CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE
WATER BRANCH
INSTREAM FLOW PROGRAM

STUDY PLAN

UPSTREAM PASSAGE ASSESSMENT FOR ADULT SPRING-RUN CHINOOK SALMON IN LOWER BUTTE CREEK, BUTTE COUNTY

February 2014

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Preface

This study plan outlines the approach and methods that will be used by the California Department of Fish and Wildlife (CDFW) to conduct an instream flow study on lower Butte Creek in Butte County, from Parrot-Phelan Diversion Dam to the downstream Western Canal Siphon. Work will be performed under contract with the U.S. Fish and Wildlife Service (USFWS), with assistance from CDFW Water Branch and North Central Region (Region 2). This study will be used to develop an instream flow recommendation that ensures passage of adult spring-run Chinook salmon (SRCS), *Oncorhynchus tshawytscha*, through lower Butte Creek into the upper watershed.

The primary objective of this study is to develop a relationship between stream flow and passage of adult SRCS. Bypass flows of 40 cfs are currently released by water operators to enhance fish habitat in lower Butte Creek between October 1st and June 30th (Agreement for Relocation 1996). However, this release rate was negotiated to maintain passage over diversion dam fish ladders, and has not been verified as the protective or optimal flow for passing fish into the upper watershed or for keeping fish in good condition. Therefore, this stream flow study will be used to quantify what flow requirements will maintain SRCS in good condition during migration over natural passage barriers.

Lower Butte Creek was surveyed to select sites most critical to upstream passage of SRCS. A stretch of the creek passing over exposed bedrock downstream of Durham Mutual Diversion Dam, referred to in this document as the Lahar formation, and several natural riffles were identified as potential barriers to passage. A two-dimensional (2D) hydraulic model will be developed to correlate stream flow to river stage, depth, and velocity through the Lahar formation and these the representative critical riffles selected. Additionally, Critical Riffle Analyses (CRA) will be used to identify the minimum stream flow rates necessary for passage of adult SRCS through the critical riffles. Temporary monitoring equipment will be installed to record water temperature and stage. The results of the hydraulic model will be combined with the CRA to identify flow regimes associated with CDFW passage criteria for SRCS. CDFW will transmit the resulting instream flow recommendations in accordance with the Public Resources Code (PRC) sections §10000- 10005 to the State Water Resources Control Board for consideration as set forth in 1257.5 of the Water Code.

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1.0 Project Overview

1.1 Background

The California Department of Fish and Wildlife (CDFW) has identified Butte Creek as a high priority stream for instream flow assessment. Butte Creek has the largest self-sustaining, genetically distinct, wild population of spring-run Chinook salmon (SRCS), *Oncorhynchus tshawytscha*, in the Central Valley (CDFG 1998; CDFG 2009). The Central Valley SRCS Evolutionarily Significant Unit (ESU) was federally listed as threatened by NOAA Fisheries on September 16, 1999 (NOAA 1999). NOAA Fisheries reaffirmed the threatened status on June 28, 2005 and again on August 15, 2011 after five-year status reviews (NOAA 2005; NOAA 2011).

The U.S. Fish and Wildlife Service (USFWS) conducted a seven-year flow investigation on Butte Creek under the Central Valley Project Improvement Act (CVPIA) to determine instream flow needs for anadromous fish (USFWS 2003). This study focused on the SRCS spawning reach from Centerville Head Dam to the downstream Parrot-Phelan Diversion Dam, referred to in this document as upper Butte Creek. This study incorporated a two-dimensional (2D) hydraulic and habitat model (River2D; Steffler and Blackburn 2002) to predict availability of physical SRCS spawning habitat over a range of stream flows in Butte Creek. In 2009, the CDFW Instream Flow Program (IFP) submitted minimum instream flow recommendations to the State Water Resources Control Board (SWRCB) for upper Butte Creek based on the 2003 USFWS study (CDFG 2009).

The Parrot-Phelan Diversion Dam to the downstream confluence of the Sacramento River is referred to, in this document, as lower Butte Creek. CDFW North Central Region (Region 2) staff identified upstream passage of adult SRCS as the critical life stage in lower Butte Creek. Passage and habitat connectivity assessments in natural low-gradient riffles typically focus on surveying the depth-sensitive areas of the stream channel (i.e., riffles). However, Region 2 staff identified an isolated exposed bedrock outcrop approximately 750 ft (228.6 m) in length directly downstream of the Durham Mutual Diversion Dam (approximately 0.5 mi (.08 km) upstream of the Highway 99 Bridge) as an area of adult SRCS passage concern in lower Butte Creek (Figures 1 and 2). The isolated exposed bedrock is part of the volcanic Tuscan formation, referred to in this document as the Lahar formation (Figure 3). This section of lower Butte Creek is confined by a levee system that restricts the channel from naturally winding around the exposed bedrock, forcing migrating adult SRCS to find their way through the narrow channels of the Lahar formation itself. Further, low flow conditions have the potential to increase stream temperatures in and around the Lahar formation, potentially amplifying SRCS passage issues.

Late-season migrating SRCS have been observed holding in a pool 0.1 mi (0.16 km) downstream of the Highway 99 Bridge. Region 2 staff hypothesize that these fish reside in the pool for a few hours to a few days before continuing through the Lahar formation into upper Butte Creek where over-summer holding pools exist (pers. comm., C. Garman 2013). Eventually, as temperatures rise and flows decrease, stranding occurs in the pool. Rescue attempts have been unsuccessful in past years, with Region 2 staff reporting a 100 percent mortality rate (pers. comm, T. McReynolds 2012).

