

DRAFT
Instream Flow Regime Recommendations
BUTTE CREEK, Butte County



California Department of Fish and Wildlife
Water Branch, Instream Flow Program
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Preface

The Department of Fish and Wildlife (Department) has a responsibility for assuring that water flow within streams is maintained at levels which are adequate for long-term protection, maintenance, and proper stewardship of fish and wildlife resources. The Department has developed recommended instream flow criteria for Butte Creek, located in Butte County, for transmittal to the State Water Resources Control Board (State Water Board) and for consideration as streamflow requirements as set forth in Section 1257.5 of the Water Code. Submission of these instream flow regime recommendations to the State Water Board complies with Public Resources Code §10001-10002.

The Department is recommending instream flow criteria for Butte Creek from Parrott-Phelan Diversion Dam and fish ladder downstream to the Western Siphon. Flow criteria were developed for each month of the adult spring-run Chinook salmon (SRCS) migration period (February through June) and water year type. This report summarizes the data sources and rationale used to develop flow criteria for adult SRCS migrating upstream through the study reach.

The Department presents to the State Water Board the enclosed set of instream flow regime recommendations for Butte Creek and believes them to be comprehensive and substantially complete. The flow criteria were based upon information developed through the Department's recent passage flow study, the results of which are summarized in the Technical Report *Instream Flow Evaluation of Upstream Spring-Run Chinook Salmon Passage in Butte Creek, California* (Cowan and Gard 2016). The Department may revise the instream flow criteria for Butte Creek at a later date based upon any new scientific information that may become available.

TABLE OF CONTENTS

Preface.....	2
List of Tables.....	4
List of Figures.....	4
Statement of Findings	5
Butte Creek Watershed.....	8
Central Valley Spring-Run Chinook Salmon in Butte Creek.....	10
Butte Creek Hydrology	14
Regulated and Unimpaired Flows by Water Year Type	14
Channel-Forming Flows	17
Flow Agreements	17
Passage Study	18
Lahar Site Methodology	19
Riffle Site Methodology	19
Species-Specific Depth Criteria	21
Summarized Lahar Site Results.....	21
Summarized Critical Riffle Results.....	24
VAKI Data Summarized	25
Site-Specific Passage Width Criteria – Lahar Site	28
Instream Flow Regime Recommendations.....	30
Base Tier (120 cfs).....	30
Middle Tier (240 cfs)	31
Upper Tier (405 cfs).....	31
Instream Flow Regime Recommendations by Month and Water Year Type.....	31
Probability of Exceedance.....	32
Standard-Setting and Desktop Methods	34
Water Year Type and Flow Monitoring Stations	35
Climate Change	37
Literature Cited.....	38

List of Tables

Table 1. Median regulated flows in cubic feet per second (cfs) recorded at USGS 11390000.	16
Table 2. Median Monthly Unimpaired Flows in cfs during the SRCS migration period..	16
Table 3. Lahar site passage flow results and corresponding widths.	21
Table 4. Riffle site River2D maximum contiguous width along the shallowest course from bank to bank.....	24
Table 5. VAKI Riverwatcher adult passage counts,	26
Table 6. Lower Butte Creek Passage Flow Criteria in cubic feet per second to pass SRCS into the upper watershed.	32
Table 7. POE expressed in percent for each selected flow criterion identified in Table 6 based on the average daily discharge reported for USGS 11390000 (1931 – 2015) by water year and month.....	33
Table 8. Standard-setting “desktop” flow criteria for passage.	34

List of Figures

Figure 1. Butte Creek Watershed Map.	6
Figure 2. Study Reach.....	7
Figure 3. The primary study site, the Lahar formation, located upstream of Highway 99 (pink line).....	9
Figure 4. Lahar formation, view facing upstream towards Durham Mutual Diversion Dam and fish ladder.....	9
Figure 5. Adult SRCS holding below the Lahar site.	13
Figure 6. Closer view of adult SRCS holding below the Lahar site in a shallow pool.	14
Figure 7. Riffle 96 shallowest course from bank to bank over site topography.....	20
Figure 8. Lahar Site – Discharge versus width with depth ≥ 0.9 feet.....	23
Figure 9. Depth profiles in the limiting choke point area of the Lahar site. Flow levels start at the upper left with 40 cfs and move clockwise around to 120, 240, and 405 cfs.	24
Figure 10. VAKI Riverwatcher installed in the fish ladder adjoining Durham Mutual Diversion Dam.....	26
Figure 11. Cumulative percentage of fish passing upstream through the VAKI device.	27
Figure 12. Stream flow monitoring stations in study reach.	36

Statement of Findings

Butte Creek is a significant watercourse for which flow criteria are needed to assure the continued viability of stream-related fish and wildlife resources (Figure 1). Butte Creek was selected for development of flow criteria since it is a significant watercourse with high resource value, and due to its importance as a source stream for the Evolutionary Significant Unit (ESU) of central valley spring-run Chinook salmon (*Oncorhynchus tshawytscha*), per National Marine Fisheries Service's Central Valley Resource Recovery Plan (Recovery Plan) (NMFS 2014). Butte Creek is also one of three streams (in addition to Mill and Deer creeks) possessing a genetically distinct population of SRCS, making it a conservation stronghold for the threatened species and paramount to the long-term recovery of the ESU (NMFS 2011). Insufficient instream flow for adult upstream migration of SRCS to their spawning grounds in the upper watershed has been identified in the Recovery Plan as a key risk to SRCS population viability in Butte Creek (NMFS 2014). Increased instream flow during migratory periods is expected to help protect current populations from further decline as well as provide opportunity for future improvements in the recovery of SRCS.

Background

The instream flow study conducted by the Department focused on upstream passage of migrating adult SRCS through a study reach defined as the stretch of stream from Parrott-Phelan Diversion Dam and fish ladder to the Western Siphon (Figure 2). The study reach was considered homogeneous based upon gradient, geomorphology, hydrology, riparian zone types, flow accretion, diversion influence, and channel metrics.

Outlined below is information on the Butte Creek Watershed, the status and trends of SRCS in the Central Valley ESU, and requirements of migrating adults. Following the background information is an overview of the data sources, water month type definitions, and local hydrology evaluation used to develop the instream flow criteria. Lastly, the instream flow criteria are outlined, followed by an overview of the uncertainty associated with climate change impacts and the Department's commitment to minimizing such impacts to the State's natural resources.

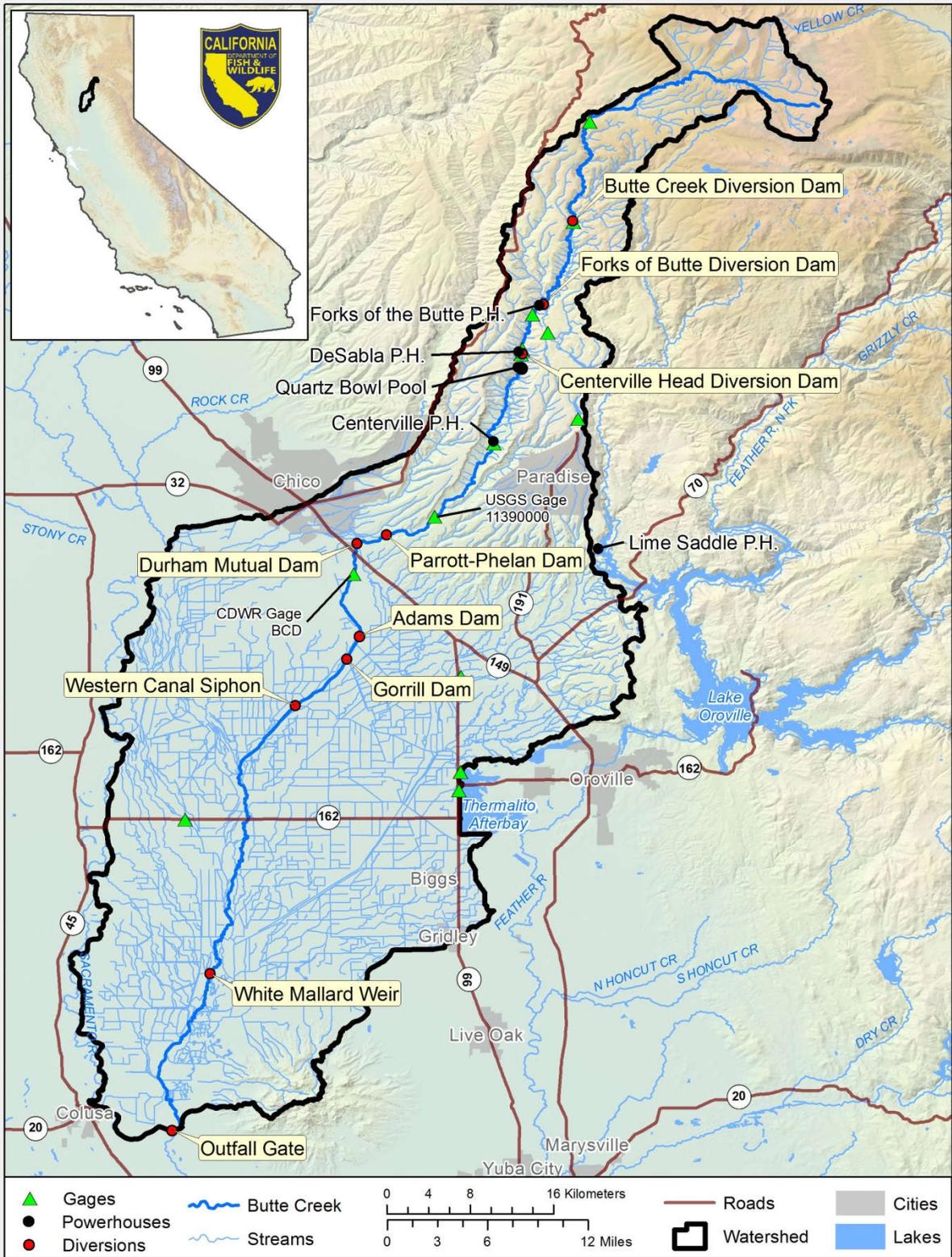


Figure 1. Butte Creek Watershed Map.

