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Preliminary Engineering Requirements for Fish Passage on Upper Butte Creek An Assessment of the Natural Barriers

Prepared by:

Cindy Watanabe
Associate Hydraulic Engineer
California Department of Fish and Game

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Background

Butte Creek is one of the few tributaries to the Sacramento River that supports a self-sustaining population of spring-run chinook salmon, listed as Threatened on the Endangered Species Act (ESA). In addition, Butte Creek supports a remnant run of Central Valley Steelhead Trout also recently listed as Threatened on the ESA. While efforts are ongoing in the lower and central sections of Butte Creek to improve fish passage conditions, the idea of expanding the range of these threatened species has attracted significant attention. The range is limited primarily by natural barriers at and below the Centerville head dam run by PG&E.

Two reports have been published on surveys of Upper Butte Creek conducted to assess the habitat upstream of the existing range. A brief summary of each report follows:

The first report "Physical Stream Survey - Upper Butte Creek, Butte County, California" was prepared by D. Holtgrieve and G. Holtgrieve in December 1995. Research of historical records determined that there were no substantiated records of salmon or steelhead occupying the reach of Butte Creek above the Centerville Head Dam. The report identified holding pools and spawning gravel in the reach as well as 35 low flow barriers. Of these 35 barriers, 19 were found in the 3.5 miles directly above the Centerville Head Dam and ranged in height from 5 to 18 feet. The conclusion in this report was that "With fairly minor barrier modification (blasting large boulders) the fish could migrate all the way to Butte Meadows in average flow years. Opening four miles of deep holding pools and three miles of spawning size gravel beds would create habitat for at least 3,000 spawning pairs."

The second report "A Preliminary Assessment of the Salmon Habitat Potential of Butte Creek, a

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Tributary of the Sacramento River, Between the Butte Head Dam and Centerville Diversion Dam, Butte County, California” was prepared by J. Johnson and W. Kier in January 1998. This report concluded that this section of Upper Butte Creek could meet the holding and spawning requirements of spring-run chinook salmon. Their survey identified 77 low flow barriers which “...would require some degree of modification -- gradient moderation, rock removal or small fish ladders -- to enable fish passage in virtually all years.”

In April, 1997 a proposal was initiated by the Institute for Fisheries Resources to open Butte Creek Canyon to salmon and steelhead production. An analysis was performed and revisions to the project proposal were suggested in a paper prepared by a Department of Fish and Game (DFG) biologist. This analysis stated that there were significant environmental and engineering issues that needed to be addressed before developing a restoration plan for Upper Butte Creek. It identified the three essential tasks listed below:

- Establish a technical advisory team, composed of biologists and engineers involved in the Butte Creek fishery habitat restoration plan, including DFG, Fish and Wildlife Service (FWS), National Marine Fisheries Service (NMFS), and Bureau of Reclamation (BOR) to help develop and guide the evaluation. In addition, maintain close coordination with the Butte Creek Conservancy.
- Evaluate all barriers previously identified as having significant potential to impede fish passage. Develop conceptual passage alternatives for each barrier, including order of magnitude cost estimates for construction and future maintenance.
- Refine the information needed to evaluate the salmon and steelhead habitat potential - flows, temperatures, gravel quality and quantity, and number and location of potential holding pools.

This report evaluates the natural barriers and potential fish passage requirements on Upper Butte Creek – the second of the three tasks listed. Although the intent of this task was to produce preliminary designs and rough cost estimates, the information available to date is insufficient to do so. Fish passage engineering integrates the biological information of salmon or steelhead abilities and behavior with the hydraulics of rivers and engineered structures to minimize impact to the fish. Thus, it is necessary to include elements of biology to support the logic and function of the engineered design. Prior to providing even a partial design for fish passage at the natural barriers, the system as a whole must be understood and particularly so where there are a significant number of barriers in a short stretch of river and two listed species. The report includes a brief discussion of hydrology/”plumbing” of Upper Butte Creek, fish passage design standards, and recommendations for further data collection to support future fish passage design.

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Spring-Run Chinook Salmon & Steelhead Trout

Spring-run chinook salmon enter Butte Creek during the spring runoff period (March-June), remain in fresh water (deep holding pools) through the summer months, and begin spawning in the fall. Spawning is usually completed from the end of September to mid-October. In Butte Creek, spring-run primarily end their migration at either the Chimney Rock or Quartz pools which are the deepest, coolest pools at the upper end of their accessible range. Spring-run use very little energy while holding through the summer and do not migrate out of the pool until they are ready to spawn. When the spring-run are preparing to spawn, they move many miles downstream to find suitable spawning habitat. Typically, spawning occurs close to the Centerville Powerhouse outfall, where cooler water is added to Butte Creek.