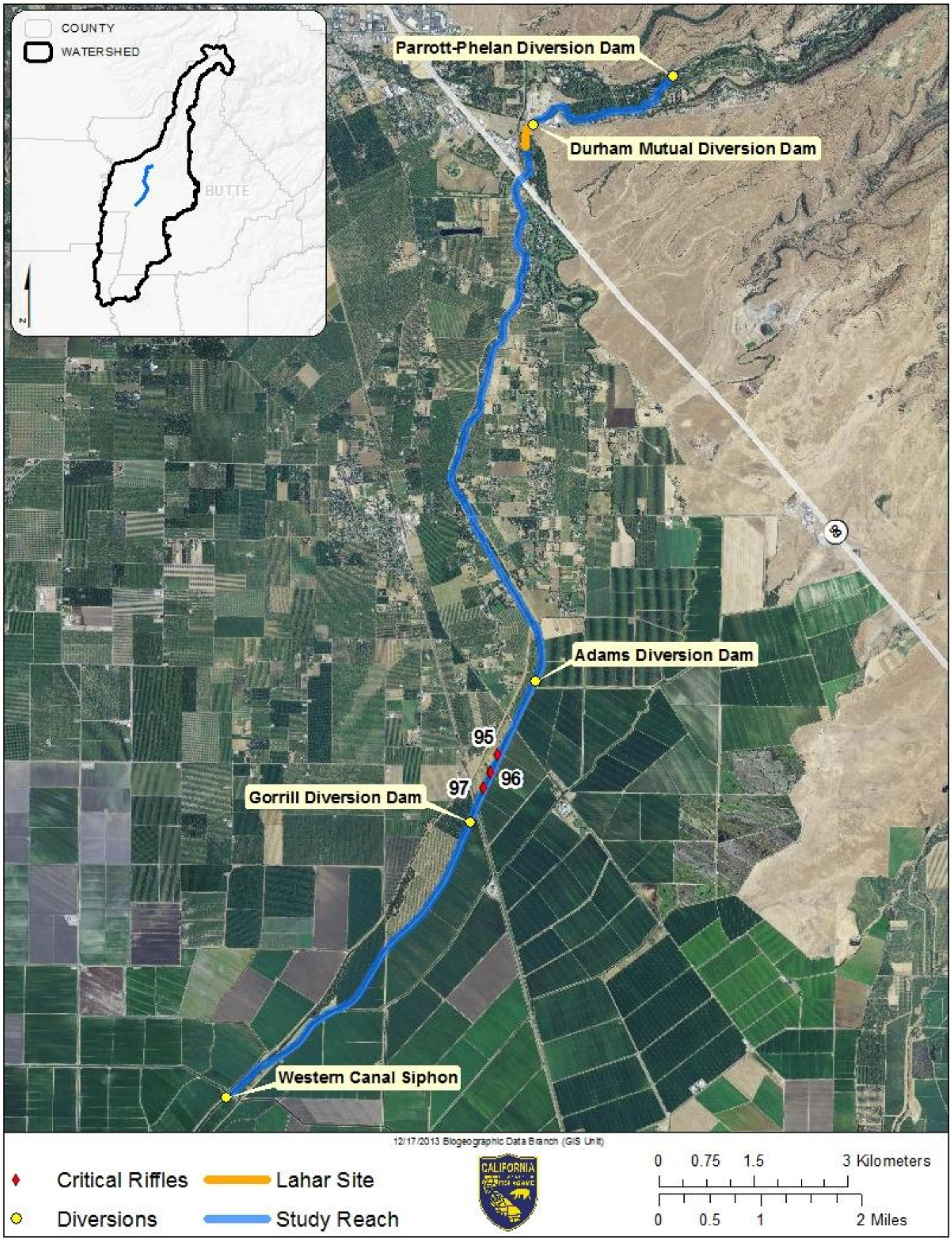

Figure 1. Map of lower Butte Creek study reach.

Figure 2. Map of Lahar site depicting Durham Mutual Diversion Dam, Lahar, and stranding pool.

Figure 3. Lahar formation facing upstream towards Durham Mutual Diversion Dam during low summer flows.

In addition to the known area of passage concern at the Lahar formation, a survey of potential critical riffles was completed between Parrot-Phelan Diversion Dam and the downstream Western Canal Siphon (Figure 1). A cluster of three critical riffles were identified just upstream of the Midway Road Bridge, 3 mi (4.8 km) south of Durham, California and 6.2 mi (10 km) downstream of the Highway 99 Bridge. All three critical riffles are located between the Adams Diversion Dam and the Gorrill Diversion Dam. Boards are installed across the Gorrill Diversion Dam from mid-April through mid-October to back up water behind the dam for agricultural water diversion. When the boards are in-place, backwater from the Gorrill Diversion Dam inundates the critical riffles by a minimum of 6 ft (1.8 m) eliminating the concern of restricted SRCS passage (pers. comm., M. Gard 2013). However, SRCS enter Butte Creek starting in March before the boards are in place and the riffles inundated causing SRCS passage at these riffles to be an issue during low water years. The three riffles included in this study (sites 95, 96, and 97) were identified during the pre-study survey as the most critical (most flow and depth-sensitive along the shallowest course) under natural flow conditions and are considered to be representative of natural critical riffle conditions present in the alluvial sediments that dominate lower Butte Creek.

Minimum flows for fish are currently provided through an agreement between CDFW, USFWS, the Bureau of Reclamation, M&T Ranch operations, and Parrot-Phelan operations. The agreement provides 40 cubic feet per second (cfs) of water for fish in lower Butte Creek from October 1st through June 30th (Agreement for Relocation 1996). As part of restoration activities occurring in the 1990s, Parrot-Phelan, Durham Mutual, Adams Ranch, and Gorrill Ranch dams blocking the upstream passage of SRCS were removed and replaced with broad crested weirs equipped with fish ladders (USFWS AFRP 2013). The current bypass amount of 40 cfs was determined to be the amount of water available through the Agreement for Relocation as well as the volume of water that would maintain passage through diversion dam fish ladders. A stream flow study is needed to determine the quantity of flows needed to allow adult SRCS to migrate through natural impediments in lower Butte Creek as well as these fish ladders. Fish rescues and the release of pulse flows, to move SRCS from the Highway 99 pool upstream above the Parrot-Phelan Diversion Dam, have had limited success in past years proving to be an inappropriate long-term management option.

The CDFW IFP will conduct an instream flow study between Parrot-Phelan Diversion Dam and the Western Canal Siphon (study reach) on lower Butte Creek to assess the concerns for SRCS passage at the Lahar formation, as well as at the three representative critical riffle sites identified. Additionally, a pressure transducer will be installed just downstream of the Lahar formation to monitor river stage (ft) and temperature (°F) so that a qualitative assessment of potential temperature impacts on SRCS migration through the Lahar formation can be made. It is anticipated that the flow study will determine the volume of flow required to maintain SRCS in good condition and create a relationship between stream flow, stream temperature, and passable conditions.

1.2 Butte Creek Watershed

Butte Creek is located predominantly in Butte County with small portions in Tehama, Glen, Colusa, and Sutter Counties (CSUC 1998; NOAA 2009). Butte Creek headwaters are located at an elevation of 7,087 ft (2,160 m) in the Jonesville Basin, Lassen National Forest (CSUC 1998). Butte Creek is approximately 90 mi (144.8 km) long and drains about 809 mi^2 (2,095 km^2) before entering the Sacramento River in two locations: the Butte Slough Outfall gates and the Sutter Bypass (Garman and McReynolds 2009). Average annual precipitation is less than 20 inches (50.8 cm) in the lower valley section of the watershed and 50 inches (127 cm) in the upper watershed.

Many small streams and springs enter Butte Creek as it flows through the Jonesville Basin, Butte Meadows Basin, and the steep canyon reach, before entering the Sacramento Valley floor near Chico. The unimpaired average annual yield of the Butte Creek watershed is approximately 243,000 acre-feet (300,000 dam^3) (Hillaire 1993). However, Butte Creek hydrology has been severely altered by multiple hydropower, municipal, and agricultural diversions as well as water imports from neighboring watersheds (CSUC 1998; NOAA 2009).