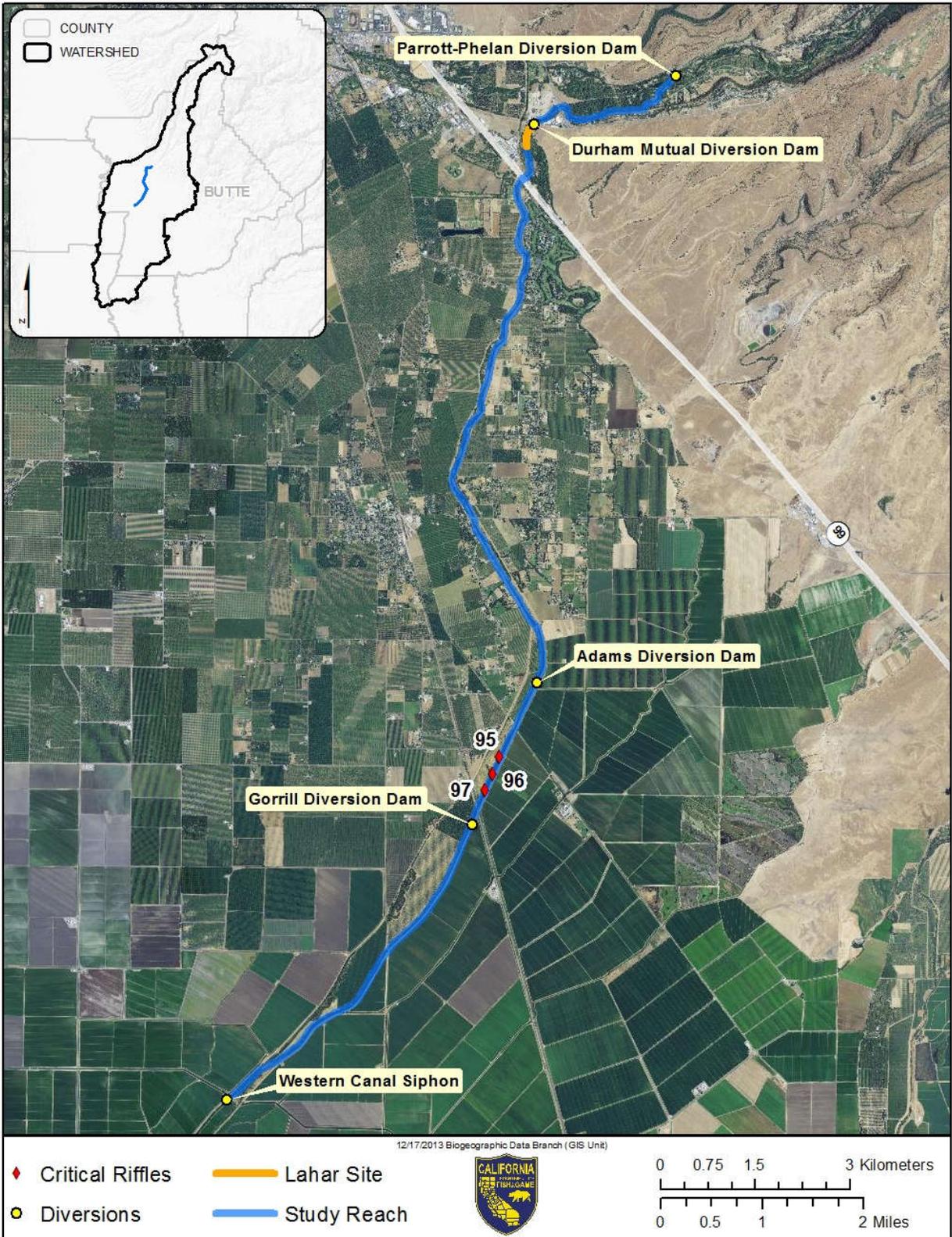


Figure 2. Study Reach.

Butte Creek Watershed

The Butte Creek watershed resides in the northeast corner of Butte County at its boundary with Tehama County to the north and Plumas County to the east. Butte Creek originates in the Jonesville Basin, Lassen National Forest, on the western slope of the Sierra Nevada mountain range, at an elevation of approximately 7,000 feet (CSUC 1998). The creek flows southwesterly before joining the Sacramento River at Butte Slough near Colusa, California. The watershed is approximately 809 square miles (mi²) and has an average annual, unimpaired flow yield of 243,000 acre-feet (Hillaire 1993 as cited in CDFG 2009). Several small streams converge in Butte Meadows forming Butte Creek before it descends approximately 25 river miles through Butte Creek Canyon finally spilling out onto the valley floor south of Chico, California.

The streambed in the valley section of Butte Creek is composed of alluvial silts, sands, and gravels of the Modesto Formation (CSUC 1998; Saucedo and Wagner 1992). Although alluvial deposits persist in the streambed, as Butte Creek moves into Butte Creek Canyon the alluvial streambed is interrupted by exposures of the Tuscan Formation. The Tuscan Formation is the predominant geologic unit in the upper watershed and consists of Lahars, volcanoclastic sediments, and tuff (CSUC 1998; Saucedo and Wagner 1992). As Butte Creek ascends from the valley floor northeast towards Butte Creek Canyon (Figure 1), the streambed abruptly changes from alluvium to bedrock, flowing over an exposed portion of the Tuscan Formation (Williams et al. 2002). The change occurs approximately one half river mile upstream from where State Highway 99 crosses over Butte Creek and approximately seven-tenths of a mile upstream from a pool where SRCS are known to hold and become stranded (Figure 3). The bedrock exposure, referred to here as the Lahar site, persists upstream for approximately one-tenth of a mile (167 meters) before terminating immediately below Durham-Mutual Diversion. Butte Creek is confined in this section by levees on both sides of the channel. The presence of bedrock does not allow the creek to flow through a natural thalweg, but instead forces flow through a network of eroded gullies (Figure 4). The streambed returns to alluvial sediments upstream of Durham Mutual Diversion.



Figure 3. The primary study site, the Lahar formation, located upstream of Highway 99 (pink line).



Figure 4. Lahar formation, view facing upstream towards Durham Mutual Diversion Dam and fish ladder.

Central Valley Spring-Run Chinook Salmon in Butte Creek

SRCS have been extirpated from the majority of their historical range within the Central Valley, and viable populations currently spawn in and inhabit three Sacramento River tributaries: Mill, Deer, and Butte creeks. The National Marine Fisheries Service has identified these three creeks as the only known tributaries in California to harbor genetically pure populations of SRCS within this ESU (NMFS 2014; CDFG 2008). Butte Creek is the most productive of the three Sacramento Valley creeks (i.e., Butte, Mill, and Deer); therefore, the viability of the Central Valley SRCS ESU is reliant upon sustaining the Butte Creek SRCS population.

SRCS utilizing Butte Creek have a unique freshwater life history pattern. Migrating adult SRCS move from the Pacific Ocean, through the Bay-Delta, up the Sacramento River, and enter Butte Creek through the Sacramento Slough, Sutter Bypass West Borrow Canal, Willow Slough, and finally into the Sutter Bypass (DWR 2003). SRCS must migrate through Butte Slough and Butte Sink before entering the valley section, defined as the reach of stream just past the Western Siphon. Fish migrate through lower Butte Creek into the upper watershed starting in mid-February and ending in late May or early June depending on water year type (Clint Garman personal communication, April 3, 2014). SRCS do not spawn until the early fall, requiring them to hold in pools over the summer. In Butte Creek, SRCS summer holding and spawning habitat range from the upper limit of anadromy below Pacific Gas and Electric (PG&E) Centerville Head Diversion Dam downstream to the Parrott-Phelan Diversion Dam and fish ladder (Holtgrieve and Holtgrieve as cited in CDFG 1998), a distance of approximately 11 miles. The uppermost three miles below Centerville Head Diversion Dam, including the Quartz Bowl (Figure 1), provide the deepest and most suitable holding habitat (CDFG 2008). Spawning starts in September and lasts into October (Clint Garman personal communication, April 4, 2014).