There is very little information available on the life history of steelhead trout in Butte Creek. Extrapolating standard information to Butte Creek, adult steelhead trout may migrate upstream from November through April and will spawn a few weeks to a few months after they enter fresh water. Unlike chinook salmon which die, up to 50 percent of adult steelhead survive to spawn in more than one season. Most steelhead will spend one to two years in fresh water and one to two years in the ocean.

The pre- and post- spawning behavior of the adult fish, and the rearing and out-migration requirements of their offspring have a direct impact on fish passage design. It is critical that spring-run salmon retain energy and suffer minimal injury if they are to reach and survive in their over-summering habitat, prior to spawning in the fall. Therefore, upstream migration routes modified by man-made structures must be made as transparent as possible. This means fish passage structures must minimize migration delay and injury to the passing fish. Typically fish passage design focuses on the upstream migration of adult fish and the downstream migration of juveniles. The need to provide both must be taken into consideration, especially when designing low flow passage routes that will minimize delay or injury prior to spawning.

Hydrology

Successful fish passage at a barrier is based on migrating fish being able to find and utilize a fish facility without harm or delay. The first step in the design process is to understand the hydrology of the creek during the migratory period. In the case of upper Butte Creek, as noted above, it is important not only to understand and incorporate hydrology for upstream passage, but also look at the range of flows and potential problems of downstream passage. Therefore we need to look at two flow periods, the upstream migration from the ocean, which for spring run typically occurs between March and June, and the downstream movement of fish to suitable spawning habitat in September through October. Steelhead trout would be able to utilize the fish passage structures under the same conditions as the spring-run. Since steelhead are stronger swimmers/leapers, the physical abilities of spring-run salmon should be used to provide a more conservative design.

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Upper Butte Creek consists of a complex system of diversion, transport and import of water for hydroelectric power generation by Pacific Gas & Electric (PG&E). The following table provides a general look at the “plumbing” to get an idea of what flow regimes we need to incorporate in our fish passage designs.

Upper Butte Creek Hydrology On-Stream Gauges Historical Streamflow Daily Values Butte Head Dam to Parrot-Phelan Diversion Dam					
Location (Upstream to Downstream)	USGS Sta # Period of Record	Flow Range (cfs) (1990-1998)			
		Winter	Spring	Summer	Fall
Below Butte Head Dam	11389720 1986-1998			7-40	
Below Forks of the Butte	11389740 1992-1998			10-60	
Forks of the Butte	11389747 1992-1998	250			
De Sabla Powerhouse	11389750 1979-1998	185			
Toadtown Canal	11389800 1984-1998	115-120 When available			
Below Centerville	11389780 1985-1998			10-60	
Centerville Powerhouse	11389775 1979-1998	185 When available from 1980-1994			
		170 When available 1995-1998			
Butte Creek near Chico, CA	11390000 1930-1998	50 - 7800 (does not include Jan 1997 flood)			

In addition to the table above, a brief description of how the pieces fit together is provided below:

Butte Head Dam, the uppermost barrier for the reach under study is a 40' high concrete diversion dam. PG&E diverts Butte Creek water via the Butte Canal to the De Sabla Powerhouse. Downstream from the Butte Head Dam, several small tributaries enter Butte Creek, increasing the flow in the creek until it reaches the Forks of Butte Diversion dam. Forks of the Butte

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Diversion Dam, an 8' high dam, is located just downstream of the West Branch of Butte Creek. This PG&E dam diverts water through a tunnel to the Forks of Butte Powerhouse. The water diverted at the Forks of Butte Diversion Dam is returned to Butte Creek upstream of the Lower Centerville Diversion Dam. Just downstream of the Forks of the Butte Powerhouse release and upstream of the Centerville Diversion Dam, Butte Canal water in combination with a portion of the water imported from the West Branch of the Feather River via the Toadtown canal is piped from DeSabra forebay to the DeSabra powerhouse and released into Butte Creek. A short distance downstream of the two powerhouses, water is recaptured at the Centerville Diversion Dam and sent via the lower Centerville Canal to the Centerville Powerhouse. The Centerville Powerhouse also receives water from the Upper Centerville Canal which consists of water diverted at the Butte Head Dam and water from the Toadtown canal that is not utilized at the DeSabra Powerhouse. This water is discharged into Butte Creek upstream of the USGS gage located on Butte Creek near Chico prior to any agricultural diversions. This gage provides a record of Butte Creek flow and the water imported from the West Branch of the Feather River via Toadtown Canal. Although this gage is out of the study area, it provides an indication of the high flow conditions that must be incorporated into fish passage designs for the winter/spring migration of spring-run salmon and steelhead.