The geology of the Butte Creek watershed is primarily characterized by unique volcanic rock features. Valley floor channel deposits from Parrot-Phelan Diversion Dam to the downstream Western Canal Siphon consist primarily of alluvium eroded from the walls of the Butte Creek Canyon. Channel deposits are a mix of sand and gravel sized material eroded from the Chico and Tuscan Formations (CSUC 1998; Harwood et al. 1981). CDFW staff observed cobble sized material also mixed in with the historic sand and gravel channel deposits. Refer to Chapter two of the Butte Creek Watershed: Existing Conditions Report (CSUC 1998) for further details of the geology, basin morphology, and hydrologic system of Butte Creek.

Listed species present in Butte Creek include Central Valley SRCS and Central Valley steelhead trout (*Oncorhynchus mykiss*). Butte Creek is considered a conservation stronghold for all life stages of SRCS because the population is considered to be persistent and viable (NOAA 2009). Non-listed Central Valley fall-run Chinook salmon are also present in Butte Creek. See Table 6.1 in the Existing Conditions Report (CSUC 1998) for a complete list of the fishes in Butte Creek.

There are two Power House Dams (DeSabla Head Dam and Centerville Head Dam) owned and operated by Pacific Gas and Electric Company (PG&E). As of 1998, there were 41 municipal and agriculture diversions and imports along Butte Creek (see CSUC 1998 Appendix E: Surface Water Gauging Stations and Butte Creek Peak Annual Flow Graph, Diversions and Imports table for a complete list). The four diversions within the study reach include Parrot-Phelan Diversion Dam, Durham Mutual Diversion Dam, Adams Diversion Dam, and Gorrill Diversion Dam. Many recreational activities are available on Butte Creek and include rafting, kayaking, tubing, swimming, fishing, hunting, camping, hiking, backpacking, horseback riding, cycling, nature viewing, gold mining, and off-road vehicle use (CSUC 1998).

1.3 Problem Statement

SRCS have been observed holding in a pool 0.1 mi (0.16 km) downstream of the Highway 99 Bridge, just below the Lahar formation and Durham Mutual Diversion Dam and above the three representative critical riffles, during migration periods. SRCS stranding in this pool is common and attempts to move and/or entice the stranded SRCS into the upper watershed (through physical relocation and pulse flows) have proven unsuccessful. This study will allow CDFW to identify flow requirements for passage of adult SRCS through the critical riffles in lower Butte Creek, past the holding pool, and though the Lahar formation into the upper watershed. Additionally, it will help CDFW to determine if the current bypass flow of 40 cfs in the Agreement for Relocation is adequate for keeping adult SRCS in good condition.

1.4 General Approach

Adult SRCS upstream migration through lower Butte Creek is the focus of the study. The primary study site, the Lahar formation, is not an alluvial riffle (Figure 3); therefore, a 2D hydraulic modeling approach is needed to assess adult passage requirements. A 2D hydraulic model using the River2D software package (Steffler and Blackburn 2002) involves developing a terrain model from topographic survey data of the site then overlaying this model with a hydraulic model that can predict both depth and velocity throughout the area being evaluated.

Minimum depth and maximum velocity are used to assess passage for migrating adult salmon. Depth and Velocity criteria are provided for Chinook salmon in Determining Stream Flow for Fish Life by Ken Thompson (1972). More recently, the SWRCB issued the Policy for Maintaining Instream Flows in Northern California Coastal Streams (SWRCB 2007), which provided updated depth criteria for Chinook salmon. The SWRCB depth criteria and Thompson velocity criteria will be used to assess passage in lower Butte Creek

The effect of temperature on SRCS migration though the Lahar formation is a concern of CDFW Region staff and will be evaluated as part of this study. Temperature data will be measured and recorded continuously throughout the project duration at a location a short distance downstream from the Lahar formation. Migration temperature criteria exist for salmon and trout and were developed by the U.S. Environmental Protection Agency for Region 10 states, Oregon, Washington, and Idaho (USEPA 2003). USEPA Regions 9 and 10 have worked together to recommend temperature criteria for Region 9 states including California. A qualitative assessment comparing temperatures measured near the lahar formation to these Region 9 temperature criteria will be completed.

In order to assess natural limitations to SCRS passage in lower Butte Creek, an assessment of alluvial riffles in the study reach will also be performed. A secondary study site consisting of three alluvial riffles has been located between the Gorrill and Adams Diversion Dams (Figure 1). These riffles were selected because they represent the most depth sensitive areas, aside from the Lahar formation, in the study reach. These riffle sites will be evaluated using the Critical Riffle Analysis (CRA) method. Flows for the CRA method will be sampled both before and after the boards are installed at the Gorrill Diversion Dam. However, because of water diversion operations downstream, access to these sites is limited and not all of the flows required for CRA can be sampled in the field. To account for the limited access, 2D hydraulic models will also be developed for the three riffle sites to supplement any missing flow regimes that cannot be sampled in the field. The minimum depth and criteria discussed above will be used to evaluate the results of both the CRA method and the 2D hydraulic modeling. Velocity is not expected to limit upstream migration at the three riffle sites. In the event velocity needs to be evaluated, estimates of velocity will be available through the 2D modeling. The effect of temperature on migration was not identified as a concern at the critical riffle sites.

The passage information resulting from this study will be used to develop a flow recommendation for lower Butte Creek from the Parrot-Phelan Diversion Dam to the downstream Western Canal Siphon. The results from this study will provide the basis for a robust flow recommendation for adult passage of SRCS through lower Butte Creek. Upon completion, this recommendation, in conjunction with the 2003 flow recommendation made by USFWS for SRCS spawning in upper Butte Creek, should provide a comprehensive assessment of SRCS flow needs in the Butte Creek watershed (CDFG 2009; USFWS 2003).

Both the 2D model development and CRA require depth, stage, discharge, and velocity measurements to be taken. The 2D model can be used to predict stages and discharges not sampled, but the method requires careful calibration. The CRA method is an empirical method and requires that three to six flows are sampled on the receding limb of the hydrograph within the same water year. Target flows for CRA data collection are predetermined using Flow Duration Analysis (CDFW 2013b). Flows within the range of those predetermined must be available to complete the analysis. Climatic conditions or unforeseen hydraulic operations in the creek upstream of the study sites could affect sampling and the study schedule.

1.5 Implications

This study will result in an instream flow recommendation for lower Butte Creek. This flow recommendation will be transmitted to the SWRCB in accordance with Public Resource Codes (PRC) §10000 - 10005. Additionally, these flow recommendations may be used to develop flow criteria to inform the flow objectives in high-priority tributaries in the Delta Watershed recommended by the Delta Stewardship Council's Delta Plan.

2.0 Project Description

2.1 Goals and Objectives

The goals of this study are to:

1. Determine flows through the Lahar formation consistent with existing minimum upstream passage depth criteria for SRCS; and
2. Determine flows through the critical riffles consistent with existing minimum upstream passage depth criteria for SRCS.