SRCS abundance had declined from an estimated historical peak of over 700,000 fish to a 5-year mean return in the late 1980s of 67-243 spawners (NMFS 2005)¹. Declines in SRCS population are attributed to several factors: poor ocean conditions, early commercial gillnet fishing, hydropower development, water development blocking access to headwater areas, habitat degradation, and hatchery practices (NMFS 2005, 2011). SRCS were listed as threatened under both the California Endangered Species Act and the federal Endangered Species Act in 1999 (FR notice: 64 FR 50394). Since 1999, The National Marine Fisheries Service has reaffirmed the listing of SRCS twice, in 2005 and 2011; SRCS remain listed as a threatened species. While SRCS found in Mill,

¹ 5-year mean or 5-year geometric mean is a population statistic used by National Marine Fisheries Service for short- and long-term population trend analysis.

Deer, and Butte creeks are all part of the Central Valley ESU, for management purposes, they are generally considered two independent populations; Mill and Deer creeks comprise one population and Butte Creek the other (NMFS 2004). The independent population of SRCS within Mill and Deer creeks is identified in the high extinction risk category due to their continued rate of decline (NMFS 2011). The ESU of Butte Creek is classified as at a low to moderate risk of extinction, but on the verge of high risk (NMFS 2011).

SRCS began repopulating Butte Creek in 1991 after significant restoration actions were initiated under the Central Valley Project Improvement Act. As part of implementation of Central Valley Project Improvement Act related activities in the Butte Creek watershed, facilities blocking migration were removed and replaced with facilities with integrated fish passage structures, such as fish ladders (DWR 2005). Prior to these restoration activities, SRCS access to spawning habitat was severely limited. Since the 1990's, fish ladders have been replaced or upgraded with state-of-the-art fish screens and new structures installed at Gorrill, Adams, Durham-Mutual, and Parrott-Phelan diversions (Figure 1). These improvements allow SRCS to access upper Butte Creek and subsequently improved returns of SRCS.

Since 1992, the Department has coordinated with other state and federal resource management agencies, as well as water interests and local stakeholders, to implement major restoration actions in the Butte Creek watershed. Restoration has been focused primarily upon anadromous fish, specifically the state and federally listed SRCS and steelhead trout. Instrumental to successful watershed restoration has been the involvement of PG&E. PG&E operates the DeSabra-Centerville Head Diversion Project (Project) located on Butte Creek near Chico, in Butte County California. Operation of the Project directly affects flows and water temperatures, which impact SRCS in the approximately 11 mile-long holding and spawning reach of Butte Creek. State and federal agencies work with PG&E on an annual basis to manage Project reservoir releases and provide more suitable water temperatures for SRCS in Butte Creek.

Index surveys conservatively indicate that Butte Creek spawning escapement estimates averaged 3,900 SRCS in the 1990's with a high of 20,212 in 1998 (CDFG 2008). Mark and recapture surveys completed between 2012 and 2014 reported 16,140 spawners in 2012, 15,887 in 2013, and only 3,616 in 2014 (Garman 2014).

Since restoration activities in the early 1990's improved access to Butte Creek for SRCS, Department staff have not observed stranding or delayed holding of adult SRCS below Western Siphon or within the study area other than in the area of the Lahar

site/Highway 99 Bridge (Tracy McReynolds personal communication, December 4, 2012).

However, despite improvements to the watershed for salmonids, in the early 2000's Department staff began observing adult SRCS holding in a shallow pool three tenths of a mile downstream of where Butte Creek passes under State Highway 99 south of Chico, California (Tracy McReynolds personal communication, December 4, 2012; Figure 3). The initial start date when adult SRCS begin holding, in the shallow pool downstream of State Highway 99, depends on hydrology and weather conditions in the area. The digital images in Figures 5 and 6 below were taken of a pool just downstream of the Highway 99 Bridge on May 10, 2013, a dry year. Department staff reported that adults appeared to hold in the pool before attempting to migrate further upstream. Department staff believes when the holding first starts that adults are merely resting in the pool before moving upstream beyond the Lahar site. The adults that migrate away from the pool are replaced by other, later arriving adults. Department staff observed that the impetus for adults to migrate upstream wanes and the adults become stranded as the run time moves into summer, flows recede, and water temperatures increase. Attempts have been made in the past to capture and relocate stranded fish into the upper watershed. Mosser et al. (2013) studied the fate of transplanted fish using radio tags and found that none of the tagged fish that were relocated survived to spawn.



Figure 5. Adult SRCS holding below the Lahar site.



Figure 6. Closer view of adult SRCS holding below the Lahar site in a shallow pool.

Butte Creek Hydrology

Watershed hydrology is considered in detail in the report entitled *Instream Flow Evaluation of Upstream Spring-run Chinook Salmon Passage in Butte Creek, California* (Cowan and Gard 2016), referred to here as the Technical Report. Hydrologic trends were evaluated in the Technical Report using return interval or flow exceedance expressed as percent probability. Flow exceedance is the method used to select flow range for sampling riffles that may be impediments to passage (Thompson 1972; CDFG 2012). In this report, monthly medians are used to estimate expected water supply for the five water year types as defined by the California Department of Water Resources (DWR).

Regulated and Unimpaired Flows by Water Year Type

Flows have been recorded above the study reach since 1922 at United States Geological Survey (USGS) stream gage station 1139000 (USGS 11390000), Butte

Creek near Chico. USGS 11390000 consistently began reporting flows starting in the 1931 water year. There are no intervening tributaries between USGS 11390000 and the study reach. However, the flows measured at USGS 11390000 are considered to represent regulated conditions since these flows include contributions of flow from the West Branch Feather River through the Hendricks/Toad Town Canal (CDFG 2008). The DeSabra-Centerville Hydroelectric Project is operated as a run-of-the-river system (SWRCB 2015), since project operations are not consumptive. However, water imported from the Feather River is added to Butte Creek through Toad Town Canal, above Centerville Powerhouse and the study reach. The contribution of imported water is recorded as part of the total Butte Creek flow at USGS 11390000, located in between Centerville Powerhouse and the study reach. The record for USGS 11390000 for the period of 1931 to the present includes flows from the West Branch Feather River as part of the DeSabra-Centerville hydroelectric project operated by PG&E, and thus represents regulated flows. To estimate unimpaired flow in Butte Creek, the average daily flows from the monitoring station on Toad Town Canal, BW-12, were subtracted from USGS 11390000 recorded downstream.

Unimpaired conditions were assumed to be equal to USGS 11390000 average daily flows minus imports from the West Branch Feather River. PG&E provided West Branch Feather River import data for the water years 1958 through 2005 as a courtesy with the understanding that the data was internal operational data only and not verified by USGS (email from Catalina Reyes, July 6, 2015). Median flows for both regulated and unimpaired conditions were estimated for the study reach using the data from USGS 11390000 for the months when the SRCS migration occur, February through June (Tables 1 and 2).

Median flows were estimated for five water year type classes: critical (C), dry (D), below normal (BN), above normal (AN), and wet (W). Water year types were defined using the Sacramento Valley Water Year Index, reported by the DWR update to Bulletin 120. This index was originally specified in the State Water Board's Water Quality Control Plan and is used to determine water year types implemented in the State Water Board's Water Rights Decision 1641 (D-1641). Year types are set by first of the month forecasts beginning in February and ending in May. Final determination is based on the May 1, 50% exceedance forecast. The index equals 0.4 times the current April through July runoff forecast plus 0.3 times the current October through March runoff plus 0.3 times the previous water year's index. If the previous water year's index exceeds 10.0, then 10.0 is used. The Sacramento Valley Water Year Hydrologic Classifications are defined as follows:

Year Type:	Water Year Index:
Wet	Equal to or greater than 9.2
Above Normal	Greater than 7.8, less than 9.2
Below Normal	Greater than 6.5, and equal to or less than 7.8
Dry	Greater than 5.4, and equal to or less than 6.5
Critical	Equal to or less than 5.4

DWR publishes Bulletin 120 four times a year, the second week of February, March, April, and May. Bulletin 120 provides forecasts of unimpaired runoff volumes used to compute the Sacramento Valley Water Year Index.

The median regulated flow for each month of the SRCS migration period was computed for each water year type using flow data from USGS 11390000 for the period of October 1, 1930 through September 30, 2015. As stated above, water year types are based on the Sacramento Valley Water Year Index; historical water year type information is provided by the DWR California Data Exchange Center at <http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST>.

Table 1. Median regulated flows in cubic feet per second (cfs) recorded at USGS 11390000 for Water Years 1931-2015.

WYT	February	March	April	May	June
Critical	229	319	290	223	136
Dry	296	438	405	306	182
Below Normal	412	514	563	415	235
Above Normal	635	717	643	525	294
Wet	797	809	825	694	363

Table 2. Median Monthly Unimpaired Flows in cfs during the SRCS migration period.

WYT	February	March	April	May	June
Critical	158	244	188	150	91
Dry	230	380	316	208	112
Below Normal	384	444	410	260	125
Above Normal	521	630	575	483	218
Wet	702	694	691	520	242

The median monthly unimpaired flows are lower than the regulated flows recorded at USGS 11390000 for each month and water year type reflecting imports from the West

Branch Feather River. This trend is unique; typically, unimpaired flows are higher than recorded flows due to the presence of consumptive diversions upstream. Flow levels at the study sites are affected by diversions from Parrott-Phelan and Durham Mutual located upstream of the sites.

