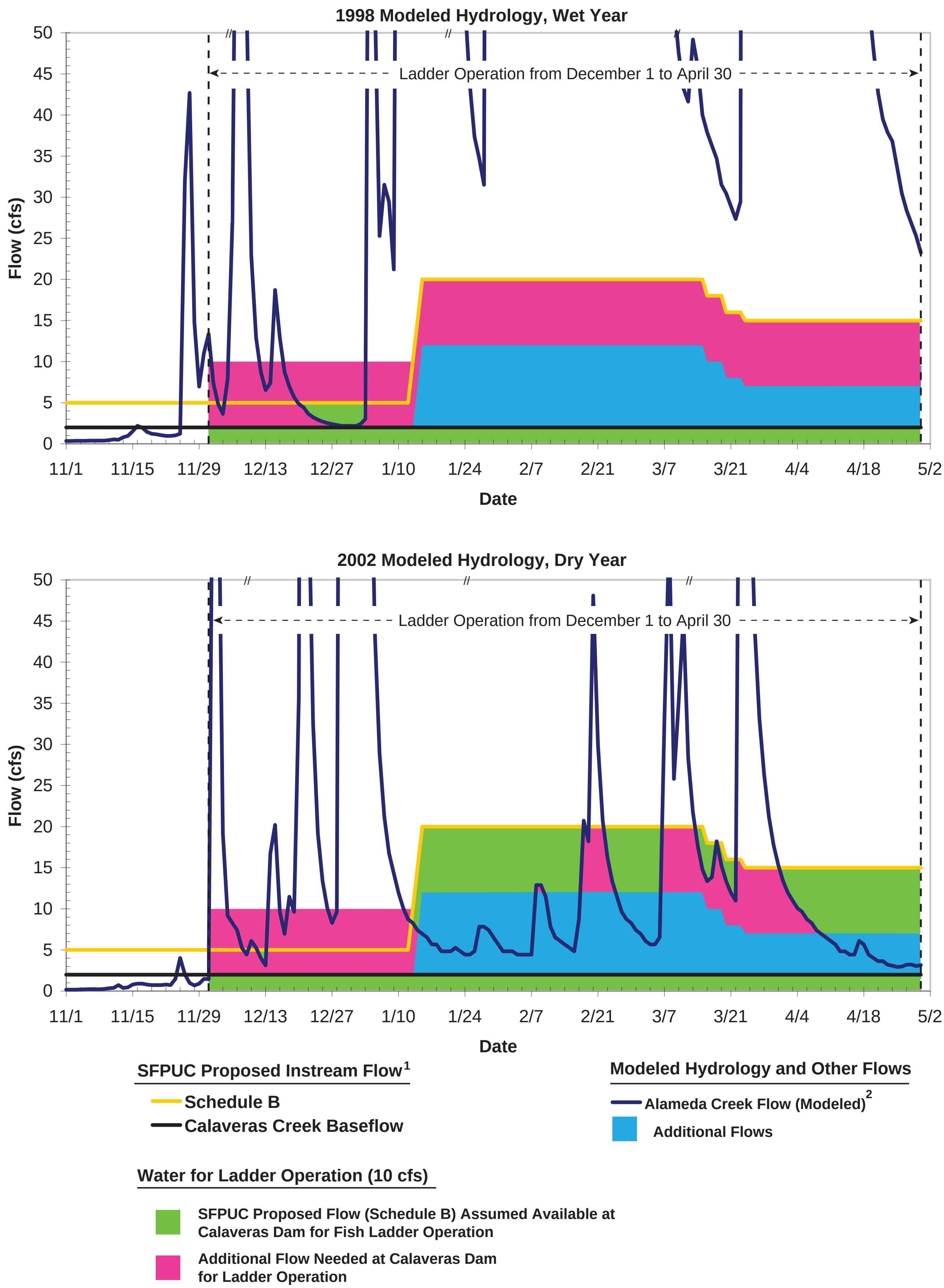
Because SFPUC is a supplier of municipal water, reductions in the amount of water stored and supplied from Calaveras Reservoir will result, in most cases, in a cost for replacement water. Therefore, a component of the annual fish ladder cost is the annual water cost. This annual water cost is described in more detail in this section, and the water cost associated with the fish ladders is estimated. This analysis has a number of limitations that likely affect the accuracy of the estimate developed, also described in this section.

Operation of a fish ladder at Calaveras Dam would require a prescribed set of minimum flows to be maintained during certain months of the year when the ladder would be in operation for adult immigration, December through April (Table 4-1). In this analysis, the minimum flow is assumed to be 10 cfs.[7] As part of the CDRP, SFPUC has proposed an instream flow schedule for steelhead, measured immediately below the confluence of Calaveras Creek and Alameda Creek, which would be met by a combination of bypassing water at the ACDD and releasing water from Calaveras Dam (Section 1.1). For the purposes of this water cost estimate, it is assumed that the SFPUC-proposed instream flows would be provided as bypass flows at ACDD whenever such flows are available. Therefore, the extent to which the SFPUC-proposed instream flows would be potentially available to operate a fish ladder at Calaveras Dam partially depends on flows in Alameda Creek. The CDRP also includes year-round base flow of 2 cfs in Calaveras Creek below Calaveras Dam (SFPUC, 2009). It is assumed in this analysis that the 2 cfs would always be available for operation of a fish ladder at Calaveras Dam, in addition to the water released at Calaveras Dam to supplement flows bypassed at ACDD, to meet instream flow schedule amounts at the confluence of Calaveras and Alameda creeks.

At the time this annual water cost was first developed, the hydrologic record for upper Alameda Creek (USGS Gage 11172945) extended only from 1995 to 2004. This is a relatively short period of record and may not accurately characterize the temporal distribution of flows that could potentially occur above ACDD. To more accurately predict the frequency and magnitude of flows in Alameda Creek, a synthetic hydrology was produced based on a correlation with the daily average flows recorded at the Arroyo Hondo gage (USGS 11173200) from 1969 to 1981 and 1995 to 2004 (no flow data are available from Arroyo Hondo for the 1982-through-1994 period). This analysis was completed to estimate potential water yields in Alameda Creek over a broader range of hydrologic conditions by extending the period of record from 10 years to 24 years. Appendix C contains a description of the model selection process and detailed flow data.

In support of the limited record of measured flow data for upper Alameda Creek, predicted daily average flows from the model described in Appendix C were used to estimate an average flow at the ACDD for each day of each year in the simulated period. These daily average flows were then used to estimate how much water would potentially have to be released from Calaveras Dam to meet the SFPUC proposed instream flow. The estimated volume of water that would be required to operate a fish ladder at Calaveras Dam is illustrated in Figure 4-9 for both a wet year and a dry year. To the extent that SFPUC proposed instream flows would be met by releases from Calaveras Dam, these flows could be used for operating a fish ladder at Calaveras Dam, without incurring additional water costs (shown in green on Figure 4-9). Any water in addition to the SFPUC proposed instream flows released from Calaveras Dam that would be required to operate a fish ladder could potentially increase the annual cost of operating the ladder (shown in pink on Figure 4-9). For example, when Alameda Creek is not flowing, and all of the SFPUC proposed instream flows are released from

[7] Attraction flow water costs were not calculated for this preliminary analysis.



Notes

[1] Instream flow schedule amounts to be bypassed at ACDD when natural flow is present (excluding Calaveras Creek baseflow which is to be provided in Calaveras Creek at Calaveras Dam). Remaining flow schedule amounts to be provided through releases at Calaveras Dam. Provision of flows via a ladder at Calaveras Dam would likely necessitate review of flow release locations and amounts.

[2] Detailed in Appendix C.

Water Potentially Required for a Fish Ladder at Calaveras Dam

Feasibility of Fish Passage at Calaveras Dam Technical Memorandum

June 2009

Figure 4-9

Calaveras Reservoir, additional water costs would only be incurred when those flows are insufficient to operate a fish ladder (i.e., flows are below 10 cfs). Table 4-3 is a comparison of the total annual (water year) flow in Alameda Creek and the additional volume of water needed at Calaveras Reservoir for fish ladder operation (beyond the required normal water year instream flows that would be released from Calaveras Dam), as predicted by the model for simulated flows in Alameda Creek for the time periods 1969 through 1981 and 1995 through 2004.

Table 4-3
Comparison of Predicted Flow at Alameda Creek and Ladder Operation at Calaveras Reservoir
(November 1 – April 30)

Water Year	Total Flow (acre-feet)	Additional Flow Required For Ladder Operation (acre-feet)
1969	29,600	2,140
1970	13,300	1,490
1971	10,500	1,230
1972	2,710	680
1973	30,500	2,260
1974	22,500	2,030
1975	23,100	1,860
1976	490	430
1977	360	450
1978	22,000	2,070
1979	9,420	1,290
1980	24,700	1,720
1981	8,250	1,100
1995	30,200	2,040
1996	23,300	2,010
1997	29,500	1,380
1998	40,800	2,330
1999	13,100	2,150
2000	14,600	1,450
2001	7,820	1,190
2002	6,280	1,160
2003	10,200	1,030
2004	8,720	1,080
Average	**16,600**	**1,500**

The estimates depicted in Table 4-3 indicate that on average, approximately 1,500 acre-feet of water, in addition to SFPUC proposed normal water year instream flows released at Calaveras Dam, would be required to operate a fish ladder at Calaveras Dam annually. For the purposes of this analysis, an estimated 2016 water rate of $1,500 per acre-foot[8] was used to estimate the annual cost that could be incurred, because it accounts for the time differential of up to several years between this estimate and the actual construction and operation of a potential fish ladder. Therefore, the average annual water cost due to operation of a fish ladder is estimated at approximately $2,250,000. This water cost is added to the annualized fish ladder component cost in Section 4.2.3.

LIMITATIONS OF ANNUAL WATER COST ESTIMATES

Several limitations are associated with the estimated annual water cost for a fish ladder, some of which may affect the accuracy of the estimate. Limitations of this analysis are listed below:

- Calaveras Reservoir, prior to the DSOD restriction, periodically filled to capacity and spilled. During years when the reservoir spills, there is a lack of capacity in Calaveras Reservoir to store water that could be potentially diverted from ACDD. Since the conceptual level feasibility analysis in this memorandum does not include development of a systems model to integrate historic spill scenarios, water year types, and the lost water diversion estimates, the net effect of spills is not assessed in this analysis of annual water costs.

- The water cost analysis is based on the assumption that the SFPUC proposed normal water year instream flows would be bypassed at the ACDD when available. The SFPUC proposed instream flows, however, include three different flow schedules to be alternately implemented depending on the annual hydrological conditions (Section 1.1). A preliminary review indicated that there is little difference in the estimated cost of additional flows to operate a fish ladder, whether simply the normal water year schedule or all three schedules (dry, normal, and wet) are used. Therefore, use of the normal water year flow schedule was assumed to be appropriate for the preliminary analysis in this conceptual feasibility study.

- Because it is based on the flows predicted by the model described in Appendix C, the water cost estimate is limited by the accuracy of the model. Any inaccuracies inherent in the modeled flows would be carried through to this water cost estimate.

4.2.3 ANNUALIZED CAPITAL AND OPERATIONS AND MAINTENANCE COSTS

In this section capital costs developed in Section 4.2.1 are annualized and combined with annual water costs developed in Section 4.2.2 and operations and maintenance costs (developed in this section) to estimate the total annualized cost of fish passage design components at Calaveras Dam. The design components are also combined to show the total estimated annualized cost of complete fish passage options at Calaveras Dam. The purpose of the preliminary cost assessment is to characterize annualized costs for design components related to fish passage that have been retained up to this point for further consideration in this technical memorandum. The cost estimates are not as detailed as those that would be used for fiscal planning or bid solicitation, but can be used to compare the relative cost among fish passage design components.

[8] Cost of water cited may be a minimum cost of replacement water (water lost from storage) as it will depend on where and how SFPUC is able to replace the water. For example, recycled water development in San Francisco is estimated to cost approximately $3,900 per acre-foot. Thus, the actual cost of replacement water will depend on replacement sources available at the time replacement water is needed.

Table 4-4 presents the estimated total annualized cost of each design component, including annualized capital costs, operations and maintenance, and associated water costs. In order to accurately compare the design component costs on an annual level, a Capital Recovery Factor (CRF) was used to convert each total capital cost into a series of equal annual costs (Cal/EPA, 1996). It is assumed that the capital costs are paid over a 30-year period at an interest rate of 5.5 percent, resulting in a CRF of 0.0688 (Table 4-4).

Table 4-4
Annualized Costs of Calaveras Fish Passage Design Components

Design Component	Total Capital Cost[1]	Annualized Capital Cost[2]	Annual O&M Allowance[3]	Annual Water Costs[4]	Total Annualized Cost
Spillway Fish Ladder	$41,760,000	$2,874,000	$270,000	$2,250,000	$5,394,000
Roadway Fish Ladder	$47,320,000	$3,256,000	$298,000	$2,250,000	$5,804,000
Calaveras Creek Fish Facility	$1,600,000	$110,000	$74,000	N/A	$184,000
Arroyo Hondo Fish Facility	$3,620,000	$249,000	$127,000	N/A	$376,000
Surface Flow Collector	$18,200,000	$1,252,000	$200,000	N/A	$1,452,000
Calaveras Haul Route	$11,440,000	$787,000	$57,000	N/A	$844,000
Oak Ridge Haul Route	$20,080,000	$1,382,000	$100,000	N/A	$1,482,000
Corral Point Haul Route	$4,940,000	$340,000	$25,000	N/A	$365,000

Notes:
1 Total capital costs presented in Table 4-2.
2 The annualized capital cost assumes a Capital Recovery Factor (Cal/EPA, 1996) of 0.0688, assuming 5.5% interest over 30 years.
3 Annual O&M cost estimate presented in Appendix B, Table B-2.
4 Water costs are detailed in Section 4.2.2.
N/A = not applicable

Order-of-magnitude operations and maintenance cost estimates were developed as part of this initial assessment of fish passage design components. These estimates, detailed in Appendix B, include 0.5 percent of the total capital cost for materials and replacement parts, as well as labor and other costs that would likely be required to operate the design components.

Annual water costs due to fish ladder operation flows are included as an operating cost that will be incurred each year that the facility is in operation (Annual O&M Allowance, Table 4-4). The total annualized fishway costs include the annual water costs that were developed in Section 4.2.2.

In Table 4-5, design components are grouped together to identify options that provide both adult immigration and juvenile emigration (in other words, “options” are combinations of components that create complete fish passage). The total cost of options is presented in the right-hand column, and is equal to the sum of costs of the design components in the option.

Table 4-5
Calaveras Fish Passage Options and Conceptual Annualized Cost Comparison

	Design Components (with annualized cost)								
Options	Spillway Fish Ladder ($5,394,000)	Roadway Fish Ladder ($5,804,000)	Arroyo Hondo Fish Facility ($376,000)	Calaveras Creek Fish Facility ($184,000)	Calaveras Haul Route ($844,000)	Oak Ridge Haul Route ($1,482,000)	Corral Point Haul Route ($365,000)	Surface Flow Collector ($1,452,000)	**Annualized Option Cost**
Oak Ridge Trap and Haul			√	√		√			**$2,042,000**
Calaveras Road Trap and Haul			√	√	√				**$1,404,000**
Surface Flow Collector Trap and Haul				√			√	√	**$2,001,000**
Spillway Fish Ladder	√		√		√				**$6,614,000**
Roadway Fish Ladder		√	√		√				**$7,024,000**

For example, the Oak Ridge Trap and Haul option would include trapping immigrating adults at the Calaveras Creek Fish Facility, hauling them upstream via the Oak Ridge Haul Route, and releasing them at the Arroyo Hondo Fish Facility. This option would also include trapping emigrating juveniles at the Arroyo Hondo Fish Facility and hauling them downstream via the same haul route for release at the Calaveras Creek Fish Facility.