The above information provides a brief look at the complex hydrology of the Upper Butte Creek system. If the hydrology remains unchanged, fish passage design flow will depend on the location of the barriers in the system. The following list is an estimate of the different reaches, each of which will require separate flow evaluation:

1. Quartz Pool to below the Centerville Diversion Dam
2. Centerville diversion dam to DeSabra and Forks of the Butte Powerhouses
3. Powerhouses to below the Forks of the Butte Diversion Dam
4. Forks of Butte Diversion Dam to first major upstream tributary
5. Major tributary to below the Butte Head Dam

Determining the design flow for each barrier will be complex for two reasons. One, upstream migration can occur at very high flows or very low flows and could be impacted by creek diversions from one reach of the river to another. The second factor is that this far up in the system spring-run can and will most likely be migrating in June and possibly July. It is difficult to determine what the actual creek flows are upstream of the diversion dams by looking at the records because of the addition of water from the West Branch of the Feather River at two locations in the creek. The upstream migration flow range can vary between 10 cfs to flows in the thousands of cfs. The downstream passage flows vary from reach to reach in the range of 10 to 40 cfs or 40 to 60 cfs again depending on location in the creek. The upstream migration design flow will depend on site specific hydraulic conditions and the intent of passage at the barrier (migration corridor or within over-summering habitat). The downstream design flow would most likely have to focus all the available flow to a single channel/ladder to optimize downstream passage.

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Note: The adequacy of the design flow range, especially at the current low flow conditions apparent in many reaches of Upper Butte Creek requires more biological evaluation (as pointed out in the DFG analysis, bullet number 3). If existing flows are inadequate to support over-summer holding and fall spawning, subsequent decisions to increase flow could result in the need to reevaluate the barriers for fish passage under the new flow conditions.

Barriers

A barrier is defined in Webster's New World Dictionary as "a thing that prevents passage or approach". This definition spells out in the most simplistic terms the obstacles we are trying to overcome to provide fish passage past a barrier. As the definition implies, a barrier does not necessarily have to be a solid rock waterfall. For fish, a barrier can be related to both physical elements and behavior. The focus in this report is primarily the physical features, bedrock falls, chutes, cascades and excessive velocities. However, behavioral traits can become important when determining design alternatives such as avoidance of dark tunnels, desire to leap or to swim in submerged conditions, etc.

A bioengineering analysis of barriers consists of knowing the fish species swimming and jumping capability, consideration of the species physical condition (fresh from ocean or as in our case, high in the watershed), and period in their life history (critical for spring-run having to hold over the summer prior to spawning in the fall). Physical assessment of the barrier for fish passage should include but is not limited to the following:

- Measurement of tailwater surface to top of waterfall surface height
- Ratio of waterfall height to plunge pool depth
- Width and length measurements
- Velocity measurements
- Pool depth and size
- Upstream and downstream slope
- Channel characteristics

Each barrier should be assessed for feasibility of providing fish passage at the barrier or by alternate routes which can be accomplished by an engineered design or by altering the barriers characteristics. Each barrier should be evaluated either physically or by observation at the design flow range to determine the actual fish passage problem. The alternative, in the case of inaccessibility at high design flows (which is probably the situation at most of the barriers in the steep walled, rugged canyon setting) would be doing a thorough analysis of the existing physical

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features by obtaining accurate ground surveys, then doing hydraulic calculations at the design flow ranges. This method could provide some insight to the depth of water and the velocities given a known flow. The calculated information could be taken to the site, when accessible, to see if there are signs of hydraulic action that confirm the calculations. The evaluation should include an assessment of the flows where barriers might become passable or alternate routes become available. It is also possible, that field review at higher flows will identify new barriers (particularly velocity) which appeared passable at low flows. Finally, the location and type of barrier and its proximity to the next downstream and upstream barrier and the creek conditions between the barriers need to be addressed. If tunneling or rerouting the channel is an option, a tunnel or modified channel configuration could provide passage around a series of barriers versus addressing each barrier individually. The impacts that could result from modifying a barrier need to be addressed in order to prevent formation of new barriers or elimination of holding pools and spawning gravels.