Channel-Forming Flows

Salmonid habitats rely on routine channel-forming flows for renewal of the channel and riparian areas needed to foster healthy riverine habitats, ecologic function, population health, and species viability (SWRCB 2014). Bankfull stage provides a level necessary to affect channel form (Dunne and Leopold 1978). Bankfull discharge occurs when levels first contact the active floodplain (Leopold and Wolman 1957). The elevation that coincides with bankfull stage is not consistent along any natural stream channel alignment. Leopold et al. (1995) estimated that a flow level that exceeded the 1.5-year return event was necessary to initiate channel-forming flows. The partial duration method or peaks over thresholds (Linsley et al. 1982) is the preferred method to estimate the channel-forming flows (SWRCB 2014). The channel-forming flow for the study reach was derived from annual floods over the last 50 years based on average daily discharge data from USGS 11390000. The channel-forming flow for the study reach is estimated to be 1,370 cfs.

Flow Agreements

PG&E's DeSabra-Centerville project diverts water from Butte Creek at the Butte Head Dam and at the Lower Centerville Diversion Dam (PG&E 2007), and water is released back into Butte Creek below DeSabra Powerhouse and Lower Centerville Diversion Dam, respectively. In addition, the Forks of Butte Creek Powerhouse, a hydro power project owned by Energy Growth partnership, Inc., is located just upstream of DeSabra Powerhouse. Flows through this project are run-of-the-river, and no water is stored as part of the project.

Flows are provided downstream of the Parrott-Phelan Diversion through an agreement between the Department, United States Fish and Wildlife Service (USFWS), the Nature Conservancy, and Parrott Investment Company, commonly known as the Butte Creek Water Exchange. The Butte Creek Water Exchange ensures 40 cfs are left instream from October 1 through June 30 (Jones and Stokes Associates 1996). Under a separate agreement with Parrott Investment Company, M&T Chico Ranch exchanges water that would be otherwise diverted from Butte Creek with water pumped directly from the

Sacramento River. The source of the water provided by the Butte Creek Water Exchange is the West Branch Feather River, not unimpaired flow Butte Creek. When outages occur in deliveries from the West Branch Feather River through Toad Town Canal, supplies may not be adequate to allow 40 cfs past Parrott-Phelan Diversion Dam and fish ladder.

Passage Study

Flow criteria developed for adult SRCS passage through lower Butte Creek rely on the results of a passage study performed by Department and USFWS staff in the Technical Report. The passage study incorporated field measurements, hydrology data gathered from a temporary monitoring station installed just downstream of the primary study site, USGS 11390000, PG&E data detailing imports from the West Branch Feather River, and two years of fish passage data from a counting device installed in the Durham Mutual fish ladder.

The passage study was conducted between 2012 and 2015 as part of the Department's Instream Flow Incremental Methodology (IFIM) evaluation of flows needed for SRCS to access their native spawning grounds in upper Butte Creek (Cowan and Gard 2016). The passage study provides the technical basis for flow criteria presented in this report and was completed through an agreement between the Department and USFWS. Staff from the USFWS Anadromous Fish Restoration Program provided technical expertise for the passage study completed and referenced in this document. USFWS staff was assisted by the Department's Instream Flow Program and North Central Region staff.

This criteria report does not include all the technical details, full description of the methods, and results that are included in the Technical Report. A summary of the methods used in the passage assessment of Butte Creek are outlined below. An electronic link to the Technical Report is provided in the literature cited section of this report.

The Technical Report documents the rationale used to select passage-limiting sites and the development of predictive hydraulic models using the two-dimensional modeling software River2D. The minimum body depth criterion for adult SRCS and the results of River2D models were combined to estimate the available wetted width meeting the depth criterion for upstream migrating adult SRCS in each passage-limiting site. Passage was assessed in two areas of the lower Butte Creek study reach. Sites were selected based on input from the Department's North Central Region staff as well as results of a conventional riffle survey performed by Department staff, described further in the Technical Report. The primary study site area, referred to as the Lahar site, is

located immediately downstream of Durham Mutual Diversion and fish ladder at river mile 43 (Figure 3). The Lahar site is located where the alluvial streambed is interrupted by a bedrock outcrop of the Tuscan Formation (Williams et al. 2002; Figure 4). The secondary study area consists of three alluvial riffles located just upstream of Midway Road in between the Gorrill and Adams Diversions at river mile 36 (Figure 2).

Lahar Site Methodology

The Lahar site is the location of most concern for adult SRCS upstream migration due to lethal stranding events that have occurred in a shallow holding pool approximately half a mile downstream of the site (Figure 3) (Tracy McReynolds personal communication, December 4, 2012). The Lahar site represents a difficult and challenging point in the river for fish passage and was included in the passage assessment. The exposed Tuscan bedrock disrupts the natural stream thalweg, decentralizing flow through a complicated and discontinuous network of narrow, rigid bedrock gullies (Figure 4).

Typically, in alluvial streams, riffles control upstream passage; however, in lower Butte Creek the Lahar formation is hypothesized to govern passage for upstream adult SRCS. The Lahar is a rigid bedrock outcropping that cannot be evaluated through methods such as Thompson (1972) that are designed to be used within steady-state alluvial channels. The Department selected the two-dimensional model River2D to evaluate the Lahar site due to its ability to capture the complex hydraulics present at the site. Two-dimensional modeling enabled staff to identify critical pathways for fish passage through the complex flow network of the Lahar formation. River2D is a commercially available version of two-dimensional modeling application that allows the end user to map a site and develop an accurate stage/discharge relationship over a broad range of hydrologic conditions. River2D Version 0.93 November 11, 2006 (Steffler and Blackburn 2002) was used to assess passage through the Lahar site. Depths along critical pathways were identified in River2D and combined with minimum depth criterion to estimate the amount of contiguous width available for upstream migrating adult SRCS.

Riffle Site Methodology

Apart from the Lahar site, the study reach is characterized by alluvial riverine deposits (Saucedo and Wagner 1992). Typically, passage assessments based in alluvial river systems focus on riffles. Critical riffles (i.e., shallow riffles which are particularly sensitive to changes in stream flow due to diminished water depth) can impede the hydrologic connectivity of natural river habitats during low flow conditions and can disrupt critical life history tactics of anadromous salmonids (CDFG 2012).

In addition to the Lahar site, the study reach was surveyed for potential passage impediments by conducting a riffle inventory survey. One hundred and twelve riffles were identified and measured during a three day survey, which took place November 5th through 7th, 2012. Three riffles, indicated on Figure 2, were selected for assessment: riffles 95, 96, and 97. Riffles 95 and 97 were found to be the most limiting to passage in thalweg depth (shallowest) and channel width (widest). Refer to Table 4 of the Technical Report for more details (Cowan and Gard 2016). Riffle 96 was also found to be one of the shallowest and widest riffles surveyed ranking near the top in passage-limiting categories, having the 7th shallowest thalweg depth and 10th widest channel width. It was included in the riffle assessment because of its shallow nature and proximity to Riffles 95 and 97.

Components of Critical Riffle Analysis (CRA), described in the Department's Standard Operating Procedure (CDFG 2012), were used to assess the riffles using River2D. CRA analysis involves choosing the shallowest course of the riffle from bank to bank and evaluating depth and width against established criteria for passage along that course. The shallowest course evaluated for Riffle 96 is shown below in Figure 7. The course coordinates and elevations were surveyed using a real-time kinematic global positioning system (RTK GPS) and the data were input into the topographic terrain model developed using River2D.

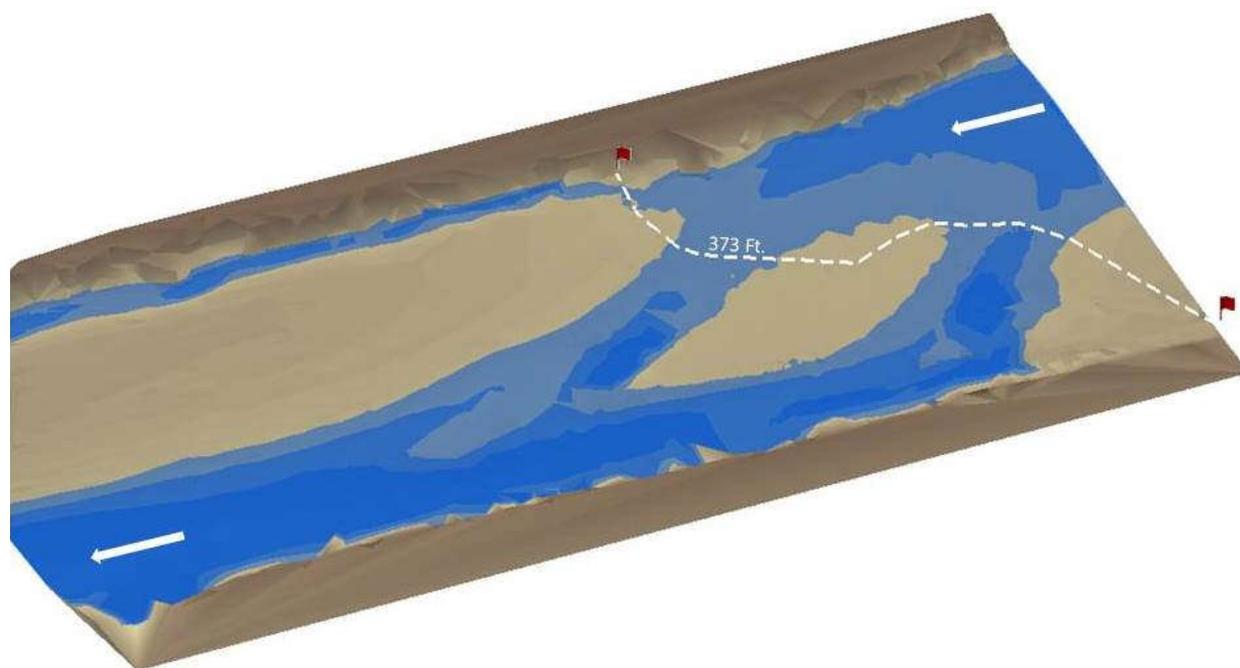


Figure 7. Riffle 96 shallowest course from bank to bank over site topography.