Because the Oak Ridge Trap and Haul option would have the same effect as Calaveras Road Trap and Haul, but costs approximately 1.8 times more and takes 10 more minutes for each one-way trip, the Oak Ridge Haul Route is eliminated from further consideration in this memorandum. The Surface Flow Collector Trap and Haul option is more expensive than other Trap and Haul options, but because it allows for collection of juveniles at a location different than Calaveras Road Trap and Haul it is retained for further evaluation in this memorandum. At an order-of-magnitude level of cost estimating, there is little difference in cost between a spillway or roadway fish ladder, so both are retained for further evaluation to determine whether a fish ladder is a desirable means of providing passage at Calaveras Dam.

4.3 HABITAT AVAILABILITY

The amount of available habitat upstream of Calaveras Dam is estimated based upon site visits, previous studies on habitat availability, discussions with knowledgeable individuals (e.g., Brian Sak, SFPUC), and an assessment of fish upstream migration at natural barriers in the Upper Alameda Creek Sub-Watershed (URS and HDR, 2009). While site visits were conducted as part of this investigation, comprehensive habitat surveys of the sub-watershed were beyond the scope of work of this feasibility study.

As discussed in Section 2.3.2, steelhead migration between a full Calaveras Reservoir and Calaveras Creek is not likely to occur with any regularity, so available spawning and juvenile rearing habitat is limited to Arroyo Hondo. As discussed in Section 2.3.1, upstream steelhead migration is not likely to occur beyond the landslide and waterfall on Arroyo Hondo, 1.8 miles above Arroyo Hondo's confluence with the average high water surface of Calaveras Reservoir. The instability of the slopes adjacent to the waterfall that forms the passage barrier at that location would affect efforts to increase its passability through physical modification (URS, 2009), although the feasibility of providing passage at the landslide has not been evaluated in detail. Based on URS site visits conducted in 2008, tributaries of Arroyo Hondo below the landslide appear to be too ephemeral and steep to provide steelhead spawning habitat, so potential spawning and rearing habitat immediately accessible upstream of Calaveras Dam is confined to the 1.8 miles of the main channel of Arroyo Hondo that lies below the landslide (Figure 2-1).

Not all of the 1.8 miles is suitable for spawning. Habitat surveys conducted in 2006 found this reach consists of 52 percent flatwater, 26 percent pool, and 22 percent riffle by length (SFPUC, 2008c). Pool habitat is dominated by bedrock-enhanced scour pools, and most of the riffles within this reach are low-gradient in nature. This reach has also been described as a moderate-gradient, confined stream with perennial flow, gravel and cobble substrate, and relatively dense riparian vegetation (Hagar, 2008). Rainbow trout currently spawn in this reach, and it is presumably suitable for steelhead as well. If steelhead passage to this reach is established, it is likely that the resident rainbow trout and re-established steelhead population would intermix and become one population. No survey to date has attempted to quantify the extent of suitable spawning habitat in this reach, but presumably it is a portion of the entire 1.8 miles.

Although none of the design components evaluated here would provide access to any habitat other than the 1.8 miles of Arroyo Hondo below the landslide, inaccessible habitat above the landslide also appears suitable for steelhead. Based on aerial survey data collected during the preparation of a report by Entrix Corporation for SFPUC, approximately 8 miles of potential adult spawning and juvenile rearing habitat would be available if adult steelhead were transported to a location upstream of the landslide on Arroyo Hondo, including 5.9 miles that is estimated to be a perennial stream even under dry conditions (City and County of San Francisco, 2003). This estimate is based on the presence of wetted channel, rather than the presence of any specific habitat such as pool, riffle, or run. Subsequently, pedestrian surveys were conducted in Arroyo Hondo in September 2006, from the landslide upstream for approximately 2 miles (Hagar and Payne, 2008). Based on a qualitative evaluation of shelter, substrate size, gradient, and water temperature, the reach appeared suitable for *O. mykiss* (and *O. mykiss* were observed at three locations). Although observed water temperatures were relatively high for this species, coldwater refugia may exist based on the observed presence of rainbow trout.

Despite the presence of suitable habitat, this study does not evaluate trap and haul to locations above the landslide in Arroyo Hondo, for several reasons. While trap and haul to other locations could be accomplished by improving existing roadways, there is no road access between Marsh Road and the landslide (Figure 4-2). The steep walls of the arroyo and confined nature of the valley at this location would make construction of such a road extremely challenging and cost prohibitive. Such construction would result in substantial impacts to sensitive habitats and species, and would degrade the quality of riparian and stream habitat in Arroyo Hondo. The topography that constrains roadway construction also constrains where a fish capture/release facility could be constructed.

While an access road could potentially be built from elsewhere, SFPUC's property does not extend all the way up Arroyo Hondo. Approximately 1.1 miles upstream of the landslide there is a pinch point in the extent of SFPUC's property created by two inholdings, such that 400 feet of the land on both sides of the stream is under private ownership (Figure 2-1). Approximately 0.1 mile upstream of the pinch point SFPUC owns another parcel, but their property entirely gives way to private ownership approximately 2.6 miles upstream of the landslide. In order to access a suitable location for a fish facility upstream of the landslide, various additional stakeholders would need to support construction of a roadway across their land to a suitable location on Arroyo Hondo, and, presumably, support access for ESA-listed steelhead to their property. Evaluating feasibility of a project of that nature, which involves multiple stakeholders, is outside the scope of this study.

4.4 POTENTIAL FOR SUSTAINABILITY

Although the primary scope of this investigation is to assess the feasibility of providing steelhead passage at Calaveras Dam, a preliminary analysis of the potential benefit of passage is also provided (Section 5.2). In this section the potential for establishing a sustainable steelhead population upstream of Calaveras Dam through provision of fish passage at the dam is qualitatively assessed based on literature review of similar passage projects, analysis of existing data, and application of basic ecological theory. While the data required for a detailed assessment of the potential for sustainability are not available, this preliminary analysis evaluates the potential for a steelhead population above Calaveras Dam to achieve sustainability. The assessment considered fish survival during freshwater residency, the amount of spawning and juvenile rearing habitat that passage would make accessible, the ability of adults to immigrate to newly available spawning habitat, the ability of juveniles to emigrate from upstream rearing habitat, and maintaining a minimum viable population size. Because this analysis is focused on fish passage at Calaveras Dam, success is defined as the ability for fish passage and related facilities to maintain a viable population of anadromous steelhead that spawn and rear upstream of Calaveras Dam.

For purposes of this technical memorandum, a sustainable steelhead population upstream of Calaveras Dam is defined as having both a long-term positive spawner replacement ratio and a minimum viable population size. The spawner replacement ratio is an estimation of the number of adult progeny that successfully return and spawn compared to the number of spawners that were used to create them. If more adult fish return in subsequent generations than were used to create them, then there is a positive replacement ratio and allowing fish passage has contributed to an overall increase in the population. If adult returns are smaller than the population used to create them, there is a net negative effect on the population and a negative contribution to overall production. When the replacement ratio is 1:1 the population is in equilibrium. Spawner replacement ratio is expected to vary from year to year based on various life stage survival rates. For example, exceptionally dry years could negatively impact juvenile survival and El Nino events would be expected to decrease ocean survival. In contrast, wet years could enhance juvenile survival and the ability for adults to successfully immigrate. Nevertheless, when averaged across years, a long-term positive spawner replacement ratio would be required for success.

In addition to natural fluctuations in productivity of the population, as described above and further examined in Appendix D, there also are potential reductions in fish production associated with implemented fish passage components. These reductions in productivity may result from reduced capture efficiencies or increased stress related mortalities associated with the handling and transport of fish.

NMFS policy regarding recovery of listed anadromous salmonids requires use of the Viable Salmonid Population concept, which requires establishment of abundance and productivity goals including a long-term spawner replacement ratio of at least 1:1, as well as a minimum viable population size (NMFS, 2000 and 2008). Shaffer (1981) states “a minimum viable population for any given species in any given habitat is the smallest isolated population having a 99 percent chance of remaining extant for 1,000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophes.” A review of the fisheries literature suggests that a minimum viable population size for Pacific salmon, including steelhead, is comprised of at least 100 breeding pairs. Emlen (1993) reports that a complete run failure for Chinook salmon occurs when the population falls below 100 breeding females. A self-sustaining population of rainbow trout in a reservoir system in British Columbia is being created with a “seed” of 100 spawning pairs of fish, based on a literature review of rainbow trout populations by Langston and Zemlak (1998). Facilitating fish passage at Calaveras Dam could potentially produce a minimum viable population of 100 spawning pairs if sufficient adult spawning and juvenile rearing habitat is available to accommodate these fish (see Appendix D for details of this estimate).

Passage directly above Calaveras Dam would only provide access to an estimated 1.8 miles of stream habitat in Arroyo Hondo downstream of the landslide (Section 4.3), so spawning and rearing habitat availability are likely to limit the number of spawning pairs that could be accommodated through provision of passage at Calaveras Dam. Although the exact number of steelhead that might be able to spawn and rear in Arroyo Hondo below the landslide is unknown, the above analysis suggests that maintenance of 100 spawning pairs would be required for the re-established population to be sustainable. The amount of spawning and rearing habitat accessible directly above Calaveras Dam is limited to that within the approximately 1.8 miles of stream habitat in Arroyo Hondo, so the stream would have to support approximately 56 (100 ÷ 1.8) spawning pairs per mile.

Based on the size of the stream relative to other streams where spawning and redd surveys have been conducted, the reach is not likely to support such a high density of spawners. Lagunitas Creek, in Marin County, provides high-quality habitat for salmonids in the San Francisco Bay area. For the past 12 years, salmon and steelhead spawning surveys have been conducted in the Lagunitas Creek watershed, which contains about 18 miles of accessible salmonid habitat (MMWD, 2007). During most years, the watershed supports about 8 to 16 steelhead redds per mile. Redds are concentrated in stream reaches where substrate and flow are favorable. Localized redd densities within favorable reaches have been observed as high as 35 redds per mile during some years. Across different watersheds, redd density is highly variable, depending on individual river and stream characteristics. Maahs and Gilleard (1993) report, for eight coastal Mendocino County streams, that redd (assumed to be mostly steelhead) densities in February range from much less than 1 redd per mile up to approximately 5 redds per mile. Steelhead redd surveys in the much larger, interior Feather River of California during 2003 indicated redd counts of 36 per mile, with nearly all redds concentrated within a few miles of the river system (DWR, 2003). Based on these data we estimate that future steelhead redd density in Arroyo Hondo could potentially range from 1 to 36 per mile.

Given the above estimate of 1.8 miles of accessible, potentially suitable steelhead habitat above Calaveras Dam, and the expectation of between 1 and 36 redds per mile, the habitat above the dam may be capable of supporting between approximately 2 (1 redd/mile x 1.8 miles of habitat) and 65 (36 redds/mile x 1.8 miles of habitat) steelhead redds annually, with the actual value likely being somewhere in between. Based on this estimate, it is unlikely that provision of passage at Calaveras Dam could independently sustain a population of steelhead (see Appendix D).

4.5 ENVIRONMENTAL CONSIDERATIONS

This section discusses non-steelhead environmental considerations related to fish passage at Calaveras Dam and Reservoir. Construction and operation of fish passage would result in some unavoidable adverse environmental impacts. Such impacts are typical when constructing nearly any type of project in natural lands in California, and should not be considered prohibitive, but this would certainly add to the overall cost of providing fish passage. In addition to evaluating the design components as in the previous sections, the environmental impacts associated with construction and operation of the different design components also should be considered before implementing fish passage. Potentially unavoidable impacts would require permitting, minimization, and mitigation.

While the specific impacts of fish passage evaluated in this technical memorandum would be addressed separately in specific permitting documents, the types of impacts that could potentially occur are outlined here.

Potential environmental consequences of implementing fish passage could include:

- Interference with the movement of resident fish species that could affect their sustainability;
- Some localized placement of fill in jurisdictional waters of the United States, including wetlands, that are regulated under the federal Clean Water Act, to construct fish passage facilities and infrastructure;
- Limited loss or degradation of riparian habitats regulated by the CDFG under the Fish and Game Code, at locations where facilities are constructed; and
- Limited loss or degradation of habitats that are potentially used by special status (federally or State listed, or State species of concern), including the California red-legged frog, the foothill yellow-legged frog, the California tiger salamander, and the Alameda whipsnake, at locations where facilities are constructed or roadwork is required.

These potential environmental consequences are described in further detail, below.

The trap and haul of juvenile *O. mykiss* to below Calaveras Dam, which otherwise would have remained resident above the dam, is one potentially unavoidable environmental consequence of fish passage, due to the non-volitional nature of passage design components at the dam. Part of the problem with capture and transport is that juvenile capture facilities could not discriminate between resident trout and anadromous steelhead. Therefore, these facilities would likely result in the capture and transport of resident trout to the release facility below the dam. If a significant portion of *O. mykiss* released below the dam were indeed anadromous steelhead and would likely return to spawn as adults, then this would not likely negatively impact the resident population. If few adults returned for inclusion in the adult immigration phase of passage, however, the relocation of juveniles below the dam could have a negative effect on the existing resident rainbow trout population.

Construction of capture facilities and fish ladders would require the placement of fill material in wetlands and other waters. Road improvements and fish capture facilities would also potentially disturb uplands and riparian areas that may provide cover, and foraging habitat for special-status amphibians and the chaparral and rocky outcrop habitats used by the Alameda whipsnake.

The California red-legged frog, the California tiger salamander, and the Alameda whipsnake are listed as threatened species under the federal Endangered Species Act. Potential impacts to these species might include mortality of amphibian larvae and adults during construction and operation of fish capture facilities. Increased vehicle traffic on roads in the watershed and operation of juvenile capture facilities associated with the trap and haul design component would increase the potential for mortality of these species.

The trap and haul design component would require the construction of juvenile capture facilities above the dam and adult capture facilities below the dam. It is also likely that the trap and haul option would require road improvements in remote portions of the Calaveras Reservoir watershed to improve the efficiency of the hauling operation.

4.6 SELECTION OF PREFERRED DESIGN COMPONENTS

This section will review the remaining, viable design components for each of the steelhead passage elements (i.e., adult immigration, juvenile emigration, and post-spawn adult emigration) and identify the most favorable, based on the analyses in the preceding sections.

4.6.1 ADULT IMMIGRATION

Design components still under consideration for adult immigration include a fish ladder and trap and haul. A fish ladder is favorable due to high capture efficiencies. Although typically associated with volitional fish passage, as stated in Section 4.1, true volitional passage is not feasible at Calaveras Dam because the surface elevation of the reservoir would often be below the spillway crest elevation. In this case, a fish ladder does not have the advantage of purely volitional passage.