The primary objective of this study is to develop relationships between stream flow and upstream passage of adult SRCS through lower Butte Creek. Relationships will be developed by collecting water depth, wetted channel topography and width, and water velocity data. The following methods will be used to analyze the data and make flow recommendations:

1. Development of a 2D hydraulic model to predict stream flow versus river stage, depth, and velocity through the Lahar formation and critical riffles;
2. Identification of the minimum stream flow rates necessary for passage of adult SRCS through three representative critical riffles using CRA;
3. Creation of a rating curve by collecting stage/discharge data downstream of the Lahar formation;
4. Analysis of the 2D hydraulic model and CRA results to identify flow regimes associated with CDFW passage criteria for SRCS;
5. A final technical report describing results of the study and instream flow recommendations; and
6. Transmittal of an instream flow recommendations to the SWRCB.

2.2 Project Organization

Table 1. Project Personnel Affiliations, Roles, and Contact Information

Name (Affiliation)	Role	Phone	Email
Bill Cowan (Water Branch)	Project Coordinator	916-445-8560	William.Cowan@wildlife.ca.gov
Mark Gard (USFWS)	Contractor	916-414-6589 (MWF) 916-799-0534 (TTh)	mark_gard@fws.gov
Tracy McReynolds (Region 2)	Project Contact	530-895-5111	Tracy.McReynolds@wildlife.ca.gov
Clint Garman (Region 2)	Project Contact	530-895-5110	Clint.Garman@wildlife.ca.gov
Diane Haas (Water Branch)	Field Crew	916-445-8575	Diane.Haas@wildlife.ca.gov
Don Baldwin (Water Branch)	Field Crew	916-445-1921	Donald.Baldwin@wildlife.ca.gov
Mike Hancock (Water Branch)	Field Crew	916-445-5358	Mike.Hancock@wildlife.ca.gov
Candice Heinz (Water Branch)	Field Crew	916-445-5358	Candice.Heinz@wildlife.ca.gov
Robert Holmes (Water Branch)	QA Officer	916-324-0838	Robert.Holmes@wildlife.ca.gov
Paige Uttley (Water Branch)	Document Review	916-445-1747	Paige.Uttley@wildlife.ca.gov

Table 2. Project Staff Responsibilities

RESPONSIBILITIES	STAFF
Instream Flow Study Plan	Bill Cowan, Mark Gard, Robert Holmes, Don Baldwin, Diane Haas, Paige Uttley
Study Design and Approach	Mark Gard, Bill Cowan, Don Baldwin, Tracy McReynolds
Field Data Collection	
Reconnaissance, study site and transect selection	Mark Gard, Don Baldwin, Diane Haas, Bill Cowan
Critical Riffle Analysis Data Collection	Bill Cowan, Mike Hancock, Candice Heinz, Diane Haas
Hydraulic Model Data Collection (2D sites)	Mark Gard, Don Baldwin, Diane Haas, Bill Cowan, Mike Hancock, Candice Heinz
Hydraulic Model Construction and Calibration	Bill Cowan Mark Gard
Quality Assurance/Quality Control	Robert Holmes Bill Cowan Mark Gard
Data Management and Reporting	Robert Holmes Bill Cowan Mark Gard Paige Uttley

2.3 Project Timeline

Table 3. Project Activities and Timeline

ACTIVITY	DATE
Preliminary Field Reconnaissance and Site Selection	November 2012 - December 2012
Establish 1D Transects and 2D Area for Hydraulic Model	December 2012
Hydraulic Data Collection	January 2013 – December 2013
Critical Riffle Data Collection and Analysis	January 2013 – January 2014
Hydraulic Model Construction and Calibration	September 2013 – March 2014
Hydraulic Data Analysis and Model Summary	September 2013 – March 2014
Final Instream Flow Study Report	January 2014 – September 2014
Flow Recommendation	July 2014 – January 2015

Table 4. Equipment Required for Each Activity and Source

ACTIVITY / EQUIPMENT	PROVIDED BY
<u>Flow Measurements:</u> Marsh McBirney Flow Meter Top setting wading rod Transect measuring tapes	 CDFW CDFW CDFW
<u>Critical Riffle Assessment:</u> Garmin GPS Unit Stadia rod Transect measuring tapes Rebar	 CDFW CDFW CDFW CDFW

ACTIVITY / EQUIPMENT	PROVIDED BY
Water Surface Elevations:	
Nikon Auto Level	CDFW
Tripod	CDFW
Stadia rod	CDFW
Transect measuring tapes	CDFW
2D Hydraulic Model Survey:	
Trimble Total Station	CDFW
Trimble Data Collector	CDFW
Tripod	CDFW
Stadia rod with Prism	CDFW
Real-Time Kinematic (RTK) GPS Unit	USFWS
Acoustic Doppler Current Profiler (ADCP)	USFWS
Cataraft	USFWS
Solinst Pressure Transducer	USFWS
Solinst Barometric Pressure Transducer	USFWS

2.4 Coordination and Review Strategy

This study is being prepared for the CDFW IFP under a contract agreement with USFWS. USFWS will complete a series of two-dimensional (2D) models to: 1) assess passage through the Lahar formation where the CRA method is not applicable, and 2) evaluate flow regimes at critical riffle sites that are not assessable for empirical data collection, which is required for input to the CRA method.

CDFW staff will coordinate with USFWS on field reconnaissance, site selection, hydraulic model data collection schedule, monitoring equipment installation, model construction and summary, and study report. Equipment will be provided by USFWS and CDFW (Table 4).

Sites are accessible via California Department of Water Resources (DWR) maintained levees. Gate access to levee roads will be obtained from DWR through USFWS and CDFW Region 2 staff. CDFW will provide advanced notification to landowners in the event that site access necessitates access through private property. CDFW staff is committed to working with local landowners and stakeholders to ensure study activities are not a burden to landowners or to recreation in and along the stream.

2.5 Compliance Considerations

No permits are needed to complete the proposed instream flow study.

3.0 Project Design and Methodology

3.1 Study Design

Critical passage sites in lower Butte Creek were found to occupy two general categories: 1) the Lahar formation, an isolated area of exposed bedrock where flow patterns are dominated by braided, eroded channels (Figure 3), and 2) low-gradient alluvial riffles. CDFW Region staff identified the Lahar formation as a study priority. Riffle sites were added as a secondary study priority to ensure that resulting flow recommendation are representative of the entire lower Butte Creek watershed. Critical riffle sites were selected based on results from a critical riffle survey performed through the study reach.

Lahar Formation

The Lahar formation is composed of bedrock ledges making a 2D hydraulic modeling approach the most appropriate method for assessing upstream passage of SRCS at this site. The model will predict the velocities and depths present in the Lahar formation over a range of flows of at least one order of magnitude. Passage will be assessed by identifying pathways through the Lahar formation where fish can migrate at decreasing flows, until a single limiting pathway is exposed. Once this single limiting pathway or critical path is identified, physical parameters such as depth and velocity will be used to assess needs for upstream migration.