To evaluate passage, CRA analysis involves estimating percentages of channel width meeting specified depth criteria at four to six distinct flows within a suitable range. Two-dimensional models were prepared to simulate the flows needed to evaluate passage conditions for SRCS, and were used to simulate changes in limiting depth and width instead of collecting a series of empirical data points at distinct flows for two main reasons: 1) two-dimensional modeling allows the end user to choose the flow regime or range of flows they wish to focus on after data collection is completed; and 2) placement of flashboards at Gorrill Dam downstream of the riffle sites limited the time available to collect the necessary number of distinct flows along the receding limb of the spring hydrograph.

Species-Specific Depth Criteria

Passage depth criteria are derived from the concept of allowing enough depth for fish to pass through a potential impediment without the body being exposed above the water surface while also minimizing abrasion against the streambed. The passage depth criterion for adult SRCS was selected as 0.9 feet based upon Thompson (1972) and the State Water Board (SWRCB 2014). Thompson (1972) originally proposed depth criterion of 0.8 feet based on adult SRCS body depth. Using the information provided by Thompson and others, the State Water Board suggested the depth criteria be expanded by a tenth of a foot to 0.9 feet to minimize abrasion. Mosley (1982) observed salmonids passing upstream in water depths shallower than the depth criteria suggested by Thompson, but observed fish suffered abrasion and loss of spawning condition.

Summarized Lahar Site Results

The results of the Lahar site River2D analysis are summarized in Table 3. The complete analysis results, including the data used to assess the jumping barriers, are given in Table 11 of the Technical Report (Cowan and Gard, 2016).

Table 3. Lahar site passage flow results and corresponding widths.

Flows (cfs) Assuming SRCS Adult Minimum Passage Depth ≥ 0.9 feet	
*-flow levels where model results indicated rapid increases in limiting width between simulated flow levels.	
Lahar Site Flow (cfs)	Contiguous Width (feet)
630	12.72
600	9.54
510	8.51
450	7.85
405*	7.52
395	5.06
390	4.11

Flows (cfs) Assuming SRCS Adult Minimum Passage Depth ≥ 0.9 feet	
*-flow levels where model results indicated rapid increases in limiting width between simulated flow levels.	
360	3.93
330	3.80
300	3.66
280	3.53
260	3.13
240*	2.98
220	2.44
200	1.70
180	1.69
160	1.46
140	1.38
120*	1.34
115	0.60
100	0.59
80	0.28
60	0.23
40	0.19
30	0.00

Table 3 provides a range of flow and contiguous width available for upstream migrating adult SRCS. Passage conditions improve incrementally for SRCS with increased flow level, but improved rapidly at three discrete flow levels as follows:

- From 115 to 120 cfs contiguous width increases from 0.60 to 1.34 feet;
- From 200 to 240 cfs contiguous width increases from 1.70 to 2.98 feet; and
- From 390 to 405 cfs contiguous width increases from 5.06 to 7.52 feet.

The results given in Table 3 were plotted and are shown below in Figure 8. The limiting widths in Table 3 were predicted to the hundredth of a foot to resolve the level where flows first exceeded the width criteria of first one and then three feet.

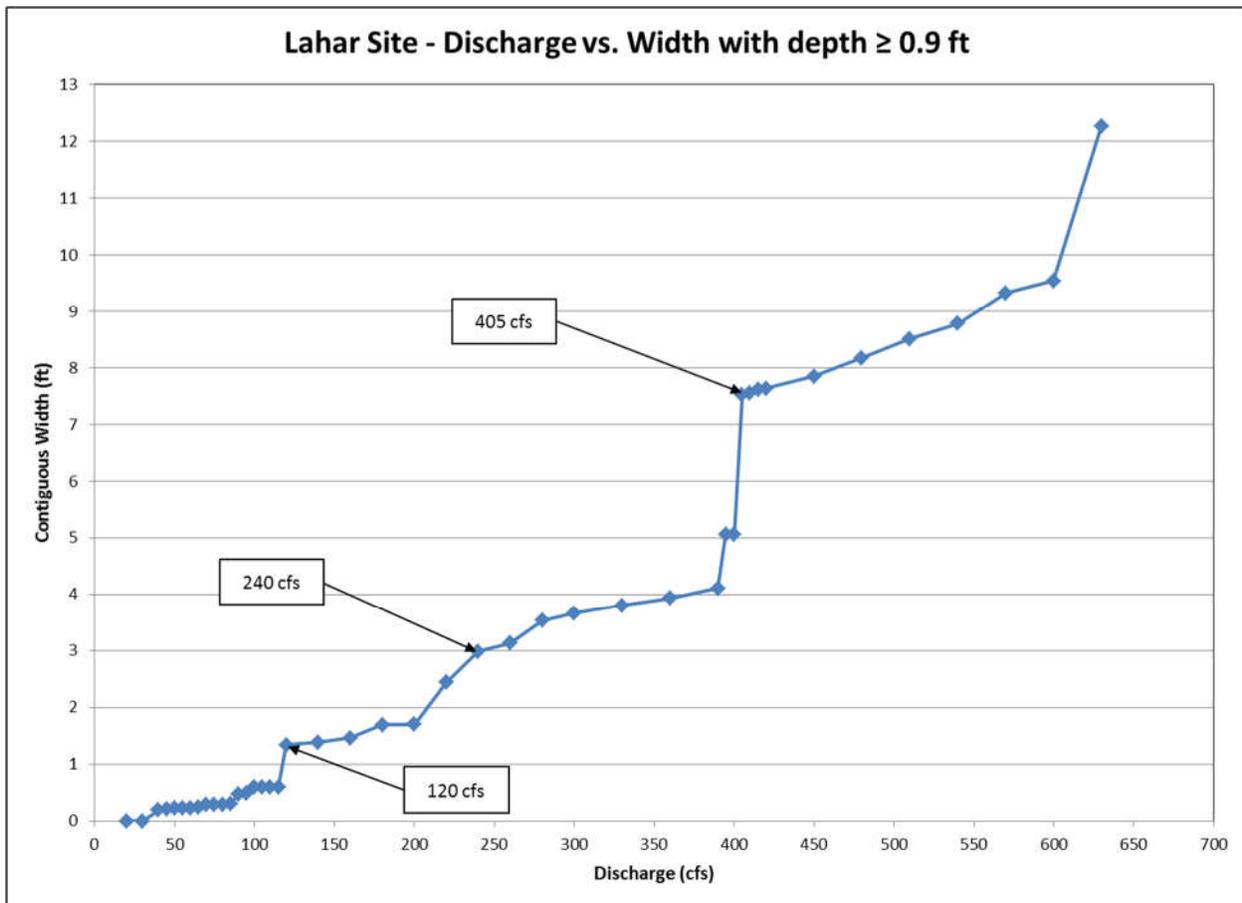


Figure 8. Lahar Site – Discharge versus width with depth ≥ 0.9 feet

The rapid changes in width occur at points in the Lahar formation referred to here as choke points. The graphic display in Figure 8 allows the viewer to see the relative amount of passage width available to SRCS and identify the passable widths of choke points in the formation most limited at a given flow. Choke points were found in the lower portion of the Lahar site on the southeast side of the formation. Figure 9 shows the depth profiles of the Lahar site in the location of the choke points at four discrete flow levels: 40, 120, 240, and 405 cfs. The graphic display has units of meters and is set to omit depths less than 0.27 meters or 0.88 feet, the minimum depth criterion for SRCS. The depth at 40 cfs is provided as a reference to current flow agreements in Butte Creek.