Less desirable regarding the fish ladder is the height of this application, which would make it the highest fish ladder in the United States. The height of the ladder introduces concerns regarding the design and ultimate capture efficiency the design component may achieve. Although the engineering challenges of the ladder do not necessarily mean that the ladder is not a viable alternative, the only spawning habitat that a ladder could consistently provide access to is the spawning habitat within the 1.8 river miles of Arroyo Hondo below the landslide, which is not likely to support a self-sustaining steelhead population. While the trap and haul design components evaluated here would access the same habitat, with the trap and haul design components there may be potential to expand access in the future to include the habitat above the landslide in Arroyo Hondo with additional stakeholder involvement. For reasons described in Section 4.3, Habitat Availability, that option was not evaluated in this analysis.

A fish ladder would also be much more expensive than trap and haul (Table 4-2). Trap and haul may be more practical than other design components evaluated for fish passage as this method is widely used and is flexible in the location that fish may be released. Adults should be released at or upstream of the juvenile capture facility as any adult spawning downstream of the facility would result in lost productivity. These considerations suggest that the Calaveras Creek Fish Facility paired with the Calaveras Haul Route provide the best combination of design components for adult immigration passage at Calaveras Dam.

4.6.2 JUVENILE EMIGRATION

Of the viable juvenile fish capture design components, that with the most favorable characteristics for high capture efficiency is the off-channel tributary fish capture screen. The capture efficiencies of surface flow collectors are lower and would likely result in a low overall productivity of the re-established population. Additionally, the surface flow collector is likely to be much more expensive than the off-channel tributary fish capture screen. For these reasons, the Arroyo Hondo Fish Facility is the preferred design component for capturing emigrating juveniles.

The physical location selected for the off-channel tributary fish capture screen in the Arroyo Hondo tributary is important both to the capture efficiency and operation of this design component as well as to the potential amount of adult spawning and juvenile rearing habitat available to the re-established population. The off-channel screen requires physical space to be available outside of the channel and floodplain for construction as well as a channel cross section that is suitable for an inflatable dam or weir for flow diversions into the facilities. The facilities will also require road access for facilities construction and maintenance, and for captured juvenile fish transport. The habitat below the facility is effectively lost for spawning and juvenile rearing to the re-established population. Therefore, the fish capture facilities would need to be located as far downstream in the tributary as possible while still meeting these criteria. A more detailed review of the tributary site conditions would need to be conducted to refine the site suitability options, but any effective loss of the already limited 1.8 miles of stream habitat would be a potentially substantial reduction in overall habitat capacity and therefore viability of the re-established population.

Of the juvenile fish transport design components considered, truck transport is the only one that is still viable. It appears to have the most favorable characteristics and would be compatible with the adult upstream trap and haul design component. Juveniles should be released at the adult capture facility in Calaveras Creek (below the dam) in order to maximize imprinting on the natal tributary and reduce straying rates upon adult return. Based on selection of the Calaveras Creek and Arroyo Hondo fish facilities as preferred design components for capturing adult and juvenile steelhead, respectively, the Calaveras Haul Route would be the best design component for linking these two locations.

4.6.3 POST-SPAWN ADULT EMIGRATION

No design components have been identified that are likely to be successful in recapturing the surviving adult spawners. Passage projects identified with steelhead as the target fish species are at run-of-the-river dams with static water surface elevations that allow for volitional downstream movement of the steelhead. The Calaveras Dam is a water supply and storage reservoir with fluctuating water surface elevations that does not accommodate volitional downstream passage. How the inability to successfully capture and transport individuals that exhibit this characteristic, which by way of repeat spawning contribute disproportionally to the composition of future generations, would affect overall productivity and sustainability of the run is unknown. No precedent for passage that would result in surviving steelhead spawners being trapped in a reservoir was identified during this study. It is unknown whether these fish would survive in Calaveras Reservoir or if they did, whether they would be able to spawn again. If they did survive, they would be potential predators that could reduce juvenile survival rates.

5 FISH PASSAGE OPTION AND ANALYSIS

This section examines the potential for success of fish passage for steelhead in conjunction with the replacement of Calaveras Dam. Section 5.1 identifies the most suitable combination of potential fish passage design components, or a fish passage option, as developed in Section 4. In Section 5.2, the potential goals and success criteria for fish passage are used to evaluate the likelihood for success and sustainability of the fish passage option.

5.1 FISH PASSAGE OPTION DESCRIPTION

Based on the analyses of all of the design components identified to provide for the three elements of steelhead passage (adult immigration, juvenile emigration, and post-spawn adult emigration), the preferred design components for passing immigrating adults and emigrating juveniles both involve trapping the migrating fish and hauling them to an appropriate release point. None of the design components identified were considered suitable for providing passage for emigrating adults that had survived spawning.

As identified in this memorandum, a Calaveras Road Trap and Haul fish passage option at Calaveras Dam would include the following three design components:

- Calaveras Creek Fish Facility
- Calaveras Haul Route
- Arroyo Hondo Fish Facility

Immigrating adult steelhead would be captured at the Calaveras Creek Fish Facility, located on Calaveras Creek, below Calaveras Dam, and below the boulder debris field (Figure 4-2). Arriving fish would be transported along the Calaveras Haul Route to their release point at or above the Arroyo Hondo Fish Facility. Emigrating juveniles would be collected with an off-channel fish capture screen at the Arroyo Hondo Fish Facility and trucked via the Calaveras Haul Route to a release location on Calaveras Creek, below the dam.

5.2 EVALUATION OF FISH PASSAGE OPTION

This section of the report reviews the characteristics of the fish passage option described above and evaluates the factors affecting the ability of that option to meet the fish passage goals and success criteria.

In the evaluation of passage, it is important to note that fish passage is almost always “technically” feasible. That is, it is almost always possible to catch fish and relocate them, given sufficient financial investment, engineering determination, and organizational commitment. Perhaps more important is whether the cost, including the time, money, and loss of these resources for other efforts, as well as unintended effects on non-target fishes and other environmental consequences, is worth the benefits that fish passage achieves. Given that fish passage is almost always technically feasible, it is important to focus the evaluation of fish passage on the ability or likelihood of successfully meeting the biological goals of fish passage, as opposed the simple physical movement of fish.

As outlined in Section 3, the typical goals of fish passage are to:

- Provide access to additional quantity of habitat to increase natural production;
- Contribute to species recovery through increased overall natural production;
- Provide access to historical habitat;

- Protect or enhance the genetic integrity and/or distinctness of stocks; and
- Reduce risk of extinction through increased natural production and creation of additional independent populations.

In this section, the fish passage option described in Section 5.1 is evaluated for its ability or likelihood to meet these goals.

5.2.1 PROVIDE ACCESS TO ADDITIONAL QUANTITY OF HABITAT TO INCREASE NATURAL PRODUCTION

As described in Sections 2.3 and 4.3, due to migration barriers above Calaveras Dam the total amount of stream habitat directly accessible above the dam is 1.8 miles in length. That limited amount of potential habitat would be reduced further by the constraints of the location of the potential juvenile fish capture facility. The quantity of habitat available directly above the dam is limited and its size would limit the potential number of pairs that could spawn there. This would result in a high cost to fish benefit ratio, and would impact the productivity of the population as described below. Alternative measures in support of CCC steelhead that provide access to greater quantity of habitat may have a better chance of achieving the goal described above, and may deliver a higher benefit-to-cost ratio.

5.2.2 CONTRIBUTE TO SPECIES RECOVERY THROUGH INCREASED NATURAL PRODUCTION

In addition to natural limitations on population productivity, such as smolt survival rates, mortality that may occur as a result of fish passage must also be considered. Each capture, handling and transport event during both juvenile downstream and adult upstream fish passage is likely to injure or kill a certain percentage of the fish involved, increasing mortality rates to levels above those experienced naturally. Failure to capture some fish at each stage of migration would be the equivalent of additional mortality, because those fish would not be able to contribute to the productivity of the re-established steelhead population.

Factors affecting the potential overall productivity of fish passage for steelhead at the replacement Calaveras Dam include:

- Potential loss of production contribution from post-spawn adult survivors or potential loss of rearing juveniles to predation if the post-spawn adult survivors are able to recover and survive in the tributary or reservoir.

- Juvenile fish capture efficiency in Arroyo Hondo may be sub-optimal due to the flashy nature of flow regimes. Juveniles tend to emigrate on peak flows and some flow events may exceed the screening capacity of the facilities resulting in reduced fish capture efficiency.

- Other passage related productivity losses could include ladder efficiency for the adult capture facility (less than a 3 percent loss), adult transport and juvenile transport (both less than 1 percent loss), and increased adult prespawn mortality rates attributable to capture, holding, transport and release stress.

Passage design components should maximize capture efficiency and minimize stress due to handling, as practicable, in order maximize production and increase the potential for fish passage at Calaveras Dam to result in a long-term spawner replacement ratio of greater than 1 (see Section 4.4).

5.2.3 PROVIDE ACCESS TO HISTORICAL HABITAT

Steelhead were historically present in the Alameda Creek Watershed, although population estimates are not available (Leidy et al., 2005). The presence of a possible fish migration barrier, a waterfall on Calaveras Creek below Calaveras Dam (see Section 2.3.2, Calaveras Creek), raises some questions about the frequency at which habitat above Calaveras Dam was historically accessible to immigrating steelhead. This waterfall (Figure 2-1) is associated with a bedrock section of stream channel that is resistant to erosion (URS and HDR, 2009; URS, 2009). While quarry activities conducted in the last century may have contributed to the observed debris in the reach, the largest barrier to passage is a bedrock outcrop not related to quarry activity.

It is unknown how long the 12-foot waterfall has existed in its current configuration. Given the height of the waterfall, and depending on the configuration of the stream channel, the tributary reaches above this feature may have only been intermittently accessible to steelhead during high flow events. The previous frequency of flows of magnitudes sufficient to make this feature passable is unknown.

5.2.4 PROTECT OR ENHANCE THE GENETIC INTEGRITY AND/OR DISTINCTNESS OF STOCKS

While the steelhead historic migration route has been blocked for decades, rainbow trout in Arroyo Hondo likely retain some of the unique genetic character of native steelhead (Nielsen, 2003; Garza and Pearse, 2008). Facilitating fish passage could potentially introduce some out-of-basin genetic stocks to upper Alameda Creek. Considering the number of hatchery steelhead produced in the Central Valley, there is a potential for some fish from the California Central Valley DPS to stray into Alameda Creek. If fish passage is implemented, it could be initiated with juvenile fish being transported downstream for release, and the upstream component be initiated only when the first juvenile release cohort return to spawn. This strategy would minimize the proportion of out-of-basin, stray steelhead that would be moved to above Calaveras Dam, thereby minimizing introduction of foreign genes into the upstream population, but it is uncertain whether juveniles from the resident rainbow trout population released below Calaveras Dam will undergo smoltification or migrate to the ocean. Alternatively, passage could be initiated by transporting adults that successfully immigrate as far as the Calaveras Creek Fish Facility to a location above the dam, as it may be fish that reach the capture location are indeed the coastal steelhead that passage would aim to establish above Calaveras Dam. In either case, maintaining a population of at least 100 breeding pairs of steelhead in the Alameda Creek Watershed should allow for adequate within-basin genetic diversity. Meffe and Carroll (1997) report that some level of gene flow among connected populations is desirable. Some low level of straying may even increase the genetic diversity and fitness of the population.

The rainbow trout population above Calaveras Dam has been more or less genetically isolated since at least the construction of the dam. However, rainbow trout from Alameda Creek have the potential to be entrained in the Alameda Creek Diversion Tunnel, transported to Calaveras Reservoir, and mix with the rainbow trout population below the Arroyo Hondo landslide. The population below the landslide is also supplemented by production that occurs above the slide. Given that Arroyo Hondo and Alameda Creek historically converged several miles downstream, the degree to which these two populations are divergent may be limited. If there is divergence, the rainbow trout population below the landslide may share the genetics of both the Arroyo Hondo population above the slide and the Alameda Creek fisheries, and the fish above the Arroyo Hondo slide may be more likely to exhibit unmixed genetic stocks (although their isolation may also have resulted in genetic drift and a reduction in genetic fitness [Campbell et al., 1999]). Also, stocked fish may have mixed with native populations above Calaveras Dam, although there is some evidence that stocking has had little effect on the genetic composition of most San Francisco Estuary stream *O. mykiss* (Nielsen, 2003; Garza and Pearse, 2008). Due to these considerations, if passage is to be implemented, further study should be initiated to evaluate which population, genetic stocks, and life stages should be included initially.

The existing adfluvial rainbow trout population will also be affected by fish passage. There is no method to differentiate a juvenile resident rainbow trout from a juvenile steelhead, so fish that would not have volitionally emigrated to the ocean will be transported downstream below the dam. This non-volitional transport of juveniles could affect the productivity and viability of the resident rainbow trout population.

5.2.5 REDUCE RISK OF EXTINCTION THROUGH INCREASED NATURAL PRODUCTION AND CREATION OF ADDITIONAL INDEPENDENT POPULATIONS

Facilitating fish passage at Calaveras Dam is unlikely to create an additional, independent population of steelhead, although it may supplement the existing CCC steelhead DPS. Passage directly above Calaveras Dam would only provide access to 1.8 miles of stream habitat (see Section 4.3). As described in Section 4.4, the 1.8-mile reach of Arroyo Hondo between the reservoir high pool and the first impassable barrier is unlikely to support 100 pairs of steelhead spawners, the estimated number of spawning pairs sufficient to create a sustainable population. This assertion is based on a review of available literature and imposition of professional judgment, rather than any direct quantification of spawning habitat or measure of current rainbow trout spawning behavior in Arroyo Hondo. A detailed spawning habitat survey would need to be conducted to assess with greater accuracy whether the available habitat in this reach could support a minimum viable population size for a sustainable steelhead population.

While passage at Calaveras Dam would not likely provide sufficient spawning and rearing habitat to indefinitely sustain an independent population, it would increase steelhead habitat availability in the Alameda Creek Watershed. If steelhead are re-established at other locations in the watershed, then habitat made available by passage at Calaveras Dam could be evaluated for its integrative value to the Alameda Creek Watershed steelhead metapopulation. Historically, steelhead likely spawned in streams throughout the watershed. Access to some of these streams may have occurred intermittently depending on annual hydrologic conditions or the state of various migration obstacles, and subpopulations within the watershed may have historically augmented each other following years of limited production in select reaches. Therefore, facilitating access to habitat upstream of the Calaveras Dam could potentially augment a steelhead metapopulation in the Alameda Creek Watershed. This benefit to a metapopulation could potentially exist even if the productivity of the population above Calaveras Dam was low in some years, or was insufficient to sustain itself without contributions from other occupied habitats in the Alameda Creek Watershed. Meffe (1997) states that management of endangered or threatened wild populations "should be consistent with the history of their genetic patterns and processes. For example, historically isolated populations should remain isolated unless other concerns [e.g., threat of extinction] dictate that gene flow must occur." Meffe also states that "Gene flow among historically connected populations should continue at historical rates, even if that calls for assisted movement of individuals."

6 CONCLUSION

Facilitating steelhead passage at Calaveras Dam would provide access to a limited amount of spawning and rearing habitat above Calaveras Dam. However, based on this preliminary analysis, an effort to reestablish steelhead in the 1.8 mile reach of Arroyo Hondo, in and of itself, has a low probability of success. This assessment of the low probability for success is mostly due to the inability to provide volitional passage and limitations in the quantity of accessible habitat available directly above Calaveras Dam to support a minimum viable population size. Without a minimum viable population size, passage would fail to create an independent population, one of the key goals of fish passage (see Section 5.2).