The following Butte Creek barriers illustrate the fish passage issues that need to be addressed. These barriers were briefly examined on July 12, 1999 by representatives from the Department of Fish and Game (DFG), National Marine Fisheries Service (NMFS), Bureau of Reclamation (BOR), and The goal of the group was to see several barriers on Butte Creek to get an idea of the fish passage problems that exist and to begin doing a technical assessment of fish passage conditions. The team hiked to the first four major natural barriers upstream of the existing salmon and steelhead range on Butte Creek. The "hike" included walking on unimproved paths, no paths and scrambling in the creek. The barriers included the waterfall at the Quartz Pool, the Centerville Diversion Dam and three barriers upstream of the dam. The group gathered preliminary survey data with the use of a hand level, stadia rod and surveyor's tape. Despite difficult field conditions (110 degree temperatures), the approximate heights of the barriers and some pool characteristics were determined. The gages below the Forks of Butte Diversion dam and the Centerville head dam were not available for 1999. However, the three previous years (1998,1997, 1996) showed flows at both gages to be approximately 47 cfs on the same day.

The following descriptions based on field measurements, notes and photos are provided for the barriers.

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Summary of Upper Butte Creek Field Trip Barrier Notes							
July 12, 1999							
Flow: 47 cfs							
Barrier Location	Fall Height	Downstream Pool length	Pool depth (base of falls)	Upstream Conditions	Alternate Routes around pool	Downstream Modifications	
Quartz Bowl Pool Below Centerville Dam	11.1 feet (Chute)	118 feet	16.5 feet	Small cascades, steep grade	None evident	Downstream weir could raise tailwater for a reduced fish ladder height	
Centerville Head Dam	14.2 feet (Dam Height)	28' wide 42' long 7.7' deep	No pool at base of dam	No information	None	None	
	11.4 feet (Cascade)	42' wide 47' long					
1st Barrier Above Centerville Dam	14.4 feet	141 feet	No information	Pool 52' long 40' wide	Possible passage around bedrock outcropping on right bank	Downstream weir could raise tailwater for a reduced fish ladder height	
2nd Barrier Above Centerville Dam	13 feet	100 feet	11.8 feet	Pool 82' long	None, steep bedrock walls both sides	Downstream weir could raise tailwater for a reduced fish ladder height	
3rd Barrier Above Centerville Dam	12'	Total 23.8'	99 feet No defined pool, lots of big boulders/bedrock structures	4.3 feet	Cascades and 3'-4' deep Pools 4' rise over 40'	Possible ladder route on left bank	Downstream weir could raise tailwater for a reduced fish ladder height
	11.8'						

Note - Holtgrieve reported that the Quartz Bowl barrier was dynamited in the 1930's, allowing passage up to the Centerville Diversion Dam. (This site should be studied carefully to determine what amount of blasting was done, its effectiveness and the overall affect to the surrounding rocks and banks. This could provide some insight to future projects involving blasting.) According to a DFG biologist, spring-run are rarely able to negotiate this barrier, even at high flows. At the time of the field trip, there were several adult salmon holding in the large pool at the base of the falls.

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In summary, the trip provided the group a feeling of the remoteness of the barriers, difficulty in accessing each site, and a brief look at the magnitude of the fish passage problems in Upper Butte Creek. Each barrier, including Centerville Diversion Dam require additional field measurements and if possible, site visits at higher flows to gain a better understanding of the actual barrier in terms of fish passage. Each barrier visited on this day seemed to provide a significant blockage, and according to the referenced reports, there are many more barriers upstream.

Fish Passage Criteria

There are standards used in fish passage design that are typically applied to manmade structures to provide unimpeded upstream passage (**no** delay and **no** physical impairment). These standards tend to be more stringent than those historically applied to passage at natural barriers. In the following section, the typical standards for fish passage design are presented, first at manmade structures, followed by a discussion of design at natural barriers.

Manmade Structures

Research and field experience has led to the following list of design standards typically applied to engineered fishways at manmade structures.

- 1' drop per pool
- 8 fps maximum velocity at fish ladder entrance
- Velocities of 5-6 fps through orifices and slots
- Energy dissipation of 4 foot pounds per second per cubic foot of water in each fish ladder pool
- Water depth of 6-12 inches over a weir
- 10% or more of the creek flow through fishway to provide attraction to entrance
 - Auxiliary water may be required at or near entrance pool
 - Energy dissipation 1 fps or less
 - May need fish screen at intake
- Resting areas where velocities are 1 fps or less
- Roughened chutes should not exceed 30 feet in length
 - More than 30 feet requires resting pools between chutes
- Extension of ladder exit upstream of spillway to prevent fallback
- Minimize impacts of debris and sediment transport
- Accessibility for Operations and Maintenance during migration season
- Target fish species
 - Adults passage (upstream/downstream)
 - Juvenile passage (upstream/downstream)
- Flow during species migration
- Flow extremes (flood and drought)