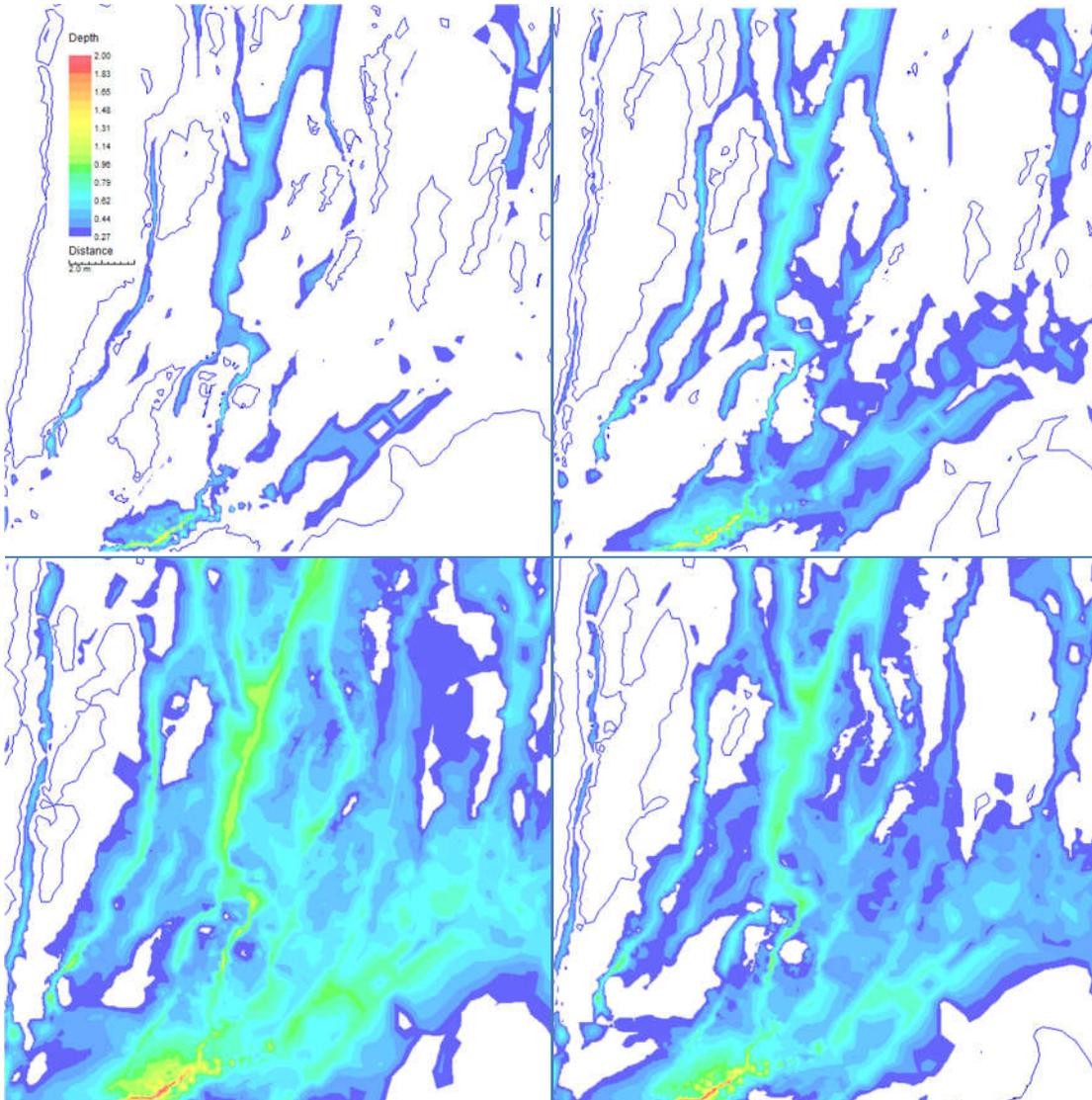


Figure 9. Depth profiles in the limiting choke point area of the Lahar site. Flow levels start at the upper left with 40 cfs and move clockwise around to 120, 240, and 405 cfs.

Summarized Critical Riffle Results

The River2D results for Riffles 95, 96, and 97 are summarized in Table 4. Trends are similar to the Lahar site where contiguous width increased abruptly at discrete flow levels. In Riffles 95, 96, and 97, the estimated contiguous width more than tripled between 315 and 325 cfs, 140 to 145 cfs, and 395 to 400 cfs, respectively.

Table 4. Riffle site River2D maximum contiguous width along the shallowest course from bank to bank.

Widths Where Depth > 0.9 feet

*-flow levels where model results indicated rapid increases in limiting width between simulated flow levels.					
Riffle 95		Riffle 96		Riffle 97	
Flow (cfs)	Contiguous Width (feet)	Flow (cfs)	Contiguous Width (feet)	Flow (cfs)	Contiguous Width (feet)
630	150	630	77	674	181
600	120	600	72	644	166
570	100	570	72	630	145
540	50	540	42	600	120
510	41	510	40	570	115
480	39	480	31	540	100
450	38	450	29	510	95
420	37	420	27	480	80
390	34	390	26	450	38
360	30	360	26	420	30
330	20	330	24	415	20
325*	20	300	19	410	20
320	8	280	17	405	20
315	6	260	17	400*	10
310	6	240	16	395	3
305	6	200	15	390	2
300	5	180	10	360	0
280	5	160	10		
260	3	145*	10		
240	3	140	3		
220	1	120	1		
200	1	100	0		
180	0				

VAKI Data Summarized

A VAKI Riverwatcher (VAKI) camera was installed in the Durham Mutual Fish ladder in January 2014, Figure 10. Fish passage data was collected over two critical water years, 2014 and 2015.



Figure 10. VAKI Riverwatcher installed in the fish ladder adjoining Durham Mutual Diversion Dam.

The VAKI device records fish movement through the ladder; the data is used to estimate the number of SRCS that pass through the fish ladder in both the upstream and downstream direction. The number of SRCS passing by month for 2014 and 2015 are summarized in Table 5. The negative count in June of 2015 indicates that more adult sized fish moved through the VAKI in the downstream direction.

Table 5. VAKI Riverwatcher adult passage counts,

Month	2014 Number of Fish	2015 Number of Fish
February	289	247
March	2295	1218
April	1939	338
May	154	149
June	57	-12
Total	4734	1939

Water Year 2014 was the first critical water year since 2008. During 2014, an estimated 4,734 adult SRCS migrated into the upper watershed, with the first SRCS passing through the VAKI device on February 14th. Figure 11 displays the cumulative percentage of the run passing through the VAKI device by day for 2014 and 2015.

The total number of SRCS migrating into the upper Butte Creek watershed in 2015 was down from the previous year by approximately 2,800 fish. The first SRCS passed through the VAKI on February 13th, almost to the day when compared to 2014. Table 5 compares when the cumulative percentage of fish passed through the VAKI device in 2014 and 2015. The numbers of fish migrating upstream in February and May were similar in 2014 and 2015, but the number of fish migrating upstream was far less fish in March and April of 2015 when compared to 2014. The percentage of fish migrating through the study reach was low in June of 2014 when compared with the other months. The VAKI device reported a negative count in June of 2015, indicating more adult SRCS moved downstream through the device than swam upstream through the device in June of 2015 (Table 5).

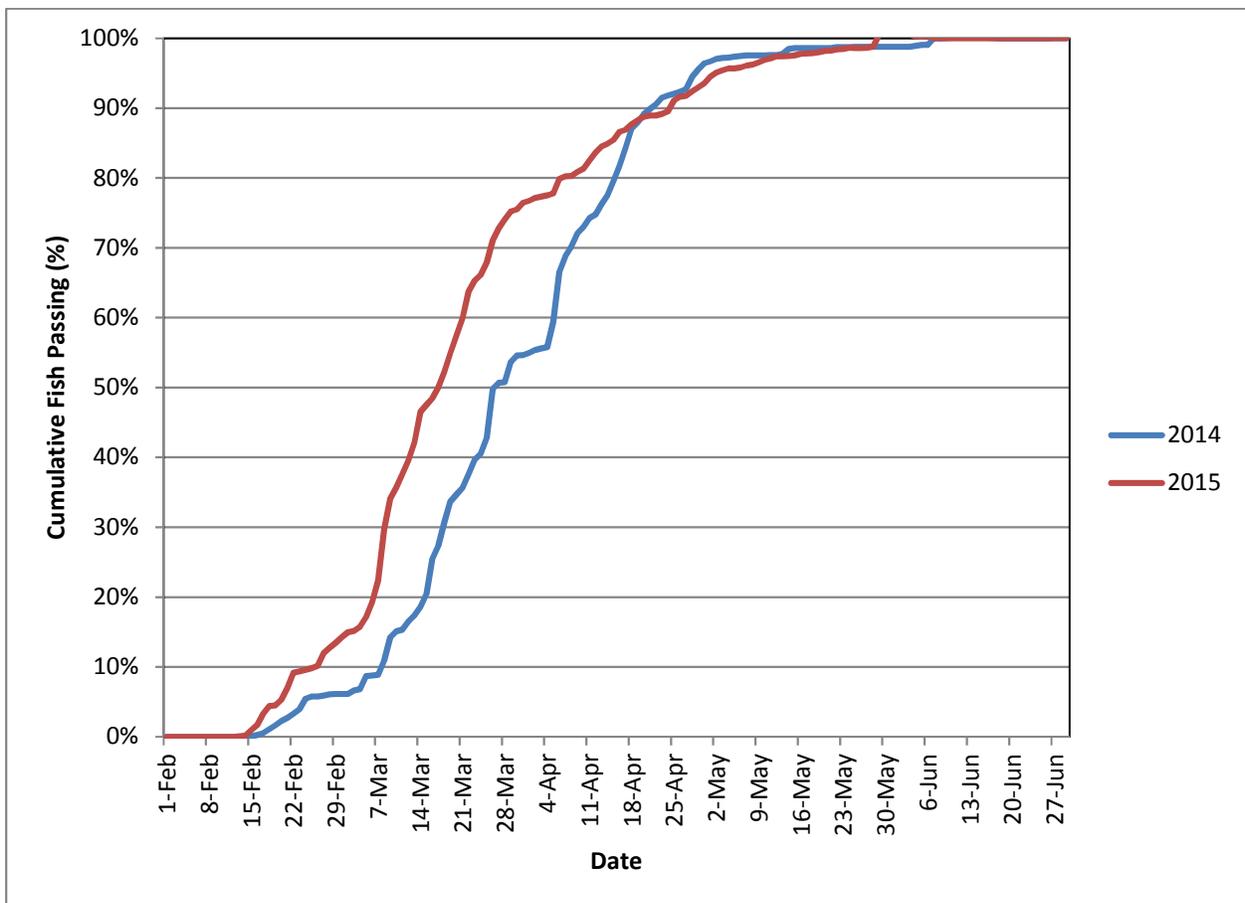


Figure 11. Cumulative percentage of fish passing upstream through the VAKI device.