Calaveras Dam is a water supply and storage reservoir with fluctuating water surface elevations. A fish ladder on the downstream face of the dam would lead to the dam crest, but a lift would be required on the upstream face of the dam to lower the fish to the reservoir water surface elevation, preventing adult immigration from being volitional. A ladder in this configuration would not provide passage for emigrating juveniles, so juveniles would have to be collected and hauled to a release point below Calaveras Dam. A fish ladder at Calaveras Dam would likely be over 2,000 feet long and have a height of more than 290 feet, making it taller than any fish ladder in the United States. The total order-of-magnitude capital cost of a fish ladder at Calaveras Dam was estimated to be over $40 million, and the cost of providing fish passage via a combination of a fish ladder for immigrating adult steelhead and trap and haul for emigrating juvenile steelhead, annualized over 30 years, and including annual water costs, was estimated at approximately $7 million per year.

Given the high cost of providing fish passage via a fish ladder at Calaveras Dam, the inability to provide volitional passage with a fish ladder, and the multiple stages at which handling would be involved in the fish ladder passage option, trap and haul for both immigrating adult and emigrating juvenile steelhead is the only potentially feasible option for fish passage at Calaveras Dam. No feasible means of successfully capturing post-spawn adult steelhead was identified. Although comparatively feasible, collection of emigrating juveniles in Arroyo Hondo could prove challenging, due to the flashy nature of the flows in that creek. The total order-of-magnitude capital cost of the design components that would be involved in the trap and haul option is estimated to be approximately $25 million. The order-of-magnitude annual cost of passage via trap and haul for both immigrating adults and emigrating juveniles is estimated at approximately $1.4 million per year.

The low probability of success for fish passage at Calaveras Dam is not based on technical restrictions alone, as it is technically feasible to provide passage for immigrating adult steelhead and emigrating juvenile steelhead. Although the Arroyo Hondo Basin is relatively large, the presence of an upstream fish migration barrier 1.8 miles above Calaveras Reservoir would severely limit the spawning and rearing habitat available to steelhead if they are transported above Calaveras Dam. The instability of the slopes adjacent to the waterfall that forms the primary passage barrier at that location would significantly affect any efforts to facilitate passage through physical modification. Habitat availability is a primary limiting factor for the potential success of fish passage at Calaveras Dam.

The integrative value of habitat above Calaveras Dam to a steelhead metapopulation could be evaluated in conjunction with other efforts to restore steelhead to the Alameda Creek Watershed, as well as broader efforts to recover the CCC steelhead DPS. However, given the inability to provide volitional passage, the cost of passage, and the limited spawning and rearing habitat that would be made accessible, alternative measures in support of CCC steelhead recovery that have a greater benefit to cost ratio should be investigated prior to implementation of fish passage at Calaveras Dam.

7 REPORT PREPARATION

This section presents a list of document preparers and acknowledges others who contributed to this technical memorandum.

7.1 LIST OF PREPARERS

This technical memorandum was prepared with the participation of professional scientists and engineers from URS, HDR|SWRI, HDR| FishPro's Fishery Design Center, and SFPUC.

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Steve Leach, URS Corporation – Senior Project Biologist responsible for task management and editorial review of this memorandum.

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Julie Pietrzak, URS Corporation – Civil Engineer responsible for developing the cost estimate and screen concepts in this memorandum.

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Gregory Reichert, URS Corporation – Senior Project Engineer responsible for technical review of engineering and cost elements of this memorandum.

William Snider, HDR|SWRI **–** Fisheries Biologist supporting coordination and review of this memorandum.

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Appendix A

Fish Ladder Technical Information

To design a fish ladder that will be most effective for target fish, species-specific criteria must be taken into consideration. In *Design of Fishways and Other Fish Facilities,* Clay (1995) reported essential fish ladder design criteria for salmonids. According to Clay (1995), the most appropriate entrance velocity for a fish ladder designed for adult Pacific salmon is 4 feet per second, with acceptable entrance velocities falling between 4 and 8 feet per second. No entrance velocity data specific to adult steelhead are available. The preferred depth of the entrance reportedly is at least 4 feet but can differ depending on site conditions (Clay, 1995). Pacific salmon are able to handle velocities (in slots over weirs) of up to 8 feet per second, with a preferred head difference between pools of one foot. Another important consideration, reported by Clay (1995), is that a minimum space per fish is required. In the case of salmonids, approximately 0.2 ft^3/lb of fish is needed (Clay, 1995).

An important aspect of fish ladder operation and performance is the ability to draw fish into the ladder once they reach the general area below the entrance (Coutant, 2001). One method for increasing the likelihood that fish will enter the ladder is to use auxiliary water to make the flow out of the fish ladder as noticeable as possible at the greatest distance without obtaining velocities that prevent fish from entering. The creation of flow to draw fish into the fish ladder is referred to as attraction flow because the increased water velocities through the ladder stimulate fish to progress upstream against these velocities (Clay, 1995). Clay (1995) indicates that a velocity of approximately 4 feet per second is generally an accepted standard for creating an attraction flow for salmonid species. However, the turbulence of the river system should be considered during the design of the ladder when determining the magnitude of attraction flows. High turbulence tends to reduce the effectiveness of attraction flow, but it is suspected that even the strongest fish cannot safely maneuver through a ladder at velocities approaching 8 feet per second for an extended period of time (Clay, 1995). Because flows exiting a fish ladder at the Calaveras Dam would comprise a significant portion of total stream flow, approach velocities likely would not be an issue in ladder design.

If a fish ladder is constructed at Calaveras Dam, it would most likely be the pool and weir ladder type if steelhead are the only target species. If passage for lamprey is deemed necessary, however, the weir and orifice variation or the vertical slot variation would likely be selected. Construction footprints and costs of the three fish ladder types are similar. The following sections provide an overview of the three most common fish ladder design variations:

- pool and weir
- pool and orifice
- vertical slot

<u>Type 1 – Pool and Weir Fish Ladder</u>

The pool and weir fish ladder is the oldest and most widely used fish ladder design. The design consists of a series of rectangular pools that are separated by walls or baffles that act as weirs. Depending on the swimming capabilities and behavior of the target species, as well as hydraulic modeling data and field experience, the drop between pools typically varies from 4 to 18 inches, although is frequently around 12 inches. The hydraulic behavior of this type of fish ladder is determined by pool dimensions and the weirs separating pools (Larinier, 2000; USACE, 1996).

The weirs separating the ladder pools control the water level in each pool. Flow through the ladder occurs by surface overflow as water spills from one pool to the next lower pool. Fish gradually ascend the fish ladder by leaping over the pool wall, or baffle. The pools offer resting areas for the fish as well as ensure adequate energy dissipation of the water to allow for safe passage. Depending on the swimming ability of the target species, pool and weir ladders can be designed to allow flow to move through one or more notches or slots throughout the fish ladder or the design can allow for flow to move over the entire baffle (Larinier, 2000; USACE, 1996).

Type 2 – Weir and Orifice Fish Ladder

The weir and orifice fish ladder is a variation of the pool and weir design with submerged orifices incorporated into the pool baffles. A primary difference between the two designs is the location of the transition area between successive pools, which, with the orifices, is located at or near the bottom of the baffle rather than near the top at a weir (USACE, 1996).

The orifices are sized according to the target fish species and are either aligned to keep fish moving with the least interference or offset to reduce flow through the facility (Clay, 1995; USACE, 1996). According to Clay (1995), typical pool dimensions for this type of fish ladder would be a length of six times the width of the orifice diameter and a width of four times the width of the orifice diameter and a suggested 18-inch drop between pools.

The design of this type of fish ladder allows water to flow over the weirs as well as through the orifices. Therefore, fish are able to ascend this type of ladder by moving over the pool walls, as they would in the pool and weir design, or through the orifices in the baffles. The size and shape of the orifices should be appropriate for the target species, but an additional factor to consider is that orifice size should also be determined by restrictions on discharge and velocity set by the system. Weir and orifice fish ladders reportedly better accommodate other species that are less likely to jump over obstacles (Clay, 1995; USACE, 1996), such as lamprey which may be pertinent to Alameda Creek in the future.

Type 3 – Vertical Slot Fish Ladder

The vertical slot fish ladder, also referred to as "Hells Gate" fish ladder, which is a type of "pool and jet" fish ladder, has the basic design of the weir and orifice fish ladder except that the orifices extend over the full height of the pool wall. The slope of these fish ladders typically is set at 10 percent (Clay, 1995; USACE, 1996).

Vertical slot fish ladders consist of baffles between the walls of the flume that act to turn the flow back upstream in order to obtain efficient energy dissipation. Vertical slot ladders allow fish to move through the baffles rather than over them, allowing fish that are less likely to be able to leap over the baffles of a ladder to use them. An additional characteristic of this type of ladder is that the slot in the pool wall typically has a width of 18 inches in diameter and can accommodate passage by larger species.

The vertical slot fish ladder design is a variation on the pool and weir design that does not have flow over the baffles, which also is similar to the weir and orifice design except with the orifices reaching the full height of the baffle (Clay, 1995; USACE, 1996).

NMFS *Anadromous Salmonid Passage Facility Guidelines and Criteria* includes criteria and guidance for the design of fish ladders for adult fish passage (NMFS, 2003). Design guidelines are presented for the ladder entry, pool dimensions, and flows, and the exit of the fish ladder passage system. NMFS guidelines suggest that the attraction flow from a fish ladder entrance should be between 5 and 10 percent of high design passage flows for streams with mean annual discharges exceeding 1,000 cubic feet per second. Fish ladder entrance heads are to be maintained between 1 to 1.5 feet. The shape of fish ladder entrances is dependent upon attraction flow requirements. However, the entrance should be at least 6 feet deep and 4 feet wide. Entrances should have downward closing slide gates, unless prior approval has been given by NMFS. Staff gates also should be included in the design of the fish ladder entrance for determination of whether entrance head criterion is being met (NMFS, 2003). Fish ladder design criteria by NMFS (2003) also specify that the water velocity between the fish ladder entrance and the first weir, as well as over submerged weirs, must be a minimum of 1.5 feet per second. Other fish ladder design criteria include a maximum hydraulic drop of 12 inches per pool and a minimum depth of 12 inches over ladder overflow weirs. Additionally, NMFS suggests that the fish ladder pool volume be a minimum of:

$$V \geq \frac{\gamma \mathrm{QH}}{4\mathrm{ft\text{-}lbs/s}}$$

where:
V = pool volume, in ft^3
γ = unit weight of water, 62.4 pounds (lb) per ft^3
Q = fish ladder flow, in ft^3/s
H = energy head of pool-to-pool flow, in feet

Fish ladder pools must be at least double in length if they are a turning pool, located at position in the fish ladder where a bend of 90 degrees occurs. Orifices also should be at least 15 inches high and 12 inches wide, and the freeboard of the ladder pools shall be at least 5 feet high (NMFS, 2003).

Specific design criteria have been established for the exit of a fish ladder, although some aspects depend upon the type of ladder design. The hydraulic drop in the exit control section of the fish ladder should range from 0.5 to 1.0 foot per pool. The exit channel upstream from the exit control section also must be a minimum of two standard ladder pool lengths. The ladder exit also should be located in a low velocity zone of less than 4 feet per second, preferably along a shoreline (NMFS, 2003).

Appendix B

Cost Estimate Backup Calculations

Each fish passage design component carried forward through the preliminary analysis was analyzed further based on its cost. This appendix describes the development of raw capital costs (Table B-1) and operating and maintenance costs (Table B-2) for each design component. Raw capital cost and operating and maintenance cost assumptions are outlined on the following pages.

Table B-1
Summary of Costs for Design Components

Description	Cost
Spillway Fish Ladder	$20,880,000
Roadway Fish Ladder	$23,660,000
Arroyo Hondo Fish Facility	$1,810,000
Calaveras Creek Fish Facility	$800,000
Calaveras Haul Route	$5,720,000
Oak Ridge Haul Route	$10,040,000
Corral Point Haul Route	$2,470,000
Surface Flow Collector	$9,100,000

Table B-1
Summary of Costs for Design Components (Continued)

ID	Description	Quantity	Unit	Unit Cost ($)	Amount ($)	Assumptions
Spillway Fish Ladder						
1.0	**Fish Ladder Structure**					LF = 3,950 LF
	Fish Ladder Entrance	1	LS	150,000.00	150,000	
	Dewatering	1	LS	100,000.00	100,000	
	Low Flow Channel Excavation	180	CY	80.00	14,400	425 LF
	Excavation for Trench below Spillway	1,800	CY	80.00	144,000	8’ W x 4’ D x 1,500 LF
	Concrete for Trench below Spillway	1,800	CY	800.00	1,440,000	8’ W x 1.5’ D x 3,950 LF
	Side Forms in Spillway Base	79,000	SF	50.00	3,950,000	5’ x 4 sides x 3,950 LF
	Wall Concrete	2,950	CY	1,000.00	2,950,000	1’ W x 10’ H x 2 sides x 3,950 LF
	Cross Walls	1,500	CY	1,200.00	1,800,000	6’ L x 10’ H x 1’ W at 6’ O.C.
	Steel Plate	3,950	LF	600.00	2,370,000	8’ W × 1.5’
	Miscellaneous Metals	1	LS	1,500,000.00	1,500,000	
	Fish Ladder Exit	1	LS	150,000.00	150,000	
2.0	**Fish Lock Structure**					
	Excavation	740	CY	80.00	59,200	777 to 730’ = 423 SF × 47’
	Gates	1	LS	1,000,000.00	1,000,000	
	Concrete Control Structure	360	CY	1,200.00	432,000	
3.0	**Mobilization, Overhead and Fee (O&F) Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	4,817,880.00	4,817,880	
	Total Raw Cost (April 2009 Dollars)				**$20,877,480**	

Table B-1
Summary of Costs for Design Components (Continued)

ID	Description	Quantity	Unit	Unit Cost ($)	Amount ($)	Assumptions
Roadway Fish Ladder						
1.0	**Fish Ladder Structure**					3,650 LF
	Fish Ladder Entrance	1	LS	150,000.00	150,000	
	Dewatering	1	LS	100,000.00	100,000	
	Excavation	3,250	CY	80.00	260,000	8' W x 3' D x 3,650 LF
	Base of Fish Ladder Box	1,650	CY	800.00	1,320,000	8' W x 1.5' D x 3,650 LF
	Side Forms of Fish Ladder Box	73,000	SF	50.00	3,650,000	5' x 4 sides x 3,650 LF
	Walls Concrete	2,700	CY	1,000.00	2,700,000	1' W x 10' H x 2 sides x 3,650 LF
	Cross Walls	1,350	CY	1,200.00	1,620,000	6' L x 10' H x 1' W at 6' O.C.
	Miscellaneous Metals	1	LS	1,400,000.00	1,400,000	
	Fish Ladder Exit	1	LS	150,000.00	150,000	
2.0	**Fish Lock Structure**					
	Excavation (Additional)	740	CY	80.00	59,200	777 to 730’ = 423 SF × 47’
	Gates	1	LS	1,000,000.00	1,000,000	
	Concrete Control Structure	360	CY	1,200.00	432,000	
3.0	**Roadway**					
	Excavation	16,750	CY	80.00	1,340,000	18’ × 9’ /2 × 27 + 2 CY/LF
	Excavation for Paving and Paving Material	3,650	LF	100.00	365,000	
	Retaining Walls	3,650	LF	1,000.00	3,650,000	
4.0	**Mobilization, Overhead and Fee Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	5,458,860.00	5,458,860	
	Total Raw Cost (April 2009 Dollars)				**$23,655,060**	