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Natural Barriers

The tendency and history of designing fish passage at natural barriers is a leniency in the above listed standards to provide partial passage at opportunistic flows. This view is outlined in Clay's summary of design conditions at natural barriers in his book Design of Fishways and Other Fish Facilities. *"The fundamental concept in the approach to the design of a fishway to overcome a natural obstruction is different from that in the case of a dam.....First, the natural obstruction to migration is in most cases a part of the natural environment of the fish it affects. The population of migrating fish has presumably become adjusted to some extent to this environment. However, if the obstruction each year takes its toll by reason of direct mortality, or physical impairment as a result of delay or damage, any facilities installed that will reduce this mortality or impairment will be beneficial. It is possible then to think in terms of the most economical installation to produce the biggest benefit, even though the result may still be far short of perfection.the standard of space requirement or size of fishway may often be less for a fishway at a natural obstruction than one at a dam...."*

Clay's view that the criteria could and should be stretched at natural barriers is most likely based on the conditions at the barrier which prevent the construction of a standard fishway. He noted *"...natural obstructions are often in locations where it is most difficult to provide for regular operation and maintenance."* which would limit the types of fish ladders and alternative mechanisms one could use. In addition, when reviewing his chapter on natural barriers, it seemed he was discussing passage at a single barrier. The significant difference at Butte Creek is that there is not just one barrier where the standards could be stretched, but 11 or more miles of potentially up to 77+ barriers. The goal should be to provide unimpeded passage at each barrier to allow the spring-run salmon to reach the Upper Butte Creek holding area in good condition so they can successfully hold over the summer and spawn in the fall. A second goal should be to avoid stranding salmon and steelhead in this stretch of river when the flow changes, where they may not be able access suitable holding pools or spawning sites. If passage were provided through this 11+ mile reach, adherence to the criteria listed for manmade structures in an effort to provide unimpeded upstream passage is required.

Design Options

To provide even a basic suggestion of a fish passage design and an associated rough cost estimate at a specific barrier is inadvisable at this time. The brief look at the above barriers provided some insight to the complexity of the fish passage problem. The additional review of the hydrology and the implications of the changes in flow at varying reaches adds another level of complexity. Appropriate fish passage design and a meaningful cost estimate of design and construction costs requires much more data and more clearly defined fish passage goals.

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Additional Related Issues

1. It is possible and probable that the removal of or passage at barriers could result in a change of the existing pool and spawning gravel characteristics. Prior to implementation of barrier modification or removal, an impact assessment should be made of the habitat identified as suitable to support salmon and steelhead adults and juveniles.
2. Should fish passage to Upper Butte Creek be pursued, a look at the passage conditions in the existing range between Parrott-Phelan Diversion Dam and Quartz Bowl Pool is recommended. Since research has indicated that the fish did not previously reach Upper Butte Creek, will spring-run salmon and steelhead have enough stamina to travel further upstream to reach suitable holding pools and spawning gravel? Fish passage improvements in the existing range may be required for migrating fish to have sufficient energy to reach the new range.

Recommendations for Further Study

In order to provide the desired preliminary design and the associated cost estimate, the following information should be obtained first:

1. Determine what a reasonable fish passage design flow range should be (especially considering drought years and past experience with river flow variations)
2. Accurately locate each barrier and identify the nature of the passage problem.
3. Observe and record data at the full range of flows likely to occur during the migration period in order to verify barrier status.

Once barriers and flows have been established, the following design information will be required.

1. Survey each barrier to obtain the topography at the barrier to include upstream, downstream and potential alternate route features. (May require a survey of the whole reach since there are so many barriers.)
2. Have a geologists, a geotechnical engineer and an explosives expert assess each barrier to determine various design parameters such as bedrock foundation conditions, stability of banks and impacts to be expected from extensive blasting.
3. Have a geomorphologist examine the bedload transport that exists and try to assess what impacts barrier modification would have on sediment transport and spawning gravel locations.

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4. Follow the procedures to obtain hydraulic stage relationships recommended by Clay (Design of Fishways and Other Fish Facilities, Chapter 2, pages 39-40).
5. Determine who will be responsible for the structures.
6. Determine who owns the property and what type of easements would be required.
7. Determine what type of access is possible and methods and limitations of transporting equipment and materials to each barrier.