2D hydraulic model data collection will include Water Surface Elevations (WSELs), bed topography, cover, and substrate distribution. WSELs will be taken following the SOP for Streambed and Water Surface Elevation Data Collection in California (CDFW 2013d). The relationship between stream stage and discharge (stage/discharge) will be developed by measuring WSEL and discharge at three to five calibration flows. Total stations and survey-grade Real-Time Kinematic (RTK) GPS units will be used at low flows to collect bed topography data (i.e. bed elevation and horizontal location) and record channel substrate and cover. Data will be collected via a series of lines across the stream channel and along individual flow channels. Each line will include a point at each change in bed slope, substrate, or cover. The lines will be spaced close enough so that bed slope, substrate, and cover uniformly change between the lines. The topography survey will extend far enough onto the floodplain to allow simulation of the entire area which would be inundated at the highest flow. Three elements, topography, channel roughness (calculated from substrate and cover characteristics), and stage/discharge, will be entered into the 2D riverine model River2D following the Steffler and Blackburn (2002) method.

Topographic data will first be processed for use in the 2D hydraulic model using the River2D_Bed software (Steffler 2002). Breaklines will be added to produce smooth bed topography. The resulting dataset will then be converted into a computational mesh using the River2D_Mesh software (Waddle and Steffler 2002). Mesh elements will be sized to 0.1 ft, where possible, to reduce the error in bed elevations resulting from the mesh-generating process, given the computational constraints on the number of nodes. The resulting mesh will be used in River2D (Steffler and Blackburn 2002) to produce depths and velocities at simulated flows.

A Physical Habitat Simulation (PHABSIM) transect will be placed at the bottom of each site to calibrate WSELs simulated in River2D. A second PHABSIM transect placed at the top of each site will be calibrated to provide the WSELs used to calibrate the River2D model. The initial bed roughness used by River2D will be based on the observed substrate sizes and cover types. A multiplier will be applied to the resulting bed roughness, with the value of the multiplier adjusted so that at the top of each site, the WSELs generated by River2D, match those predicted by the PHABSIM transect. The River2D models will be run at the same flow the validation dataset was collected, and the output used in a Geographic Information System (GIS) to determine the difference between simulated and measured velocities, depths, bed elevations, substrate, and cover. If significant differences are found, the bed topography will be adjusted to correct the observed errors and the models will be re-run. The final report will include these differences, how well the models predicts observations before modification of the bed topography, and implications of interpretation based on potential bed topography adjustments.

An independent dataset of 50 random points will be collected for the Lahar formation to validate the physical predictions of the model. At each validation point, the bed elevation and horizontal location will be determined using a total station or Real Time Kinematic (RTK) GPS. The depth and velocity will then be measured, and the substrate and cover will be recorded.

A pressure transducer will be installed near the Lahar formation to monitor river stage (ft). River stage data and field discharge measurements will be used to create a rating curve. The rating curve will be used to develop a continuous estimate of discharge and will be routinely calibrated by field discharge measurements. River stage data will also be used to generate the downstream boundary condition for the hydraulic model.

Critical Riffle Sites

Riffles are characterized by exposed substrate and broad channel width and are referred to in this document as critical riffles. Lower Butte Creek was surveyed from the Parrot-Phelan Diversion Dam to the Western Canal Siphon with the shallowest path from bank to bank identified at riffles or other shallow areas in the stream. The wetted width was also measured with an electronic distance meter, and the location of the riffle recorded with a GPS unit. The greatest depth (thalweg) along each path was measured to 0.01 ft (0.03m). Critical passage sites were selected following methods developed by Thompson (1972). CRA will be used to identify the minimum stream flow rates needed for adult SRCS passage through three representative critical riffles in lower Butte Creek.

Passage through the riffles will be evaluated following methods in the CDFW CRA Standard Operating Procedure (SOP) (CDFW 2013a) using depth and width criteria developed originally by Thompson (1972) for salmonid passage as follows:

1. At least 10% of the entire length of the transect must be contiguous for the minimum depth established for the target fish; and
2. A total of at least 25% of the entire transect must be at least the minimum depth established for passage of the target fish.

The CRA depth passage criterion for adult Chinook salmon is 0.9 ft (0.27 m) (CDFW 2013a).

Measurements will be taken at the three critical riffle sites to capture the variability in salmon passage flows needed between Gorrill and Adams Diversion Dams. Data for CRA will be collected over a minimum of four to six flow events, typically taken during the receding limb of the hydrograph. These sampling events will be timed to capture the full range of discharges needed to adequately bracket and identify passage flows for SRCS life stages (CDFW 2013a). CRA sampling events will occur before boards are in place in the spring at Gorrill Diversion Dam and after they are removed in the fall to provide the most opportunities to capture the full range of discharges needed.

The three critical riffle sites identified for this study are all located upstream of where lower Butte Creek crosses under Midway Road. They were selected because the shallowest observed course, from bank to bank, at these sites was shallowest of all the riffles surveyed. These riffles were selected to evaluate their passage characteristics under natural flow conditions, where natural flow conditions are defined as conditions where the water surface elevation at the riffles is not affected by anthropomorphic activities such as water diversion. From approximately April 15th to October 15th the portion of the creek where the riffles are located is inundated as a result of a backwater effect from the downstream Gorrill Diversion Dam installing temporary boards to block water.

To evaluate flows that cannot be surveyed using the CRA method, 2D models of the riffles will be prepared by USFWS. Careful consideration will be required to evaluate data collected using the CDFW CRA empirical method in conjunction with the predictive stage/discharge 2D model. The critical riffle study sites in Butte Creek are situated in relatively broad, low gradient areas that can be very long. Consequently, at lower stages, flow through these areas may become braided. The 2D models will be used to evaluate whether the CRA criteria should be isolated to braided segments, leading to the creation of intermediary “banks” during low-flow conditions.

For unwadeable areas deeper than 3 ft (0.9 m), 2D model data will be collected along lines across the river with an Acoustic Doppler Current Profiler (ADCP) and RTK GPS mounted on a small cataraft. The RTK GPS will be used to record the initial and final locations of each line, as well as the WSEL of each line so that depths can be converted into bed elevations. Velocities collected by the ADCP will also be used to validate the physical predictions of the model.

Sampling bias will be minimized by using standardized methodology from the CDFW SOP manuals. Additionally, field workers will use standardized coding for substrate and cover and will be trained in the field prior to data collection. Data collected in the field will be reviewed and entered into electronic spreadsheets as soon as possible after staff returns to the office. Missing data or data in error will be reported to the Project Coordinator for evaluation. If new or replacement data is required, the Project Coordinator will coordinate with staff and USFWS to schedule additional field data collection during the current hydrologic season.

3.2 Identification of Study Reaches and Sampling Sites

The lower Butte Creek study reach extends 13 river miles (20.9 km) from the Parrot-Phelan Diversion Dam to the downstream Western Canal Siphon (Figure 1). The Lahar formation and three representative critical riffles are located within this reach.