Table B-1 Summary of Costs for Design Components (Continued)						
ID	**Description**	**Quantity**	**Unit**	**Unit Cost ($)**	**Amount ($)**	**Assumptions**
Arroyo Hondo Fish Facility						
1.0	**Off Channel Fish Screen**					
	Excavation for Canal	330	CY	80.00	26,400	50' W x 3' D x 60' L
	Dewatering	1	LS	65,000.00	65,000	
	Base of Canal for Flow Diversion	170	CY	800.00	136,000	50' W x 1.5' D x 60' L
	Side Walls of Canal for Flow Diversion	30	CY	1,000.00	30,000	2 - 6' H x 1' W x 60' L
	Weir	35	CY	1,200.00	42,000	Concrete - 50' L
	Fish Screen	2	EA	150,000.00	300,000	10’ H x 37.5’ L
	Debris Rack	1	LS	500,000.00	500,000	50' long
2.0	**Holding Pool**					
	Base of Holding Pool	5	CY	800.00	4,000	8' W x 1.5' D x 10' L
	Side Walls of Holding Pool	10	CY	1,000.00	10,000	4 - 6' H x 1' W x 10' L
	Screen	1	EA	150,000.00	150,000	10' x 10' - predation screen
	Flow Pipes	150	LF	150.00	22,500	24" dia. culverts
	Flow Screens	2	EA	50,000.00	100,000	
3.0	**Loading Area**					
	Prepare Subgrade	100	SY	30.00	3,000	
	Asphalt Surfacing Plus Base	100	SY	65.00	6,500	
4.0	**Mobilization, Overhead and Fee Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	418,620.00	418,620	
	Total Raw Cost (April 2009 Dollars)				**$1,814,020**	

Table B-1
Summary of Costs for Design Components (Continued)

ID	Description	Quantity	Unit	Unit Cost ($)	Amount ($)	Assumptions
Calaveras Creek Fish Facility						
1.0	**Diversion Structure**					
	Excavation	100	CY	80.00	8,000	10' W x 5' H x 50' L
	Dewatering	1	LS	65,000.00	65,000	
	Weir	100	CY	1,200.00	120,000	40' L x 8' H
2.0	**Fish Ladder Structure**					
	Excavation	55	CY	80.00	4,400	8' W x 3' H x 60' L
	Base of Fish Ladder Box	20	CY	800.00	16,000	6' x 1.5' x 60' L
	Side Forms of Fish Ladder Box	1,200	SF	50.00	60,000	5' x 4 sides x 60 LF
	Wall Concrete	30	CY	1,000.00	30,000	1' W x 6' H x 2 sides x 60 LF
	Cross Walls	15	CY	1,200.00	18,000	6' L x 6' H x 1' W at 6' O.C.
3.0	**Holding Pool**					
	Base of Holding Pool	5	CY	800.00	4,000	8' W x 1.5' H x 10' L
	Side Walls of Holding Pool	10	CY	1,000.00	10,000	4 sides x 6' H x 1' W x 10' L
	Screen	1	EA	150,000.00	150,000	10' x 10' - predation screen
	Flow Pipes	150	LF	150.00	22,500	24" dia. culverts
	Flow Screens	2	EA	50,000.00	100,000	
4.0	**Loading Area**					
	Prepare Subgrade	100	SY	30.00	3,000	
	Asphalt Surfacing Plus Base	100	SY	65.00	6,500	
5.0	**Mobilization, Overhead and Fee Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	1851,220.00	185,220	
	Total Raw Cost (April 2009 Dollars)				**$802,620**	

Table B-1 Summary of Costs for Design Components (Continued)						
ID	**Description**	**Quantity**	**Unit**	**Unit Cost ($)**	**Amount ($)**	**Assumptions**
Calaveras Haul Route						
1.0	**Roadway**					Total Length = 15 miles
	Prepare Subgrade	39,500	SY	30.00	1,185,000	5.6 miles long × 12' wide
	Asphalt Surfacing Plus Base	39,500	SY	65.00	2,567,500	5.6 miles long × 12' wide
	Safety	15,800	LF	15.00	237,000	Assume 3 miles of guardrail
	Drainage	1	LS	300,000.00	300,000	
2.0	**Transport**					
	Full Size, Modified Pickup Truck	1	EA	60,000.00	60,000	
	Transport Tank	1	EA	4,100.00	4,100	
	Creek Access Ramp	1	LS	50,000.00	50,000	
3.0	**Mobilization, Overhead and Fee Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	1,321,080.00	1,321,080	
	Total Raw Cost (April 2009 Dollars)				**$5,724,680**	

Table B-1
Summary of Costs for Design Components (Continued)

ID	Description	Quantity	Unit	Unit Cost ($)	Amount ($)	Assumptions
Oak Ridge Haul Route						
1.0	**Roadway**					Total Length = 10.5 miles
	Prepare Subgrade	69,000	SY	30.00	2,070,000	9.8 miles long × 12' wide
	Asphalt Surfacing Plus Base	69,000	SY	65.00	4,485,000	9.8 miles long × 12' wide
	Safety	37,000	LF	15.00	555,000	Assume 7 miles of guardrail
	Drainage	1	LS	500,000.00	500,000	
2.0	**Transport**					
	Full Size, Modified Pickup Truck	1	EA	60,000.00	60,000	
	Transport Tank	1	EA	4,100.00	4,100	
	Creek Access Ramp	1	LS	50,000.00	50,000	
3.0	**Mobilization, Overhead and Fee Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	2,317,230.00	2,317,230	
	Total Raw Cost (April 2009 Dollars)				**$10,041,330**	

Table B-1
Summary of Costs for Design Components (Continued)

ID	Description	Quantity	Unit	Unit Cost ($)	Amount ($)	Assumptions
Corral Point Haul Route						
1.0	**Roadway**					Total Length = 3 miles
	Prepare Subgrade	16,200	SY	30.00	486,000	2.3 miles long × 12’ wide
	Asphalt Surfacing Plus Base	16,200	SY	65.00	1,053,000	2.3 miles long × 12’ wide
	Safety	5,300	LF	15.00	79,500	1 mile of guardrail
	Drainage	1	LS	120,000.00	120,000	
2.0	**Transport**					
	Full Size, Modified Pickup Truck	1	EA	60,000.00	60,000	
	Transport Tank	1	EA	4,100.00	4,100	
	Excavation	1	LS	50,000.00	50,000	
	Creek Access Ramp	1	LS	50,000.00	50,000	
3.0	**Mobilization, Overhead and Fee Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	570,780.00	570,780	
	Total Raw Cost (April 2009 Dollars)				**$2,473,380**	
Surface Flow Collector						
1.0	**Surface Flow Collector**					
	Gulper System	1	LS	7,000,000.00	7,000,000	Based on Baker Dam Gulper System
2.0	**Mobilization, Overhead and Fee Allowance**					
	Contractor Mobilization and O&F Allowance (30%)	1	LS	2,100,000.00	2,100,000	
	Total Raw Cost (April 2009 Dollars)				**$9,100,000**	

Table B-2
Estimated Annual O&M Costs

Description	Cost
Spillway Fish Ladder	$269,868
Roadway Fish Ladder	$297,668
Calaveras Creek Fish Facility	$74,000
Arroyo Hondo Fish Facility	$127,297
Surface Flow Collector	$200,197
Calaveras Haul Route	$57,200
Oak Ridge Haul Route	$100,400
Corral Point Haul Route	$24,700

Table B-2 Estimated Annual O&M Costs (Continued)					
Item	**Quantity**		**Unit Cost**	**Amount**	**Total**
Spillway Fish Ladder					
Labor					**$61,068**
Maintenance person labor cost (average 3.0 hrs/day)	0.38	FTE	133,500	50,730	
Seasonal fish technician direct labor cost (average 3.0 hrs/day for 120-day peak immigration period)	0.12	FTE	63,900	7,668	
Annual inspections and maintenance labor cost (assume 2 people for 3-day period)	0.01	FTE	267,000	2,670	
Material Costs					**$208,800**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		41,760,000	208,800	
Total Annual O&M Costs					**$269,868**
Roadway Fish Ladder					
Labor[1]					**$61,068**
Maintenance person direct labor cost (average 3.0 hrs/day)	0.38	FTE	133,500	50,730	
Seasonal fish technician direct labor cost (average 3.0 hrs/day for 120-day peak immigration period)	0.12	FTE	63,900	7,668	
Annual inspections and maintenance labor cost (assume 2 people for 3-day period)	0.01	FTE	267,000	2,670	
Material Costs					**$236,600**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		47,320,000	236,600	
Total Annual O&M Costs					**$297,668**

Table B-2
Estimated Annual O&M Costs (Continued)

Item	Quantity		Unit Cost	Amount	Total
Calaveras Creek Fish Facility					
Labor					**$66,294**
Fisheries biologist labor cost (average 4.0 hrs/day for 5-month operating period)	0.21	FTE	133,500	28,035	
Driver/Maintenance person labor cost (average 4.0 hrs/day for 5-month operating period)	0.21	FTE	133,500	28,035	
Seasonal technician labor cost (average 4.0 hrs/day for 120-day peak immigration period)	0.16	FTE	63,900	10,224	
Material Costs					**$8,000**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		1,600,000	8,000	
Total Annual O&M Costs					**$74,294**
Arroyo Hondo Fish Facility					
Labor					**$109,197**
Fisheries biologist labor cost (average 8.0 hrs/day for 4-month operating period)	0.33	FTE	133,500	44,055	
Driver/Maintenance person labor cost (average 8.0 hrs/day for 4-month operating period)	0.33	FTE	133,500	44,055	
Seasonal technician labor cost (average 8.0 hrs/day for 120-day peak immigration period)	0.33	FTE	63,900	21,087	
Material Costs					**$18,100**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		3,620,000	18,100	
Total Annual O&M Costs					**$127,297**
Surface Flow Collector					
Labor					**$109,197**
Fisheries biologist labor cost (average 8.0 hrs/day for 4-month operating period)	0.33	FTE	133,500	44,055	
Driver/Maintenance person labor cost (average 8.0 hrs/day for 4-month operating period)	0.33	FTE	133,500	44,055	

Table B-2
Estimated Annual O&M Costs (Continued)

Item	Quantity		Unit Cost	Amount	Total
Seasonal technician direct labor cost (average 8.0 hrs/day for 120-day peak immigration period)	0.33	FTE	63,900	21,087	
Material Costs					**$91,000**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		18,200,000	91,000	
Total Annual O&M Costs					**$200,197**
Calaveras Haul Route[1]					
Material Costs					**$57,200**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		11,440,000	57,200	
Total Annual O&M Costs					**$57,200**
Oak Ridge Haul Route[1]					
Material Costs					**$100,400**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		20,080,000	100,400	
Total Annual O&M Costs					**$100,400**
Corral Point Haul Route[1]					
Material Costs					**$24,700**
Estimated at 0.5% of total capital cost (see Table 4-2)	0.005		4,940,000	24,700	
Total Annual O&M Costs					**$24,700**

Notes:
Labor costs include fringe and overhead (3.0 multiplier assumed).

FTE = full time equivalent
O&E = operation and maintenance
[1] All labor for trap and haul is included in fish facility O&M estimates.

Appendix C

Arroyo Hondo – Alameda Creek Flow Model Development

At the time this model was developed the hydrologic record for upper Alameda Creek (U.S. Geological Survey [USGS] Gage Station 11172945) extended from 1995 to 2004. This is a relatively short period of record and may not accurately characterize the temporal distribution of unimpaired flows that could potentially occur above the Alameda Creek Diversion Dam (ACDD). To more accurately predict the frequency and magnitude of unimpaired flows that could potentially be available during the diversion period (November through April), a synthetic hydrology was produced using the unimpaired mean daily flows recorded at the Arroyo Hondo gage (USGS 11173200) from 1969 to 1981 and 1995 to 2004 (no flow data are available for the 1982 through 1994 period). The purpose of this model is to estimate potential water yields from upper Alameda Creek over a broader range of hydrologic conditions by extending the period of record from 10 years to 24 years.

As would be expected in adjoining basins, the correlation between the frequency and duration of flow increases and decreases between upper Alameda Creek and Arroyo Hondo for the November-through-April period from 1995 through 2004 are similar despite differences in drainage area above the flow gages between the two watersheds (approximately 21,000 acres above the gage on Alameda Creek above ACDD and approximately 49,000 acres above the gage on Arroyo Hondo). Three distinct annual water yield volumes for upper Alameda Creek were selected to illustrate similarities in the frequency and duration of flows occurring in upper Alameda Creek and Arroyo Hondo from the November-through-April period for the 10-year period of record at the upper Alameda Creek gage. For both creeks, the lowest flows were observed in 2001, the highest flows were observed in 1998, and the second-highest flows were recorded in 1997 (Figures C-1, C-2, and C-3).

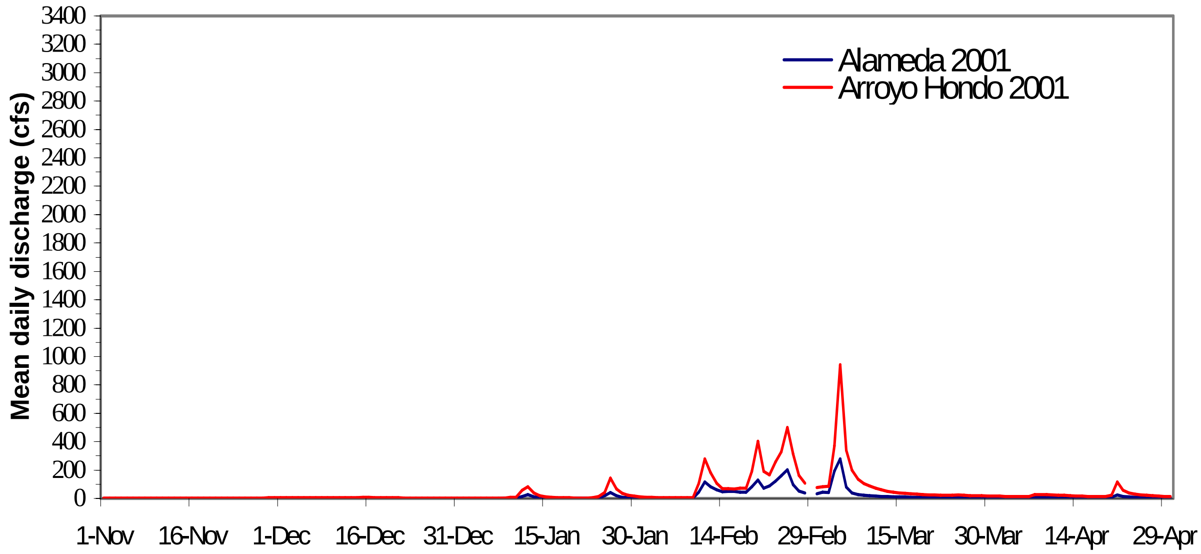

Figure C-1 Flows Recorded at the Upper Alameda Creek Gage (USGS 11172945) and Arroyo Hondo (USGS 11173200), April through November, 2001