Site-Specific Passage Width Criteria – Lahar Site

The study parameters used to develop flow criteria with predictive hydraulic modeling were water depth, contiguous width meeting depth criterion, and velocity. The Butte Creek IFIM passage study incorporated depth criterion for adult SRCS of 0.9 feet (SWRCB 2014), with the River2D model outputs to estimate contiguous width available to migrating adult SRCS over a range of simulated flow levels. Thompson (1972) developed criterion for sustained swimming velocity of 8 feet per second (ft/s) for migrating adult SRCS. The velocity criterion was used to confirm that velocities predicted in each River2D simulation run did not exceed the 8 ft/s threshold. Species and life stage-specific width criteria were not applied to the study results in the Technical Report. Selection of width criteria for salmonid migration requires some level of professional judgement and is considered here in the criteria report.

Limited scientific data is available concerning the length of contiguous width necessary for migrating fish to pass through natural stream barriers. Width criteria are limited to the percentage-based criteria developed by Thompson (1972). The percentage-based criteria were later adopted by the Department for use in the CRA Standard Operating Procedure (CDFG 2012). The method targets two thresholds: twenty-five percent of the total width of the riffle meeting the minimum depth criteria, and the longest contiguous wetted width of no less than ten percent of the total width of the riffle. The flows yielding these percentages are computed from regression analysis of data collected along the shallowest course from bank to bank. The Thompson method is meant to be applied to natural river systems where low gradient riffles have less than a 4 percent slope and the streambed is comprised of gravel and cobble substrate (CDFG 2012). Consequently, the Thompson method and associated width criteria could not be applied to the bedrock-dominated streambed of the Lahar formation.

Butte Creek is confined below Durham Mutual Diversion where the Tuscan bedrock is exposed. The structure of the Lahar site restricts the movement of migrating adult SRCS into narrow, bedrock gullies. The rigid bedrock structure of the Lahar site more resembles a rigid fishway than the single-thread, alluvial, stream channels found in the rest of the study reach. A literature review of the minimum width prescribed for fish passage structures such as notches, orifices, and vertical slot ladders was conducted to establish a range of widths thought to pass fish through rigid formations such as the network of eroded gullies in the Lahar formation. The following references were reviewed to develop width criteria for the Lahar site:

- Fish Passes -- Design, dimensions and monitoring, published by the Food and Agriculture Organization of the United Nations (FAO), Rome, 2002;

- Guidelines for Salmonid Passage at Stream Crossings, National Marine Fisheries Service Southwest Region (NMFS), 2001;
- Anadromous Salmonid Passage Facility Design, NMFS Northwest Region, 2008;
- New Concepts in Fish Ladder Design: Analysis of Barriers to Upstream Fish Migration, Volume III of IV, Powers et al., 1985;
- Summary of Hydraulic Studies for Ladder and Flume Fishway Design, Nimbus Hatchery Fish Passage Project, U.S. Department of the Interior Bureau of Reclamation (USBR), 2011;
- Fishway Guidelines for Washington State, Washington Department of Fish and Wildlife (WDFW), 2000;
- Fish Passage and Barrier and Surface Water Diversion Screening and Prioritization Manual, WDFW, 2009; and
- Fisheries handbook of engineering requirements and biological criteria, Bell, 1991.

Generally, fish passage structures are developed with a range of widths dependent on velocity of flow as well as the presence, depth, and length of neighboring pools (FAO 2002; NMFS 2001; NMFS 2008; Powers et al. 1985; USBR 2011; WDFW 2000; WDFW 2009; Bell 1991).

Most references specify a minimum width of one foot. FAO (2002) gives widths of one foot for notches in pool pass cross-sections and for slot pass cross-sections. Powers et al. (1985) cites two earlier publications that specify a slot width of one foot. USBR (2011) specifies orifice diameters ranging from 5.5 inches at 4.6 to 5 cfs to 10.9 inches at 17.6 to 20 cfs for proposed new, overtopping weir fish ladders with orifices. WDFW (2000) states that standard widths of vertical slots are 12 and 15 inches. NMFS (2008) states that the passage corridor for vertical slot ladders typically consists of one to 1.25 feet wide vertical slots between pools.

Only one reference specifies a width of two feet. Specifically, WDFW (2009) specifies an average scour line width of two feet for assessing and prioritizing fish passage at natural barriers in western Washington. Two references specify widths of three feet. NMFS (2008) specifies a minimum culvert width of three feet when using the hydraulic design method. WDFW (2009) specifies an average scour line width of three feet for assessing and prioritizing fish passage at natural barriers in eastern Washington.

The fishway design methods (i.e., FAO 2002; Powers et al. 1985; USBR 2011; NMFS 2008) specified minimum widths for notches, slots, and orifices starting at approximately one foot. Other methods that assessed natural barriers and culvert designs (i.e., NMFS 2001; WDFW 2009), derived minimum design widths ranging from two to three feet

depending upon conditions. Based on the literature review, and assuming the minimum depth criteria are met, the Department chose minimum passage width criteria of one to three feet to evaluate passage conditions in the Lahar site.

Instream Flow Regime Recommendations

An objective of the Department is to manage SRCS populations for optimum production of naturally spawning adult fish. Migrating adults require adequate flows to navigate from the Pacific Ocean, through the Bay-Delta, the Sacramento River, into Butte Creek, and finally access over-summer holding pools in upper Butte Creek Canyon below Centerville Head Dam.

As a result of the improvements completed to the watershed in the late 1990s for fish passage, escapement of SRCS improved post restoration activities. Even with improvements, upstream migrating adult SRCS were still observed being delayed, holding, and eventually becoming stranded in a pool below the Lahar site (Mosser et al. 2013). Since stranding has not been observed in the remainder of the study reach, flow conditions in the Lahar site, upstream of the pool, are assumed to be the primary impediment to passage in the study reach.

Passage conditions in the Lahar site were evaluated using species-specific depth criteria and site-specific contiguous width criterion for adult SRCS. The River2D model results were used to locate the most likely pathways for adult migration within the network of eroded gullies of the Lahar site based on the adult depth criterion of 0.9 feet at each flow level simulated. Once pathways were identified, the River2D results were used further to identify the point within each pathway where contiguous width was most limited or constricted; examples are given in Figure 8. The results of the analysis are provided in Table 3 and Figure 8.

Three threshold flow levels were selected from the River2D analysis: 120 cfs represents the minimum or base tier, 240 cfs is the middle tier threshold, and 405 cfs the upper tier threshold flow. Each flow level provides the most incremental benefit to upstream passage within a distinct flow range, while meeting or exceeding the depth and site-specific width criterion for adult SRCS.

Base Tier (120 cfs)

Results of the passage study indicated 120 cfs was the lowest flow level where the minimum species-specific depth criterion of 0.9 feet and site-specific width criterion of one contiguous foot would exist continuously along a pathway through the Lahar site (Figure 8). The incremental benefit in contiguous width increased rapidly between 115

and 120 cfs (Table 3 and Figure 8). The River2D model was used to determine that contiguous width more than doubled from 0.6 feet to 1.34 feet over only a 5 cfs change in flow level. One hundred and twenty cfs represents the minimum flow threshold for adult SRCS migrating upstream through the lower Butte Creek based on the limiting-pathway analysis. Below 120 cfs, the River2D model did not detect a continuous pathway for passage that met the minimum body depth criterion of 0.9 feet and site-specific minimum width criterion of 1 foot.

Middle Tier (240 cfs)

The second or mid-tier flow threshold was selected because model simulation results indicated adult SRCS will experience a sharp increase in passage width at 240 cfs. The increase in contiguous width occurred from 200 to 240 cfs; contiguous width increased from 1.7 to 3.0 feet (Table 3). The increase in contiguous width corresponds to the upper range of the minimum site-specific contiguous width criterion identified for the Lahar site.

Upper Tier (405 cfs)

Model outputs show the next major rapid change in contiguous width after 240 cfs occurred between 390 and 405 cfs, where the contiguous width increased from 4.1 to 7.5 feet (Table 3). In months and water year types when water supply allows, there is a noticeable incremental benefit to passage conditions by maintaining flow levels at or above 405 cfs (Figure 8). Limiting passage width is more than double the upper recommended minimum range of three feet suggested here for adult SRCS migrating through the Lahar site at 405 cfs and above.