Lahar Formation

The Lahar formation is located just downstream of the Durham Mutual Diversion Dam (Figures 2 and 3). The Lahar formation located in lower Butte Creek is unique and characterized by exposed bedrock of volcanic origins within the stream bed. Stream channel passage over the Lahar formation does not follow the geomorphic processes commonly observed in alluvial channel units such as riffles, pools, runs, and glides. As a result, the Lahar formation can act as a barrier to fish passage by interrupting the natural course of the stream thalweg. The Lahar formation study site begins at the top of the formation, immediately adjacent to the Durham Mutual Diversion Dam and extends downstream approximately 750 ft (228.6 m) to include the steep transition into alluvial deposits. Calibration flows will be taken just downstream of the Lahar formation study site in an area representative of the stream channel and having uniform depth and unobstructed flow. The unique Lahar formation may be a deterrent to upstream passage under most flow conditions, and potentially acts as a complete barrier to SRCS adult migration during summer low flows.

Critical Riffle Sites

Critical passage sites are expected to be found at some riffle areas. Riffles exist at grade changes in the channel and are characterized by exposed substrate and a broad channel width. The most critical areas (those riffles with the shallowest thalweg depths) were identified as study sites.

CRA sampling sites were identified using CRA SOP (CDFW 2013a) methods by CDFW and USFWS staff familiar with the study area. Staff waded the creek from Parrot-Phelan down to Western Canal. A total of 113 riffles, including the Lahar formation, were identified. Staff located the shallowest path from bank to bank of each riffle in the field and recorded the greatest depth along the path with a stadia rod. The depth measured with the stadia rod was assumed to correspond to the channel thalweg at that point in the creek. The results were later summarized and ranked by depth. Three of the seven shallowest riffles occurred in the same area and were chosen for this study. The three representative riffles used here ranked as follows:

- Site 97, Rank 1, thalweg depth 0.4 ft (0.12 m);
- Site 95, Rank 2, thalweg depth 0.5 ft (0.15 m); and
- Site 96, Rank 7, thalweg depth 0.7 ft (0.21 m).

The riffles selected for analysis are located just upstream of Gorrill Diversion Dam (Figure 4). Passage at these sites can be an issue between March 1st (when SRCS upstream migration begins) and the date of board installation at Gorrill Diversion Dam (usually between April 1st and May 1st).

Critical riffle site parameters will be recorded over a four- to six-part sampling series to capture the full range of discharges needed to identify passage flows. See Appendix A for blank data sheet. Parameters for each critical riffle include:

- Staff gage stage height
- Left Bank Wetted Edge (LBWE)
- Right Bank Wetted Edge (RBWE)
- Total length of the transect from headpin to tailpin
- Depth at regular intervals along the transect (the number of intervals is dependent on the width of the riffle and must be sufficient to capture changes in depth)

Data will be collected at the Lahar formation and critical riffle sites for input into 2D hydraulic models. Parameters include:

- Water surface elevations (WSELs)
- Bed topography
- Cover
- Substrate

WSELs will be taken at three to five flows spanning at least one order of magnitude. Bed topography, cover, and substrate will be taken at multiple points across each site to capture the full variability of each parameter, and extend far enough onto the floodplain to allow simulation of the entire area which would be inundated at the highest flow. In addition, bed topography, substrate, cover, depth, and velocity will be collected in an independent dataset of 50 random points at the Lahar formation to validate the physical predictions of the model.

A continuous record of creek flow stage, water temperature, and ambient air temperature will be recorded by a pressure transducer and thermometer installed approximately 0.10 mi (0.16 km) downstream of the Lahar formation. Routine measurements of WSEL and discharge will be made near the installation to develop a rating curve to match the continuous recording of stage with discharge. The installation will be allowed to collect data for a full calendar year.

Figure 4. Map of Critical Riffles Upstream of Gorrill Diversion Dam.

3.3 Biology

Butte Creek supports the largest self-sustaining, genetically distinct wild population of Central Valley SRCS (CDFG 1998; CDFG 2009). Migrating adult SRCS enter Butte Creek from March through mid-July, and hold over the summer in pools in the upper watershed (Williams et al. 2002). SRCS begin spawning in late September in the area from above the Parrot-Phelan Diversion Dam up to Centerville Head Dam, which represents the upstream migratory limit for SRCS in Butte Creek (CDFG 2009). Steelhead and fall-run Chinook salmon also utilize Butte Creek.

3.4 Hydrology

Butte Creek hydrology is complex as a result of the PG&E DeSabla-Centerville hydroelectric power project. Figure 5 displays the major hydrologic features of the watershed. The project generally consists of two reservoirs, three powerhouses, 14 diversion and feeder dams, 5 canals, and associated equipment and transmission facilities located on Butte Creek and the West Branch Feather River (SWRCB 2013). The existing project license expired on October 11, 2009 but continues to operate on an annual license issued by FERC (SWRCB 2013). During winter and spring, base flows typically provide adequate flow for full powerhouse operations; however, during the summer months base flow is augmented by reservoir releases. In the fall, the powerhouses operate at reduced capacities due to low stream flows (SWRCB 2013). The diversions from the West Branch Feather River utilize the cold water stored in Philbrook Reservoir to provide cold water releases for SRCS holding below Lower Centerville Diversion Dam. The unimpaired average annual yield of the Butte Creek watershed is approximately 243,000 acre-feet (300,000 dam^3) (Hillaire 1993).

The headwaters of Butte Creek originate in the Jonesville Basin Lassen National Forest at an elevation of 7,087 ft (2,160 m) (CSUC 1998). As Butte Creek transitions through the steep canyon section of Jonesville Basin, the stream flows in a south-southwest direction and is fed by numerous small tributaries and springs. Below PG&E’s Centerville Head Dam, the gradient becomes less steep. Upon leaving the canyon, Butte Creek flows through the valley section, which extends to the Butte Slough Outfall gates where the Creek first enters the Sacramento River. In the valley section, four dams (i.e., Parrot-Phelan, Durham Mutual, Adams, and Gorrill Diversion Dams) and multiple diversions remove water for irrigation. Most diversions operate from April to September; Parrot-Phelan, the most upstream dam, diverts water year-round (NMFS 2009). Dams in the lower basin section also impound and divert water for wildlife and agricultural uses. Butte Creek extends downstream of the Butte Slough Outfall and passes through the Sutter Bypass for approximately 40 mi (64 km) before entering the Sacramento River near Verona.