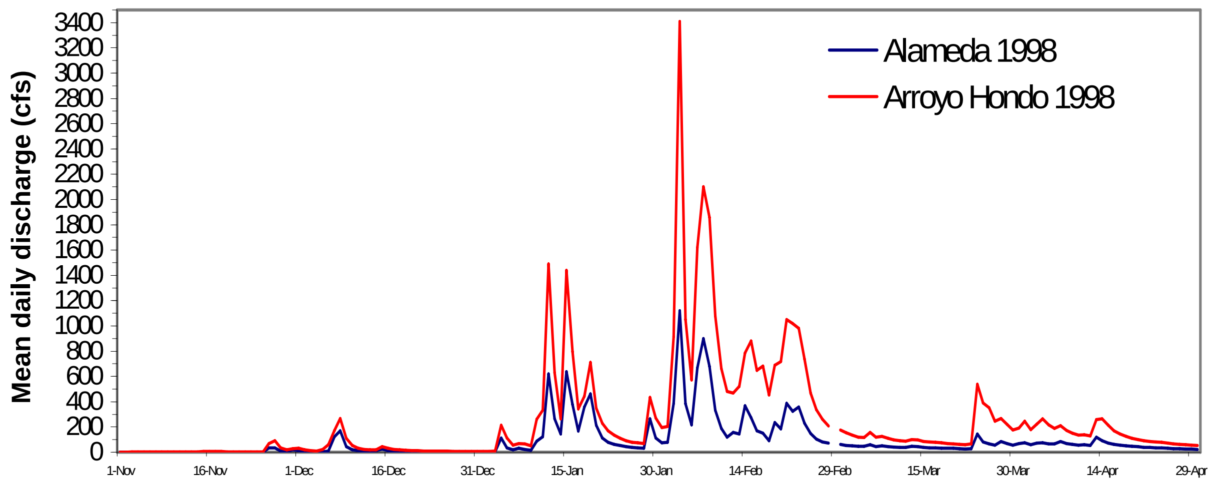

Figure C-2 Flows Recorded at the Upper Alameda Creek Gage (USGS 11172945) and Arroyo Hondo (USGS 11173200), April through November, 1998

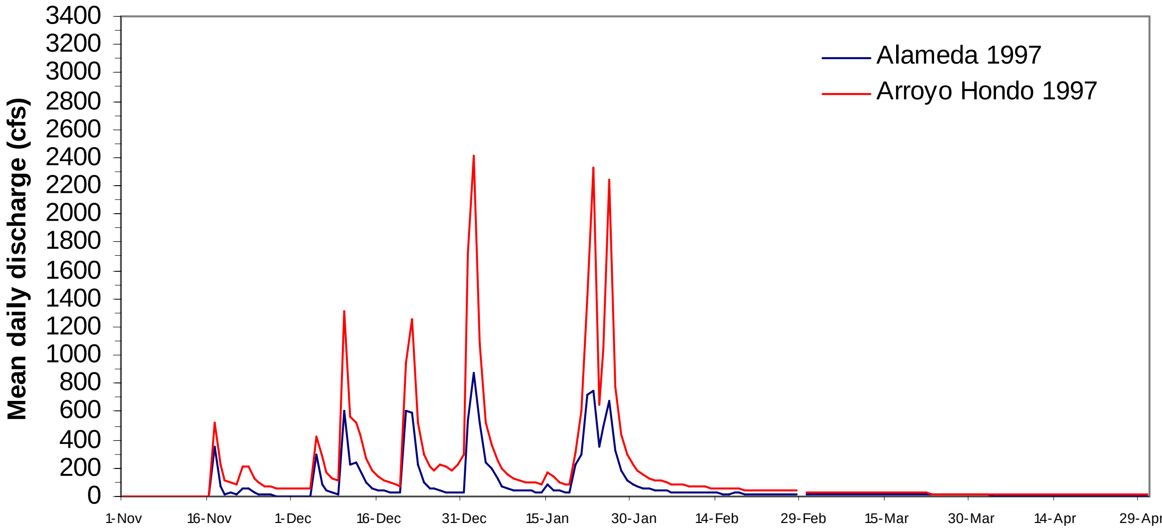

Figure C-3 Flows Recorded at the Upper Alameda Creek Gage (USGS 11172945) and Arroyo Hondo (USGS 11173200), April through November, 1997

Alameda Creek mean daily flows (in cubic feet per second [cfs]) from USGS 11172945 were expressed as functions of Arroyo Hondo mean daily flows (cfs) from USGS 11173200 for the period 10/1/94 through 9/30/04 in which mean daily flows are available at both gages (N = 3,653). Twenty models were fitted to this data to select a "best" fit model that can be used to predict mean flows at Alameda Creek from Arroyo Hondo mean daily flows for the periods 10/1/68 through 9/30/81 and 10/1/94 through 9/30/04 (N = 8,401).

Because the range of Arroyo Hondo mean daily flows was broader during the periods 10/1/68 through 9/30/81 and 10/1/94 through 9/30/04 (i.e., 0.11 – 3,580 cfs) than during the period used in model fitting (i.e., 0.21 – 3,580 cfs), only models capable of describing the general pattern of the 1994–2004 data without predicting negative values within the 0.11 to 3,580 cfs flow range were chosen to fit to the 1994–2004 data.

Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002) was used to select the best fit out of 20 different models used to characterize the relationship between mean daily flows in Alameda Creek and

Arroyo Hondo. The deterministic components of the 20 chosen models are expressed by the following equations, where *X* are the Arroyo Hondo mean daily flows, and *Y* are the Alameda Creek mean daily flows.

Model 1: $Y = \alpha + \beta \times X$

Model 2: $$Y = \begin{cases} \beta \times X, & \text{if } X \le \dfrac{-\delta}{(\phi - \beta)} \\ \delta + \phi \times X, & \text{if } X > \dfrac{-\delta}{(\phi - \beta)} \end{cases}$$

Model 3: $Y = \beta \times (X/1,000) + \delta \times (X/1,000)^2$

Model 4: $Y = \beta \times (X/1,000) + \delta \times (X/1,000)^2 + \phi \times (X/1,000)^3$

Model 5: $Y = \beta \times (X/1,000) + \delta \times (X/1,000)^2 + \phi \times (X/1,000)^3 + \gamma \times (X/1,000)^4$

Model 6: $Y = \beta \times (X/1,000) + \delta \times (X/1,000)^2 + \phi \times (X/1,000)^3 + \gamma \times (X/1,000)^4 + \eta \times (X/1,000)^5$

Model 7: $Y = \beta \times (X/1,000) + \delta \times (X/1,000)^2 + \phi \times (X/1,000)^3 + \gamma \times (X/1,000)^4 + \eta \times (X/1,000)^5 + \varphi \times (X/1,000)^6$

Model 8: $Y = \alpha \times (1 - \exp(-\beta \times X))^{\phi}$

Model 9: $Y = \alpha \times X \times \exp\left(-\beta \times X^{\delta}\right)$

Model 10: $$Y = \frac{\alpha \times X}{(1 + \beta \times X)^{\delta}}$$

Model 11: $$Y = \frac{\alpha}{(1 + \exp(\beta - \delta \times X))^{1/\phi}}$$

Model 12: $Y = \alpha \times \exp(-\exp(\beta - \delta \times X))$

Model 13: $$Y = \alpha \times \left(1 - \exp\left(\frac{-X^{\beta}}{\delta^{\beta}}\right)\right)$$

Model 14: $Y = \alpha - \beta \times \exp\left(-\delta \times X^{\phi}\right)$

Model 15: $Y = \alpha \times X^{\beta}$

Model 16: $Y = \alpha + \beta \times \ln(X + \delta)$

Model 17: $Y = \alpha \times \left(\frac{X}{\beta + X} \right)$

Model 18: $Y = \frac{\alpha + \beta \times X^{\delta}}{\phi + \gamma \times X^{\eta}}$

Model 19: $Y = \alpha - \beta \times \delta^{X}$

Model 20: $Y = \left(\alpha - \beta \times X^{\delta} \right) \times \left(1 - \exp\left(-\phi \times X \right) \right)^{\gamma}$

These models were fitted to the 1994–2004 data using least squares, assuming that the residuals are normally distributed with mean 0 and standard deviation σ. **Table C-1** displays the values of the parameter estimates, the estimated standard deviation of the residuals:

$$(\hat{\sigma} = \sqrt{\sum_{i=1}^{N} residual_i \Big/ N})$$

as well as the coefficient of determination (r^2) of the fits for the 20 models.

The best of the 20 fitted models was selected using Akaike's Information Criteria (*AIC*). *AIC* was calculated using the formula:

$$AIC = N \times \ln\left(\hat{\sigma}^2 \right) + 2 \times K \text{ (Burnham and Anderson, 2002),}$$

where K is the number of estimated parameters, and N is the sample size (i.e., $N = 3{,}653$). $\hat{\sigma}^2$ was estimated as the square of $\hat{\sigma}$.

Table C-2 displays the *AIC* for the 20 fitted models, together with the *AIC* differences (i.e., ΔAIC_i), the model likelihoods (i.e., Λ_i) and the relative model probabilities or Akaike's weights (i.e., w_i). The model selected as the best model for the data out of the 20 models corresponds to the model whose fit produced the smallest *AIC*. The *AIC* differences were calculated as $\Delta AIC_i = AIC_i - \min\left(AIC \right)$, while the model likelihoods were calculated as:

$$L_i \ \alpha \ \exp\left(-\frac{1}{2} \times \Delta AIC_i \right)$$

and the Akaike's weights as:

$$w_i = L_i \Big/ \sum_{i=1}^{20} L_i$$

These three additional quantities provide an insight on the relative performance of each fitted model within the set of 20 chosen models.

Table C-1
Parameter Estimates (α, β, δ, … φ), Estimated Standard Deviation of the Residuals (σ) and Coefficient of Determination (r^2) for Models 1 through 20

Model #	1	2	3	4	5	6	7	8	9	10
α	2.975049							1466.574	0.54162	0.543218
β	0.403938	0.50693	513.7127	545.5698	518.8926	504.6668	456.7227	0.000392	0.000452	0.000241
δ		157.0493	-58.8984	-107.484	-28.5329	37.6201	361.519		0.867958	0.866488
ϕ		0.294126		12.8433	-38.8836	-116.483	-704.497	1.033065		
γ					9.107153	41.53868	461.9796			
η						-4.38543	-132.714			
φ							13.98496			
σ	28.502	25.240	25.395	25.233	25.174	25.163	25.078	25.261	25.294	25.269
r^2	89.61%	91.86%	91.76%	91.86%	91.90%	91.91%	91.96%	91.84%	91.82%	91.84%
Model#	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
α	759.6594	759.9175	1468.419	1447.333	1.075529	-8864.22	2711.217	0.000867	-29016.9	543.3766
β	-5.55747	1.412449	1.023939	1447.333	0.865079	1157.901	5009.693	0.000793	-29020.1	-0.00279
δ	0.002533	0.002529	2620.058	0.000316		2111.945		1.33372	1.013714	1.508866
ϕ	0.000936			1.026675				0.005707		0.001421
γ								4.75E-05		1.202162
η								0.798152		
φ										
σ	32.174	32.166	25.267	25.268	26.161	25.271	25.269	25.097	28.785	25.060
r^2	86.77%	86.77%	91.84%	91.84%	91.25%	91.84%	91.84%	91.95%	89.41%	91.97%

Table C-2
Number of Estimated Parameters (k), Akaike's Information Criteria (AIC), AIC Differences (ΔAIC_i), Model Likelihoods (Λ_i), and the Relative Model Probabilities or Akaike's Weights (w_i) for Models 1 through 20.

Model #	*k*	*AIC*	ΔAIC_i	Λ_i	w_i
1	3	24,480.9	934.4	1.2727E-203	0.000
2	4	23,594.9	48.4	3.09021E-11	0.000
3	3	23,637.8	91.3	1.51974E-20	0.000
4	4	23,592.8	46.3	8.89275E-11	0.000
5	5	23,577.7	31.2	1.69582E-07	0.000
6	6	23,576.5	30.0	3.08977E-07	0.000
7	7	23,553.9	7.4	0.024393928	0.024
8	4	23,600.9	54.4	1.52383E-12	0.000
9	4	23,610.6	64.1	1.20723E-14	0.000
10	4	23,603.2	56.7	4.78382E-13	0.000
11	5	25,370.2	1,823.7	0	0.000
12	4	25,366.4	1,819.9	0	0.000
13	4	23,602.8	56.3	5.90299E-13	0.000
14	5	23,604.9	58.4	2.04703E-13	0.000
15	3	23,854.9	308.4	1.09276E-67	0.000
16	4	23,604.0	57.5	3.22527E-13	0.000
17	3	23,601.4	54.9	1.18256E-12	0.000
18	7	23,559.5	13.0	0.00149855	0.001
19	4	24,555.2	1,008.7	9.2001E-220	0.000
20	6	23,546.5	0	1	0.975

With an *AIC* equal to 23,546.5, model 20 was selected as the best model of the set (Table C-2). The model 20 regression is described by the following equation:

$$Y = \left(543.3766 + 0.00279 \times X^{1.50887}\right) \times \left(1 - \exp\left(-0.00142 \times X\right)\right)^{1.20216},$$

with residual errors assumed to be distributed as $\hat{\varepsilon} \sim N\left(0,\ 25.05957\right)$.

Figure C-4 displays the observed Alameda Creek mean daily flows as a function of the Arroyo Hondo mean daily flows in the 10/1/94–9/30/04 period (circles) together with the flows predicted by model 20 (line). The standard error, σ, is equal to 25.1 and the correlation coefficient, r2, is equal to 0.92 (Table C-1).

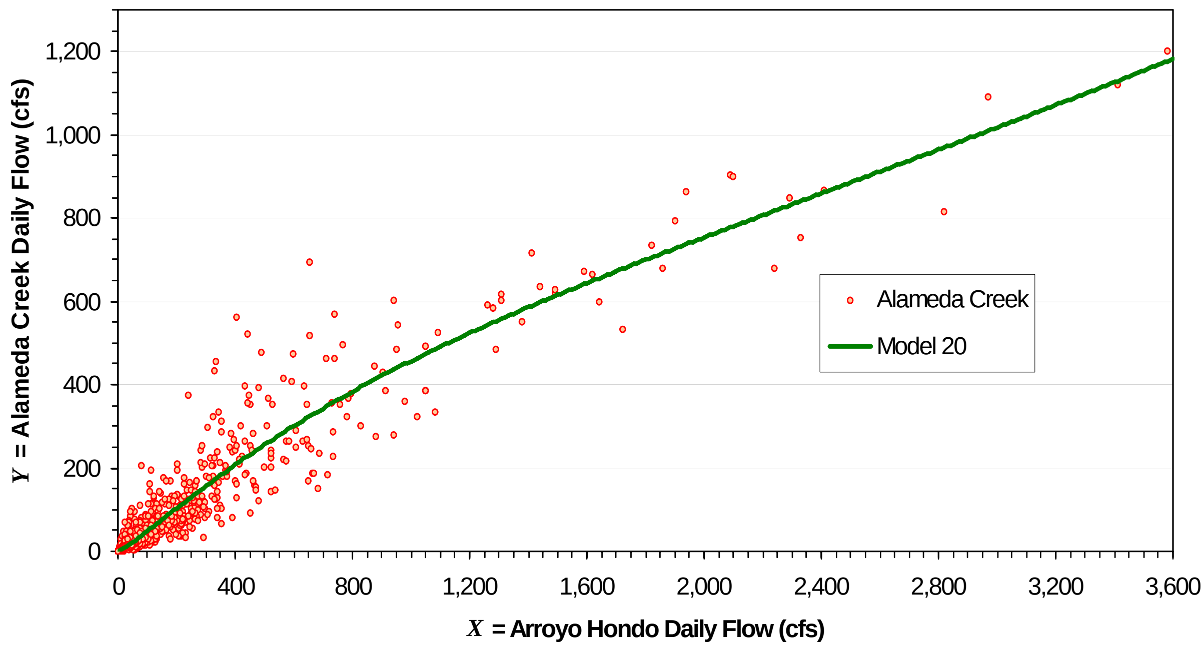

Figure C-4 Observed Flows in Arroyo Hondo and Alameda Creeks with Model Prediction Line

The equation from model 20 depicted in the graph in Figure C-1 was used to produce a synthetic hydrology for upper Alameda Creek for the 1969-through-1981 and 1995-through-2004 time periods. **Figures C-5 through C-14** give a graphical depiction and comparison of daily means for flows observed in Alameda Creek compared to the model-predicted flows for Alameda Creek during water years from 1995 through 2004.