Instream Flow Regime Recommendations by Month and Water Year Type

The flow criteria selection was completed in a collaborative process by the Butte Creek Instream Flow Technical Team including the study authors, technical staff from the Department's North Central Regional Office, and technical staff from the Department's Instream Flow Program. The team evaluated the results of the Technical Report over a range of expected water supply conditions with the goal of providing a protective instream flow regime recommendation that additionally considered water supply availability in the Butte Creek basin. The time period assessed for flow criteria is based on historical timing of SRCS migration, February through June. Monthly flow conditions were expressed by computing the median flow value for the five water year types defined for the Sacramento Valley Water Year Index. When selecting flow values, the regulated monthly median flow was considered an upper threshold for expected water supply; one of three tiered threshold flow levels was selected accordingly for each

month and water year type. Flows providing the most incremental benefit for each month and considering water year type are presented in Table 6.

Table 6. Lower Butte Creek Passage Flow Criteria in cubic feet per second to pass SRCS into the upper watershed.

Water Year Type	February (15 – 28) ^{1,2}	March ²	April ²	May ^{2,3}	June (1 -15) ^{2,3}	June (16 – 30) ^{2,3}
Critical	120	120	120	120	120	-(⁴)
Dry	120	240	240	120	120	-(⁴)
Below Normal	240	405	405	240	120	120
Above Normal	405	405	405	405	240	120
Wet	405	405	405	405	240	120

1 – Includes the 29th of February in leap years.

2 - When average daily flows do not meet the flow criteria full natural flow is recommended.

3 - Coordinated pulse flows (CPF) may be executed to promote upstream movement of SRCS.

4 – Spring-run assumed to end before June 16th in dry and critical water years.

The flow regimes given in Table 6 are based on the results of the Technical Report. Substantial changes in site conditions within the study reach would require the Department to re-evaluate the flow regimes given in Table 6 and may result in the need to collect additional field data.

Riffles 95 and 97 were not considered when evaluating passage flows criteria for migration of adult SRCS through the study reach. The flows needed for successful passage through riffles 95 and 97 were anomalously high when compared with the Lahar site and riffle 96. Based on the results of the riffle survey conducted for the study (Cowan and Gard 2016), riffle 96 was more representative of the other critical riffles observed in the riffle survey conducted for the study reach. Passable flow levels identified for riffle 96 are consistent with the flow levels identified at the Lahar site. A complicating factor when considering the impact of riffles 95 and 97 is their location upstream of the Gorrill Ranch Diversion. The placement of flashboards at the Gorrill facility inundates the riffle sites beginning sometime in April, eliminating the sites as potential passage impediments during approximately half of the SRCS adult migration period. Finally, stranding of adult SRCS at riffles 95 and 97 has not been observed by Department staff in the past.

Probability of Exceedance

The probability of exceedance (POE) of the monthly passage flow criteria is given in Table 7. Exceedance probabilities were computed for each month and water year type using the regulated mean daily discharges for only those identified months (February through June) and water year types. This method provides the most specific estimate of flow probability, but limits the number of values used to establish the POE function.

Lack of efficiency with sample sizes less than 100 are particularly significant (Vogel and Fennessey 1994) when establishing POE. The minimum number of daily flows used to estimate POE in Table 7 was 254. The limiting month and water year type was February in Below Normal years. There were only nine Below Normal years since 1958.

Table 7. POE expressed in percent for each selected flow criterion identified in Table 6 based on the average daily discharge reported for USGS 11390000 (1958 – 2015) by water year and month.

Water Year Type	February*	March	April	May	June*
Critical	84%	96%	89%	89%	64%
Dry	99%	97%	99%	99%	97%
Below Normal	70%	77%	91%	96%	99%
Above Normal	83%	95%	95%	74%	71%
Wet	94%	88%	93%	85%	88%

*-POEs calculated based on daily flow records of the entire month.

The POE of the base tier threshold, 120 cfs, which was selected for each month in a critical water year, ranged from 84 percent in February, rising up to 96 percent in March, 89 percent in April and May, before falling to 64 percent in June. As noted previously, 120 cfs provides a minimum width of 1 foot at a minimum depth of 0.9 feet at the most limiting point for fish migration through the Lahar site.

In dry years, the POE of the lower tier threshold, 120 cfs, was 99 percent in February. The middle tier, 240 cfs, POE was 97 percent in March. The low threshold, 120 cfs, was selected in April, May and, June based on historical water supply. The POE of selected flows in April and May were 99 percent and 97 percent in June.

All three thresholds, low, middle, and high, were selected for different months in below normal water years. The middle tier threshold, 240 cfs, selected for February and May has POEs of 70 and 96 percent, respectively. The upper tier flows, 405 cfs, has POEs of 77 and 91 percent in March and April, respectively. Based on water supply, the low tier flow (120 cfs) was selected in June and had a POE of 99 percent.

In above normal and wet years, only middle and upper tier thresholds, 240 cfs and 405 cfs, respectively, were selected. These months are expected to produce conditions in the Lahar site where flow is not a limiting factor to passage assuming the selected thresholds are maintained. The POEs in these months range from 95 to 71 percent.

The POE of each flow selected in Table 6 exceeded 50 percent, or the median, for each month and water year type.

Standard-Setting and Desktop Methods

The Butte Creek flow criteria were compared with two standard-setting methods, the Canadian Department of Fisheries and Oceans (CDFO) Flow Alteration Limit method (CDFO 2013) and the State Water Board’s Policy for Maintaining Instream Flows in Northern California Coastal Streams (Policy) regional equation for minimum fish passage (SWRCB 2014). Both are “desktop” methods performed without collecting site specific data, and are based on drainage area and/or other watershed hydrology statistics. The CDFO uses 30% of the mean annual discharge as a low flow threshold below which more detailed technical studies are required to evaluate the effects of flow alteration on riverine conditions. The State Water Board’s fish passage equation was developed by R2 Resource Consultants, Inc. (R2 2008) from regressions of data collected from streams in Idaho, an early study completed in the policy area, and 13 validation sites within the policy area. The policy area consists of coastal California streams from the Mattole River to San Francisco, and in coastal streams entering the San Pablo Bay. The policy area excludes the Sacramento River valley, including Butte Creek, but the authors noted that “[t]he relation appears to be descriptive of streams over a region broader than the Policy area, and is generally consistent across passage depth requirements” (p. E-3). The results of these methods are summarized in Table 8.

Table 8. Standard-setting “desktop” flow criteria for passage.

Method	Equation	Result
Flow Alteration Limit (CDFO 2013)	30% of the Mean Annual Discharge (cfs)	122 cfs
Policy for Maintaining Instream Flows in Northern California Coastal Streams (SWRCB 2014)	$Q_{fp} = 19.3 Q_m D_{min}^{2.1} DA^{-0.72}$ $Q_{fp} = \text{minimum passage flow (cfs)}$ $Q_m = \text{mean annual discharge (cfs)}$ $D_{min} = \text{minimum passage depth (feet)}$ $DA = \text{drainage area (mi}^2\text{)}$	132 cfs

The CDFO Flow Alteration Limit threshold flow level only differs from the base tier threshold flow selected in this report by two cfs. The minimum passage flow computed using the State Water Board regional equation was 132 cfs. The difference is only 12 cfs or 9 percent compared to the base tier threshold computed for the study. The minimum passage flow selected for the study reach, 120 cfs, is based on the results of the Technical Report and site-specific width criterion, and provides a reasonable flow threshold when compared with the two standard-setting methods above.

Water Year Type and Flow Monitoring Stations

Instream flow regime recommendations were set on a monthly basis considering water year type. DWR maintains a forecast of water year type for the Upper Sacramento River watershed until February when the forecast is set for the spring. The forecast is reported on the California Data Exchange Center website: <http://cdec.water.ca.gov/cgi-progs/rivfcst/USACBUL>.

There is a flow monitoring station located upstream of the Lahar site and the riffles evaluated in the IFIM passage study (Cowan and Gard 2016). USGS 11390000, Butte Creek near Chico, is located three-tenths of a mile downstream of Centerville Covered Bridge and is approximately five miles upstream from the Lahar site (Figure 12). There are no streams that contribute to flow between the gage and the Lahar site. There are two diversions between the Lahar site and USGS 11390000, Parrott-Phelan and Durham Mutual diversions. Diversions from Parrott-Phelan are reported by DWR on the California Data Exchange Center, stream gage BPD. Durham Mutual reports average monthly diversions to the State Water Board, Division of Water Rights on a three year cycle. In addition, current information about Durham Mutual diversions may be available from the watermaster for the Butte Creek service area. The DWR watermaster maintains a stream flow gage just downstream of Oroville-Chico Highway, Butte Creek near Durham (BCD). BCD is located between the Lahar site and the riffles, approximately five and half miles upstream from Riffles 95, 96, and 97 (Figure 12). The stream gage BCD is the logical choice to monitor compliance of recommended stream levels due to its location downstream of the Lahar site. If the BCD stream gage were used for this purpose, the Department recommends the gage receive regular maintenance and that the gage rating be confirmed routinely to maintain accurate monitoring information.



Figure 12. Stream flow monitoring stations in study reach.

Climate Change

The Department is committed to minimizing, to the maximum extent practicable, the effects of climate change on the State's natural resources. Changes in temperature and precipitation could result in alteration to existing flow regimes in fresh water systems. In addition, these changes may impact groundwater recharge and lead to more overdrafting, as well as impact hydropower and hatchery project operations and water diversion projects. Given the uncertainty associated with climate change impacts, the Department reserves the right to modify the instream flow criteria for Butte Creek as the science and understanding of climate change evolves.

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