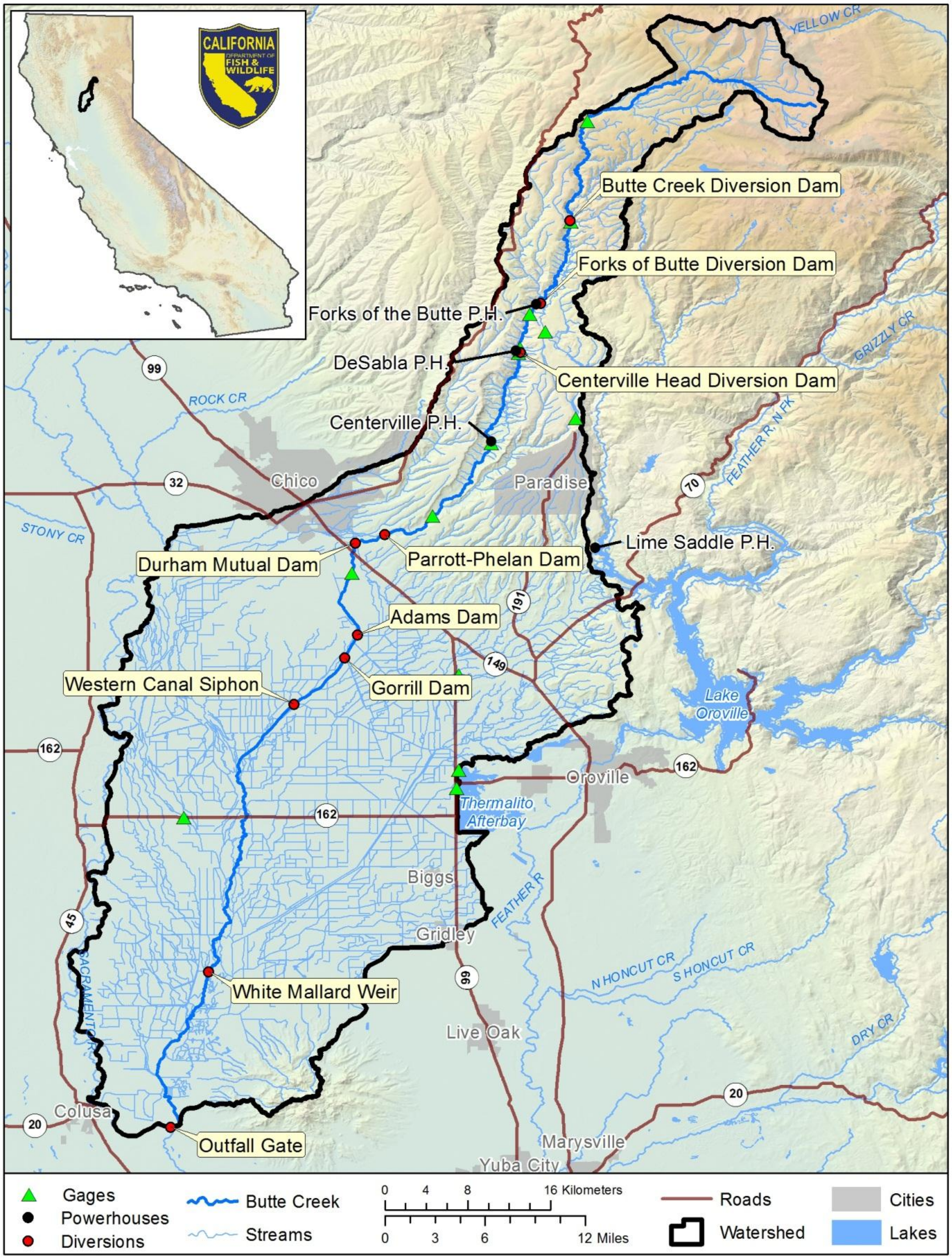

Figure 5. Major Hydrologic Features of the Butte Creek Watershed

Stream flow gaging stations are present in Butte Creek near the study sites. The U.S. Geological Survey (USGS) operates gage number 11390000 located near Honey Run Covered Bridge Road, referred to in this document as Covered Bridge. The gage is approximately 5 mi (8 km) upstream of Durham Mutual Diversion and fish ladder, halfway between the towns of Chico and Paradise, California. The mean daily flow record reported at gage 1139000 dates back to the year 1930. USGS reports data from this station on the USGS Water Resources website (USGS 2013). DWR began gaging the Parrot-Phelan diversion (BPD), located approximately 2 river mi (3.2 km) upstream of the Lahar site, in 1999. DWR also operates a gage (BCD) on Butte Creek near Durham, California approximately 3 river mi (4.8 km) upstream from the critical riffle sites. The gage near Durham started reporting in 1999. DWR reports the results for all three gages (including USGS gage 11390000, BCK) through the California Data Exchange Center website (DWR 2013a, b, c). Flows from all three gages will be used to track flows and schedule field data collection. Mean daily flow upstream of the Lahar formation was estimated by subtracting diversions made at Parrot-Phelan from the record reported for Covered Bridge. Mean daily flow for the critical riffle sites were represented by the DWR gage near Durham.

Target flows for sampling in Butte Creek were determined using the SOP for Flow Duration Analysis in California (CDFW 2013b). Daily exceedence flows were calculated using an unimpaired flow record at Covered Bridge for water years 1986 through 2005. Unimpaired flows were calculated by adding flows from Little Butte Creek to the unimpaired flow record for Centerville Powerhouse. Exceedence flows given in Table 5 were used to select the target flow range at the Lahar formation and critical riffle sites.

Table 5. Target Flows to be Sampled at the Lahar Formation and Critical Riffle Sites.

EXCEEDENCE PERCENTAGE	BUTTE CREEK UNIMPAIRED FLOW ESTIMATED AT COVERED BRIDGE (CFS)
10%	724
30%	411
50%	290
70%	209
90%	150

3.5 Connectivity

Under certain stream conditions, the Lahar formation serves as a seasonal barrier to adult SRCS. The upstream transition from the alluvial deposits onto the Lahar formation is steep, especially under low flow conditions, and creates a potential jump barrier to adult migrating SRCS. In addition, drainage is not centralized for effective fish passage under low flows, and the passageway(s) within the Lahar formation are not obvious. Water flows through and over the Lahar formation along many different pathways. CDFW Region 2 staff hypothesize that the lack of clear hydraulic connectivity within the formation creates added stress and a barrier to passage, especially later in the migration season when lower flows are combined with elevated water temperatures. In the event that a jump barrier is identified at the Lahar formation study site, the barrier will be evaluated using techniques developed in Analysis of Barriers to Upstream Migration (Powers and Orsborn 1985).

CDFW staff has observed migrating SRCS stopped at the Lahar formation, upstream of where the channel bed changes from alluvial deposits to bedrock, before retreating downstream to the holding pool below Highway 99 where they can later become stranded. The steep banks leading down to the pool have made access difficult and fish rescue attempts largely unsuccessful.

Critical riffles are shallow and sensitive to changes in stream flow due to lowered water depth (CDFW 2013a). It is thought that changes in stream flow and associated water depth could be limiting the hydrologic connectivity of riverine habitats and inhibiting critical salmonid life history strategies in the lower Butte Creek. Adequate water depths of sufficient width are necessary to identify passage flows and promote passage of adult and juvenile salmonids at critical riffle sites. Critical riffles are potential barriers to upstream and downstream passage, possibly impeding adult movement to and from holding and spawning areas, hindering smolt outmigration to the Sacramento River, and preventing rearing juveniles from moving between adequate summer freshwater rearing habitats (CDFW 2013a).