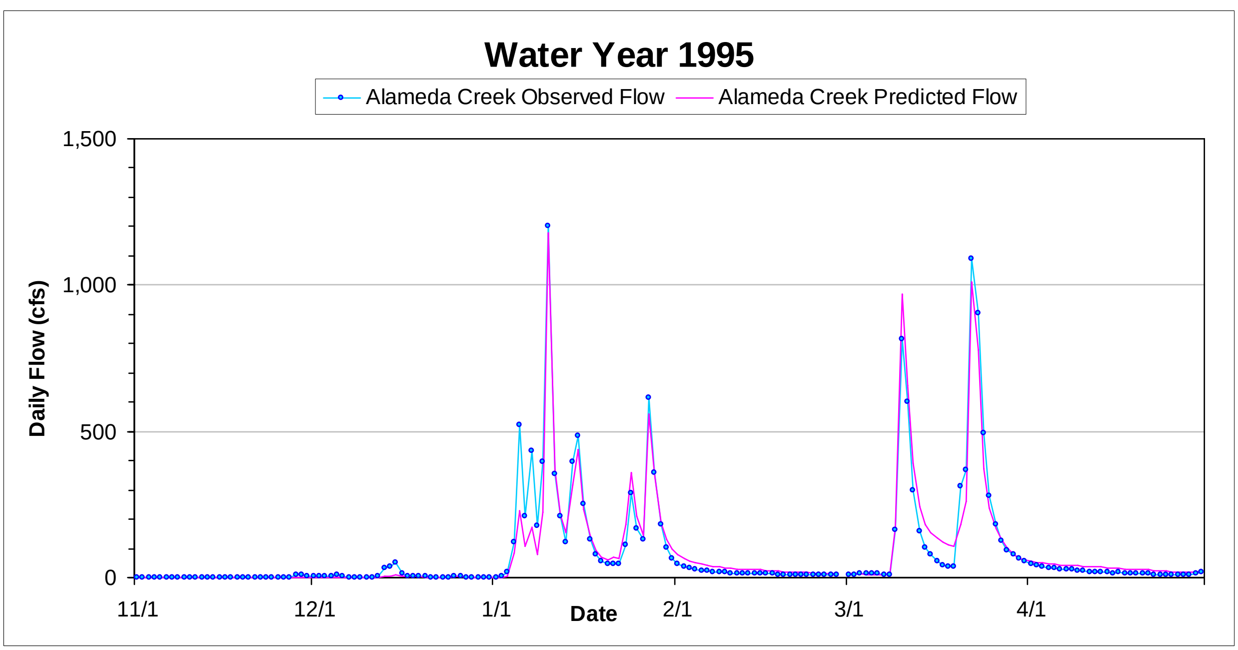

Figure C-5 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 1995

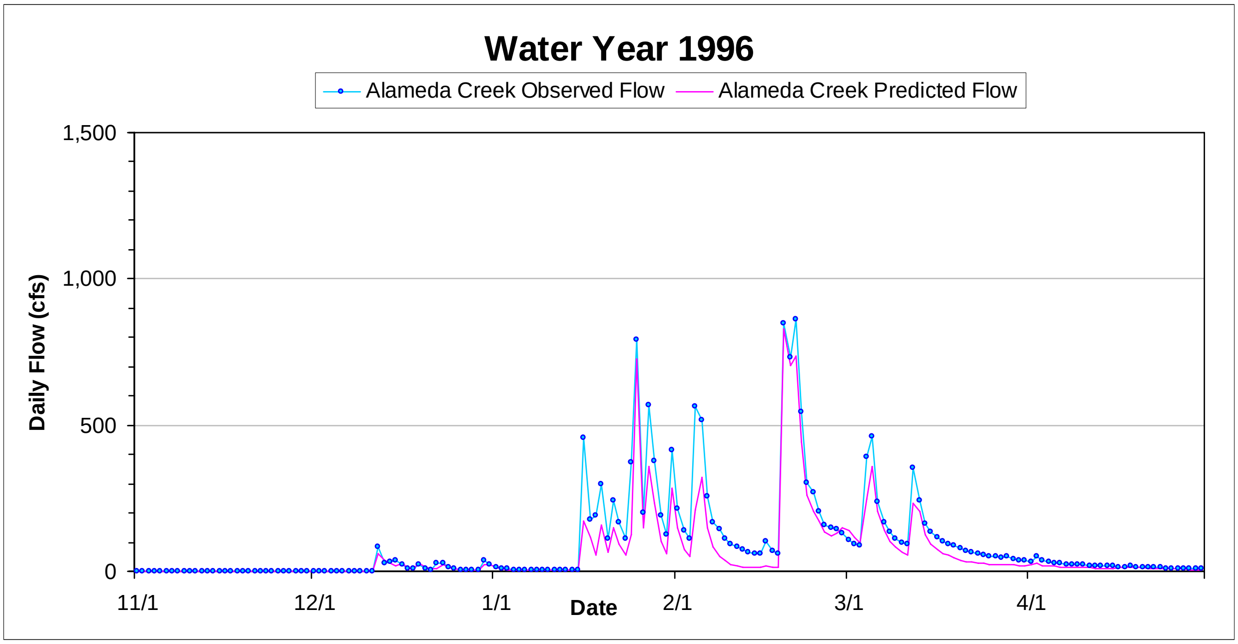

Figure C-6 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 1996

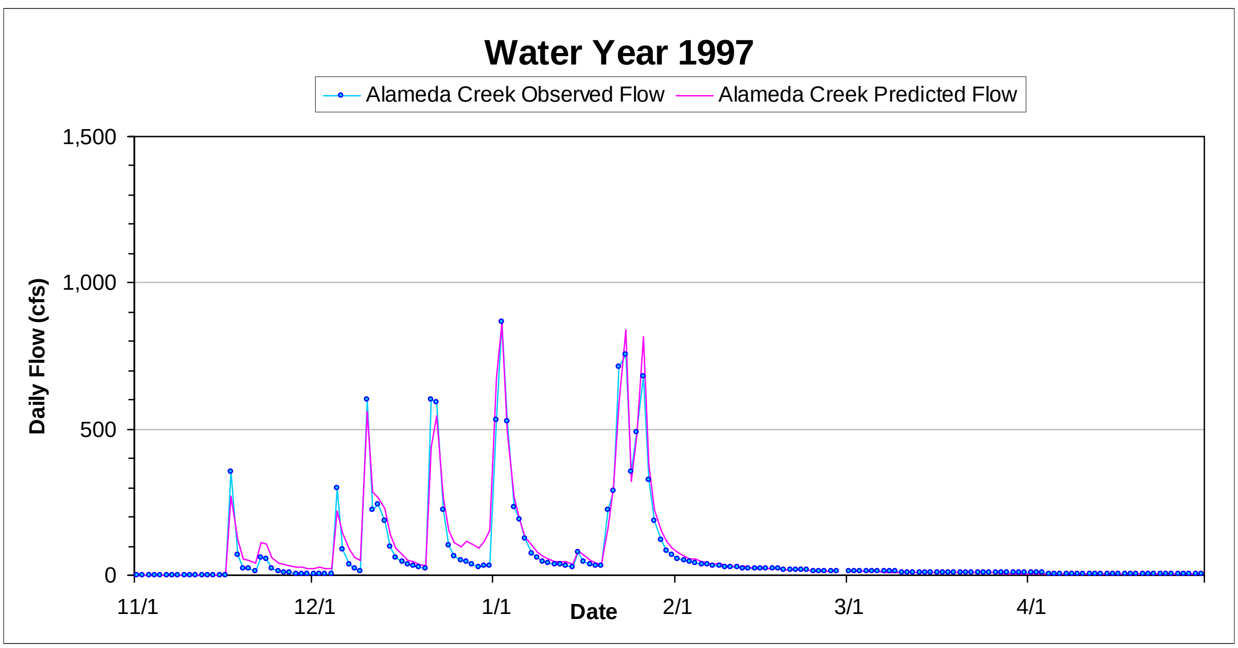

Figure C-7 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 1997

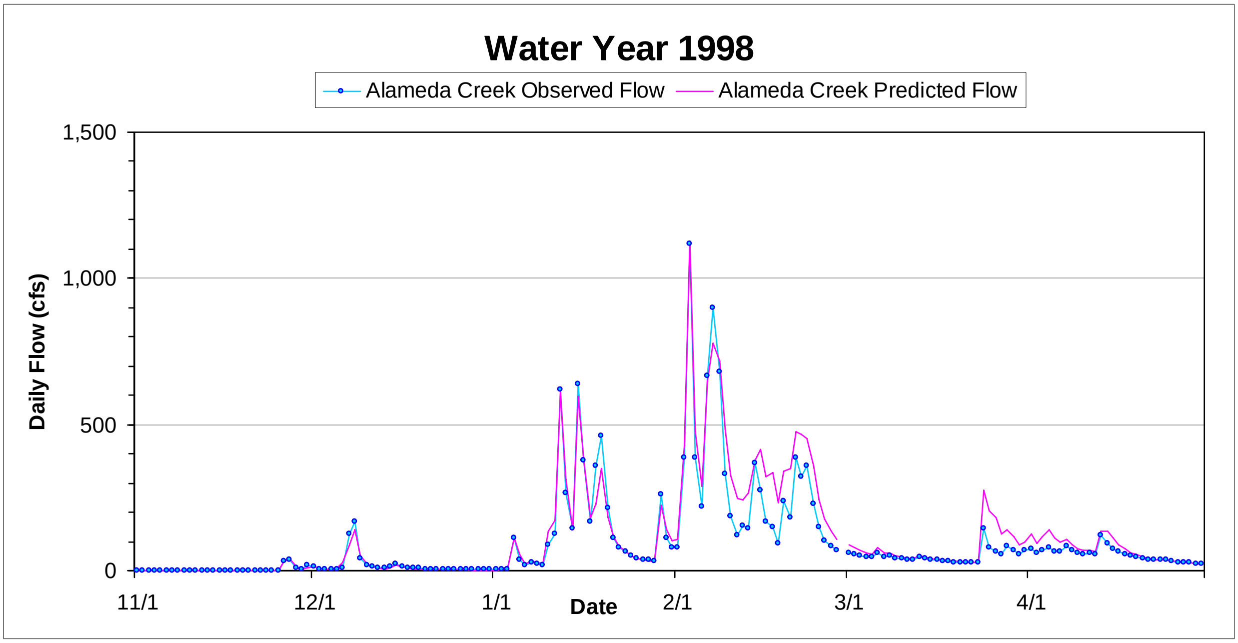

Figure C-8 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 1998

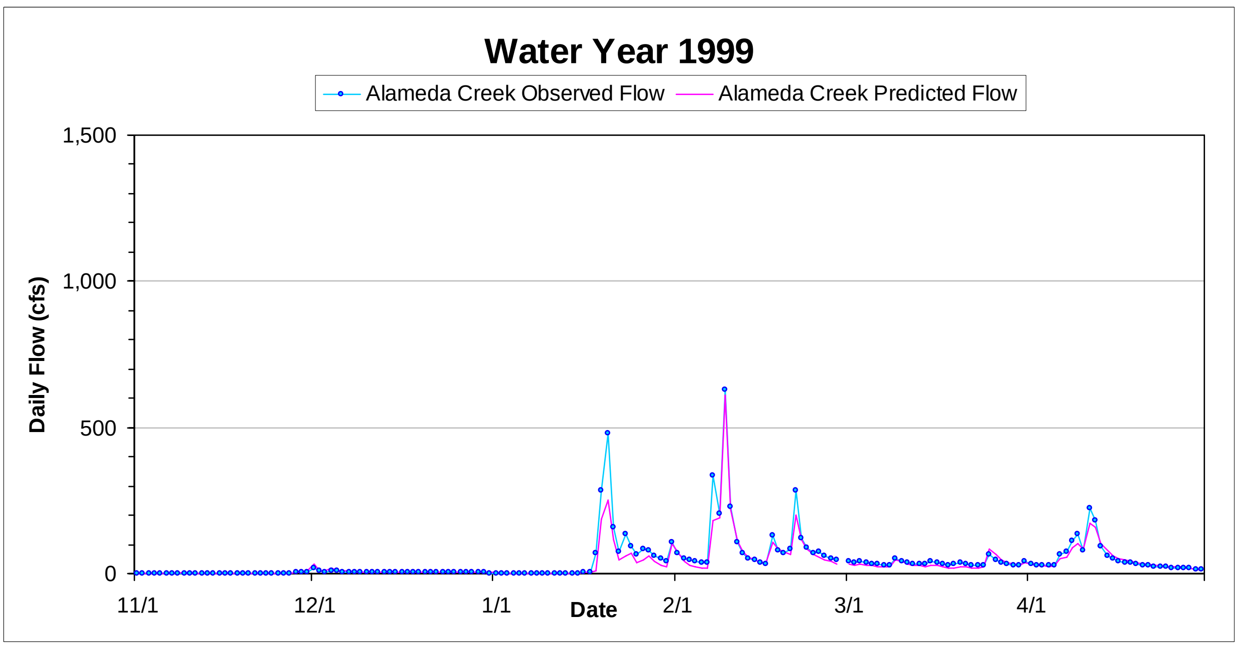

Figure C-9 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 1999

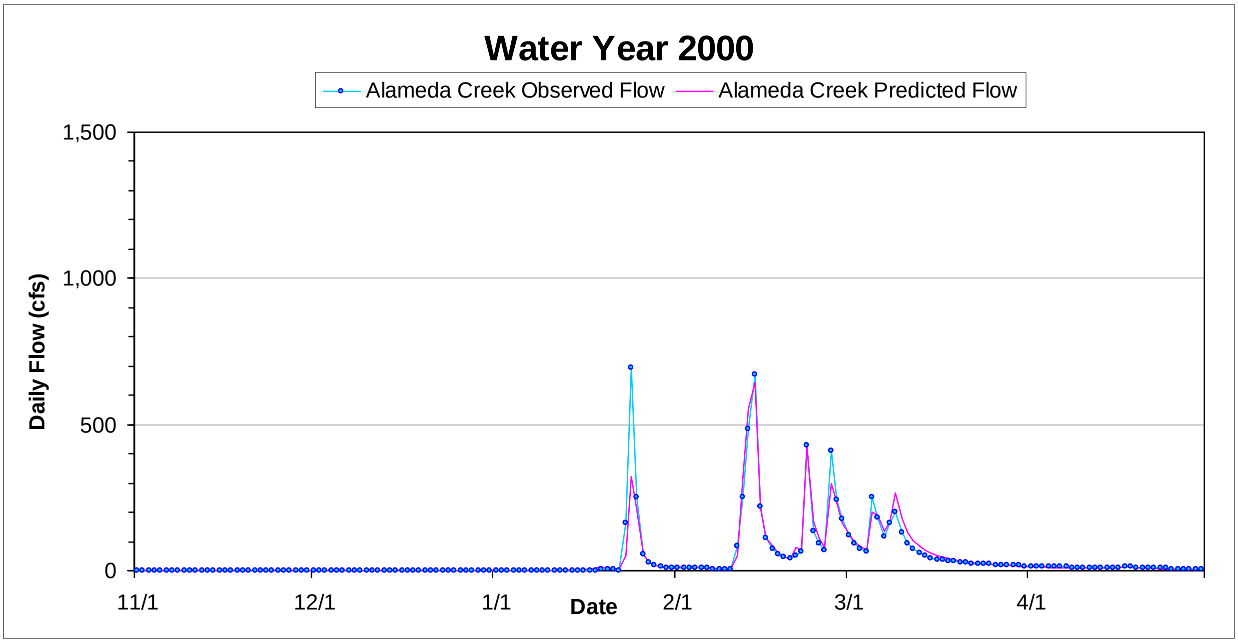

Figure C-10 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 2000

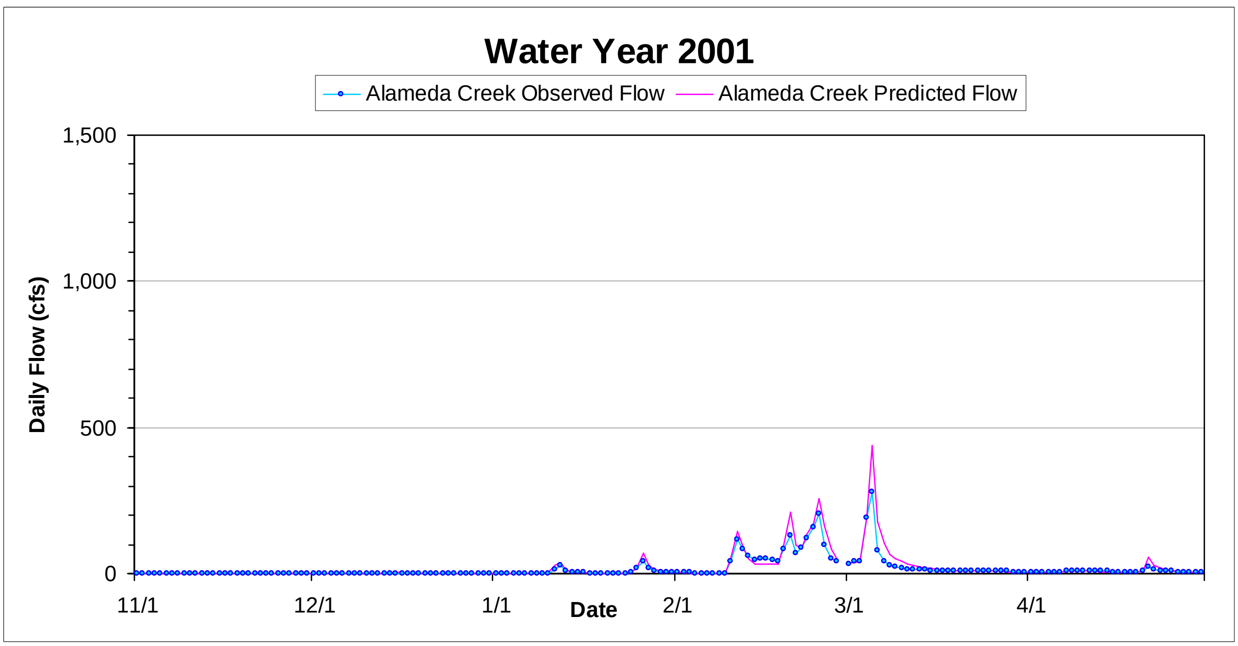

Figure C-11 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 2001

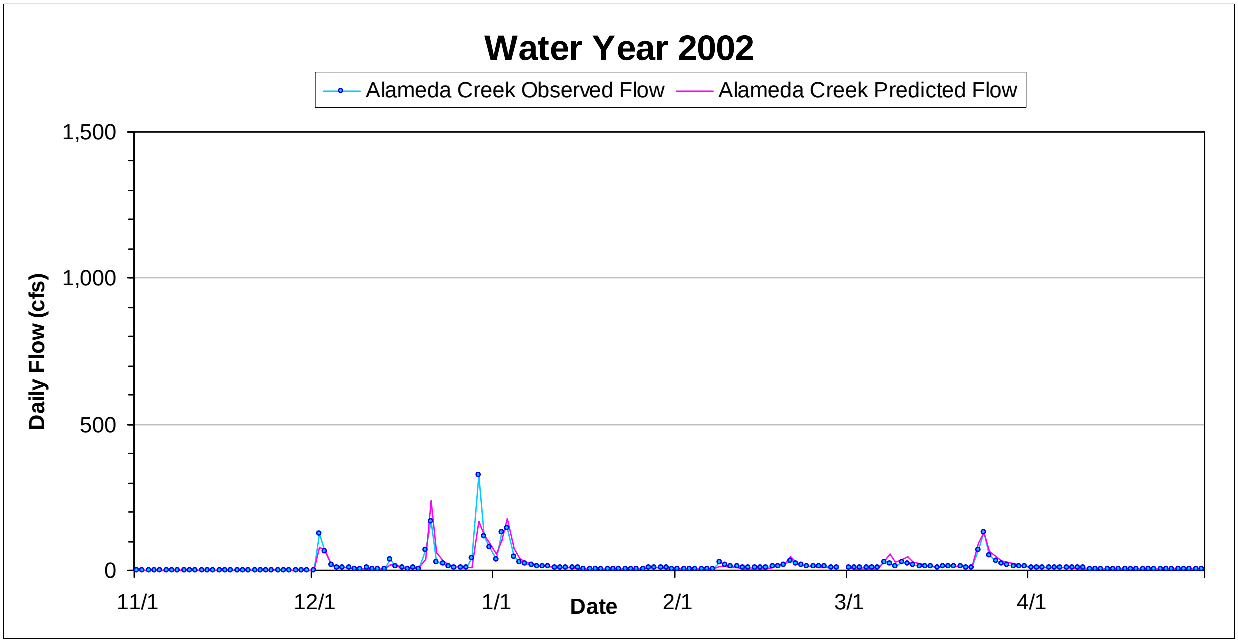

Figure C-12 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 2002

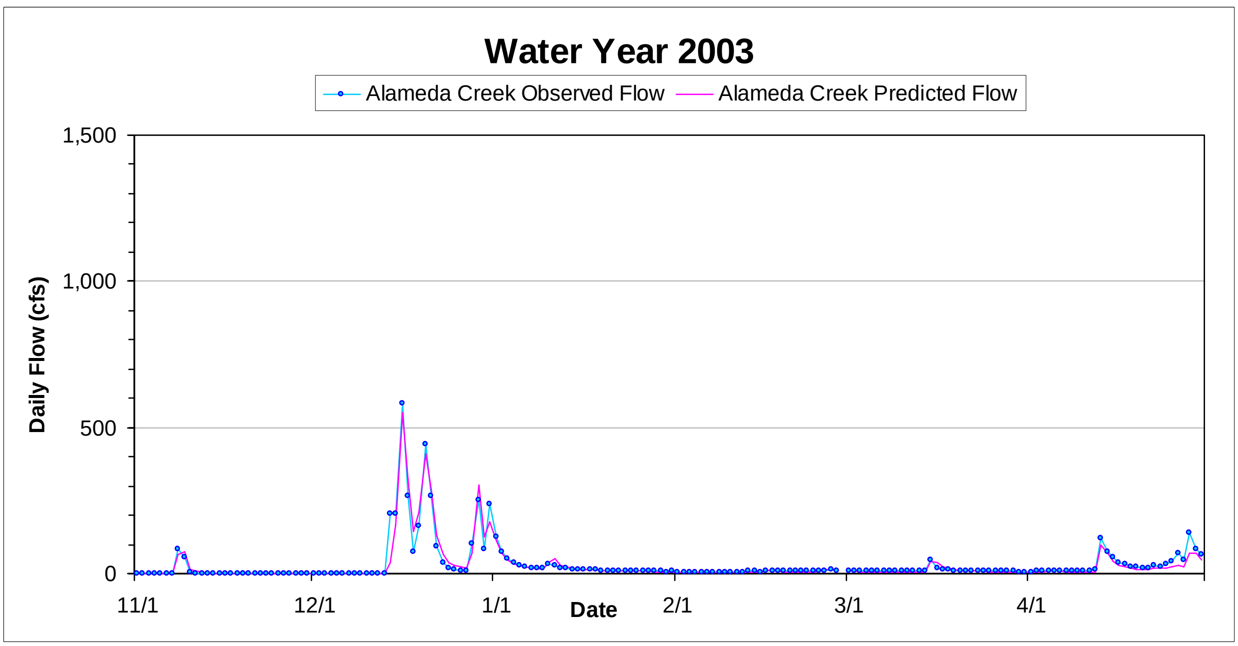

Figure C-13 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 2003

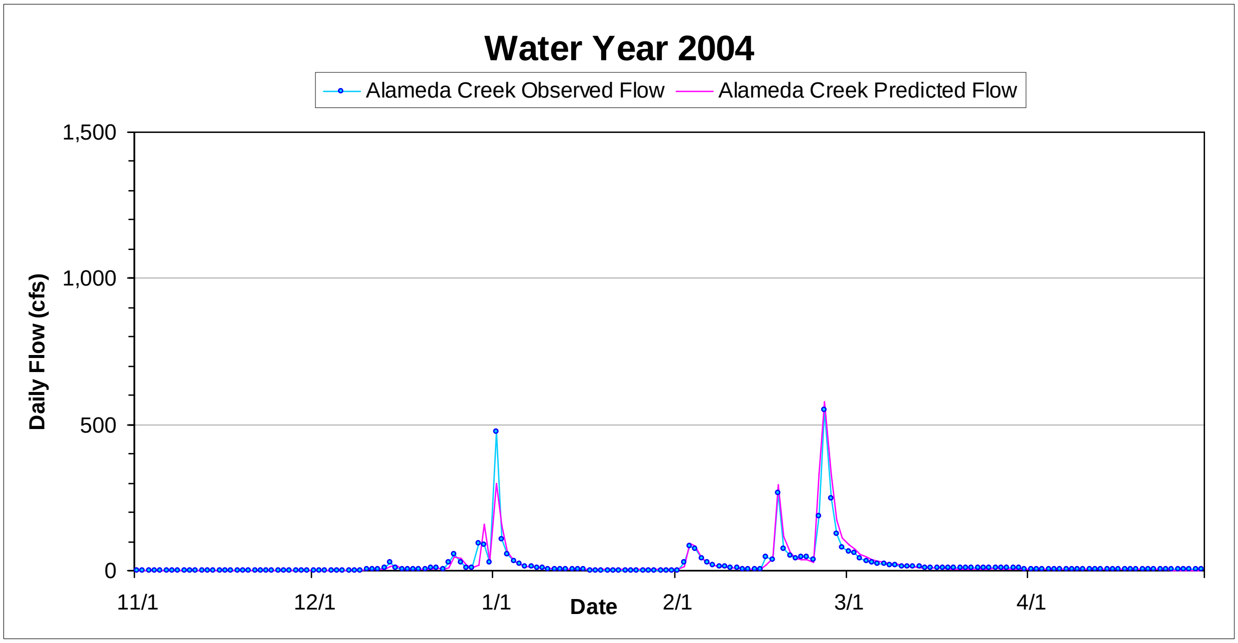

Figure C-14 Arroyo Hondo, Alameda Creek Observed Mean Daily Flows and Predicted Alameda Creek Mean Daily Flows for Water Year 2004

Appendix D

Technical Information on Minimum Viable Population Size

Ecologists have developed several models to determine minimum viable population sizes. These models have been characterized as population viability analyses. The basic model used to characterize population growth is

$$N_{t+1} = \lambda N_t \qquad (1)$$

where,

N_{t+1} is the estimated population size in the next generation; λ is the rate of population growth; and N_t is the number of breeding pairs currently in the population (i.e., initial population size). If $\lambda=1$ the population is stable, if $\lambda<1$ the population is declining, and if $\lambda>1$ the population is growing (Taylor, 1995).

For salmonids the growth rate of the population, λ is dependent upon the proportion of individuals surviving from one life stage to the next, and can be expressed as,

$$\lambda = E \cdot S_1 \cdot S_2 \cdot S_3^y \cdot S_4 \qquad (2)$$

where,

E = Eggs produced from previous generation
S_1 = Egg to fry survival
S_2 = Fry to smolt survival
S_3 = Annual ocean survival
y = Years in ocean (since steelhead will spend at least 2 years at sea, y equal to 2)
S_4 = migration to spawning ground survival