3.6 Geomorphology

The Tuscan Formation is a major geologic feature that covers approximately 2,000 mi^2 (5,180 km^2) of Butte Creek from Marysville to Oroville. The Tuscan Formation is the result of a Pliocene volcanic mudflow, commonly referred to as lahar. The deposit is composed of angular and subangular volcanic and metamorphic fragments in a matrix of gray-tan volcanic mudstone (Harwood et al. 1981; Lydon 1969). As Butte Creek cuts its way through the Butte Creek canyon to the valley floor, the slope changes dramatically and becomes less steep. The stream channel passes over and through exposed portions of the Tuscan Formation at the Lahar study site before spilling out into to the valley floor. In the valley section, the stream bed of Butte Creek is composed of alluvium from the Modesto Formation and Bank deposits (Saucedo and Wagner 1992).

In the lower Butte Creek study reach, the stream channel is composed of alluvial deposits upstream of the Durham Mutual Diversion Dam, exposed bedrock from the Tuscan Formation immediately downstream of the Diversion Dam forming the Lahar site, and then back to alluvium as the river enters the valley floor. Water drains over and through the Lahar via a complex braided network of trenches and gullies of varying depth (Figure 3). Remnant alluvial deposits (sand, gravel, and cobble) still remain in deep areas of the Lahar formation, especially where velocities are low. Several hundred yards downstream of the Durham Mutual Diversion Dam, the stream channel bed transitions back to alluvial sand and gravel deposits. A 2D hydraulic model will be used to assess upstream passage through the Lahar formation study site from the Durham Mutual Diversion Dam to the downstream transition back to the alluvial deposits.

3.7 Water Quality

Although overall water quality is considered excellent in the upper Butte Creek watershed, it is degraded in the lower system (CSUC 1998). Butte Creek is unique among the remaining SRCS streams in that the holding and spawning habitat is below 931 ft (283.7 m) elevation (CDFG 2009). As a result, water temperatures in Butte Creek have historically exceeded temperatures ideal for SRCS holding and spawning and it is hypothesized that these elevated stream temperatures during periods of low flow may be creating a thermal barrier to salmonid migration (Garman and McReynolds 2009). A pressure transducer will be installed just downstream of the Lahar formation to assess this.

4.0 Quality Assurance/Quality Control

4.1 Sampling Procedure (Standard Operating Procedures)

CRA data collection will be completed consistent with the applicable CDFW SOP (CFDW 2013a).

Field sampling techniques used to develop the data needed for the 2D models will follow standards set by USFWS for application of River2D (Steffler and Blackburn 2002).

Velocity, discharge measurements, and water surface elevation surveys will be completed consistent with the applicable CDFW SOP (CFDW 2013c, d).

4.2 Quality Objective and Criteria

The calibration of equipment necessary to conduct flow measurements and WSELs will follow the subsequent procedures to ensure sample accuracy.

Marsh-McBirney flow meters will be calibrated each day by a field team member before use in the field as described in the Discharge Measurements SOP (CDFW 2013c).

WSELs will be measured to the nearest 0.01 ft (0.3 cm) using standard surveying techniques (differential leveling) as described in the Water Surface SOP (CDFW 2013d). Wetted streambed elevations will be determined by subtracting the measured depth from the surveyed WSEL at a measured flow. Dry ground elevations to points above bankfull discharge will be surveyed to the nearest 0.1 ft (0.03 m). WSELs will be measured along both banks and in the middle of each transect if conditions allow. If the WSELs measured for a transect are within 0.1 ft (0.03 m) of each other, the WSELs at each transect will be derived by averaging the two to three values. If the WSELs differ by greater than 0.1 ft (0.03 m), the WSEL for the transect will be selected based on the side of the transect considered most representative of the flow conditions. The range of flows simulated will go up to the mean unimpaired flow in the highest flow month. Water surface elevations will be collected at a minimum of three relatively evenly spaced calibration flows, spanning approximately an order of magnitude. The calibration flows will be selected so that the lowest simulated flow is no less than 0.4 of the lowest calibration flow and the highest simulated flow is at most 2.5 times the highest calibration flow.

Data collected as part of the CRA will be checked for errors and completeness upon return to the office. Data will be entered into electronic spreadsheets for analysis. Errors or missing data will be reported to the Project Coordinator. Data collected for the 2D model will be reviewed by USFWS staff for errors and completeness. USFWS will contact the CDFW Project Coordinator to resolve issue with data errors or missing data.

4.3 Corrective Actions

If data collection errors or missing data are discovered, the Project Coordinator will review the issues with the appropriate Quality Assurance/Quality Control personnel to develop a plan for correction. Data collected will be reviewed as soon as possible upon return to the office so that if re-sampling is required it can be scheduled to occur during the current sampling season.

5.0 Data Management and Reporting

5.1 Data Validation

Data entry will be performed by USFWS and Water Branch staff. Water Branch will check critical riffle data. USFWS will download topographic data from field instruments and check the 2D model data. All data generated by this project will be maintained in both field logbooks and electronic spreadsheet formats.

Instream flow studies can be impacted by changing conditions because stream beds shift with high flow events that mobilize bed load. Annual hydrological conditions rarely follow historical averages. To assess potential variability at critical riffle sites, data is being collected at three representative riffles. Other critical riffle sites (not in the same area) have been identified in case data collection is halted at the current site and must be restarted in a new location. The Lahar formation is unique; there are no similar sites where data could be collected in case the Lahar formation study site became unavailable. The Lahar formation is not located on or near private property; access to the area is open to the public. The 2D model being prepared at the Lahar formation study site can be used to predict stage discharge over a range of flows without having to sample each flow. Staff will periodically sample the creek stage and associated discharge to maintain an up to date hydraulic rating curve at the Lahar formation study site.

5.2 Data Storage and Reporting

Water Branch staff will assess the data for the CRA. Water Branch and USFWS staff will analyze the data and complete the 2D hydraulic modeling together.

USFWS staff will draft the hydraulic model section of the report. Water Branch staff will complete the final report and post to the CDFW website.

CDFW will store the hard copies and electronic data.

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Appendix A. Critical Riffle Analysis Field Data Sheet

Critical Riffle Analysis for Fish Passage in California
Standard Operating Procedure DFG-IFP-001

Page 1

Location: ____________ Date: ____________

Site Name: ____________ Field Staff: ____________

Riffle Name: ____________ Photo File Name: ____________

Site Description: ____________ Staff Gage Start: ____________

GPS Coordinates: ____________ Staff Gage End: ____________

CRA Sample Event No. (1-6) and Targeted Flow: ____________ Time Start: ________ Time Stop: ________

Critical Riffle Total Width hp to tp (ft): ____________ LBWE: ________ RBWE: ________

Reference Discharge (cfs): ________ Target Species: ____________

Meter Number: ________

Notes:

Station	Distance	Depth
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Station	Distance	Depth
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