Life stage survival rates reported in the literature can be used to estimate λ; however, they are highly variable due to differences in inherited traits between populations as well as natural and anthropogenic environmental disturbances. For example, Moyle (1976) reports numbers of eggs ranging from 200 to 12,000 per adult female, but the number is generally found to be around 2,000 eggs per kilogram of adult body weight.

If conservative assumptions are made for values of variables used to estimate the growth rate of the population, λ, it is possible to estimate the number of adults that could potentially return if there was enough spawning habitat to support 100 breeding females, N_t, in the upstream tributaries of Calaveras Reservoir. One hundred female steelhead producing at least 2,000 eggs per kilogram of body weight (weighing a minimum of 2.5 kilograms) could reportedly produce a total of 5,000 fertilized eggs, E. Estimates for egg to fry survival rates reported by Healey (1991) range from 14 to 94 percent in Chinook salmon. Bradford (1995) reviewed the literature on Pacific salmon survival and reports an average egg to smolt survival of 7 percent. Healey (1991) reports average ocean survival rates of 20 to 36 percent annually. Based on other values reported in the literature, it is assumed that the egg to fry survival rate, S_1, is 14 percent; ocean survival, S_3 is 20 percent per year; and that migration to spawning ground survival, S_4 is a product of both the reported 80 percent, and an estimated 90 percent survival rate from handling and transport through facilities and devices. Using these estimates for survival during key life stages and equations (1) and (2), the number of returning adults from initial population of at least 100 breeding pairs (i.e., 100 females) can be estimated as,

$$N_{t+1} = \left[(5{,}000)\cdot(0.14)\cdot(.07)\cdot\left(0.20^{2}\right)\cdot(0.80)\cdot(0.90)\right]\cdot 100 = 141$$

Of the estimated 141 returning adults produced from the initial 100 females, it is uncertain what proportion would be male or female. However, if we assume that the sex ratio is 1:1 there would be approximately 70 females to produce eggs for the next generation. However, since the rate of population growth, λ, is dependent only on life stage survival rates, the number of individuals in the population would continue to increase (i.e., $\lambda = 1.41$).

These generalized estimates are presented to illustrate that, in theory, fish passage at Calaveras Dam could potentially produce a sufficient number of returning adults if sufficient adult spawning and juvenile rearing habitat is available to accommodate 100 breeding pairs.