DRAFT
Instream Flow Criteria
MILL CREEK, Tehama County

Site CR2, looking downstream

California Department of Fish and Wildlife
Water Branch, Instream Flow Program
830 “S” Street
Sacramento, CA 95811

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OVERVIEW

The Department of Fish and Wildlife (Department) has interest in assuring that water flows within streams are maintained at levels that are adequate for long-term protection, maintenance, and continued viability of stream-related fish and wildlife resources. The Department has developed instream flow criteria for lower Mill Creek for consideration by the State Water Resources Control Board (State Water Board) as streamflow requirements, as set forth in §1257.5 of the Water Code and under Action 4 of the California Water Action Plan: Protect and Restore Important Ecosystems for flow enhancement. Submission of these flow criteria to the State Water Board complies with Public Resources Code (PRC) §10002.

The Department is recommending instream flow criteria for lower Mill Creek, from the Upper Diversion Dam, operated by Los Molinos Mutual Water Company, downstream to the confluence with the Sacramento River. The annual criteria are based on migration periods of adult Chinook Salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*), and include a low flow threshold. This report summarizes the data sources and rationale used to develop the flow criteria.

The Department believes these criteria to be comprehensive and substantially complete. The flow criteria are based upon information developed through a recent flow study, the results of which are summarized in the Technical Report *Instream Flow Evaluation: Temperature and Passage Assessment for Salmonids in Mill Creek, Tehama County* (CDFW 2017b). The Department may revise instream flow criteria for Mill Creek based upon any new scientific information that may become available.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

BACKGROUND

Mill Creek is a significant watercourse for which instream flow criteria need to be established, in order to ensure the continued viability of stream-related fish and wildlife resources. Mill Creek was selected for development of flow criteria because of its high resource value. Mill Creek is one of three streams (in addition to Butte and Deer creeks) that support wild and persistent populations of Central Valley spring-run Chinook Salmon (SRCS; *Oncorhynchus tshawytscha*; CDFG 1998). This makes Mill Creek a conservation stronghold for the species and paramount to the long-term recovery of the Central Valley SRCS Evolutionary Significant Unit (ESU; NMFS 2014). Mill Creek also supports a distinct population segment of Central Valley anadromous Rainbow Trout (*Oncorhynchus mykiss*), commonly known as steelhead; populations of Central Valley fall and late fall-run Chinook Salmon ESU (FRCS; LFRCS), and Pacific Lamprey (*Entosphenus tridentatus*). Finally, recent evidence suggests that Mill Creek supports non-natal rearing habitat for the Sacramento River winter-run Chinook Salmon ESU (WRCS; Phillis et al. 2017).

The Central Valley Chinook Salmon and Steelhead Recovery Plan (NMFS 2014) classified Mill Creek as a high priority Core 1 watershed because of its potential to support independent viable populations of SRCS and steelhead. Through a coordinated effort between the State Water Board and the Department, Mill Creek is identified as one of five priority streams to implement Action 4 (Protect and Restore Important Ecosystems) of the California Water Action Plan (CNRA, CDFA, and CalEPA 2014). Mill Creek is identified as a priority stream in the State Water Board's *Instream Flow Studies for the Protection of the Public Trust Resources: A Prioritized Schedule and Estimate of Cost* (SWRCB 2010). Mill Creek is also identified as a priority stream in the US Fish and Wildlife Service (USFWS) *Final Restoration Plan for the Anadromous Fish Restoration Program: A Plan to Increase Natural Production of Anadromous Fish in the Central Valley of California* (USFWS 2001). Insufficient streamflow for adult salmonids migrating through lower Mill Creek has been identified as a key stressor to SRCS and steelhead population viability in the watershed. Year-round flow, along with increased instream flow during migratory periods, is expected to help protect current salmonid populations from further decline as well as provide opportunity for future improvements in the recovery of SRCS and steelhead in Mill Creek.

The instream flow study conducted by the Department and summarized in the report, *Instream Flow Evaluation: Temperature and Passage Assessment for Salmonids in Mill Creek, Tehama County* ("Technical Report", CDFW 2017b), focused on assessing aquatic habitat connectivity and upstream passage of salmonids through lower Mill Creek. Study methods included evaluations of: physical passage conditions for salmonids through shallow critical riffles, temperature regimes, and flows necessary to maintain aquatic connectivity and riffle production. The instream flow criteria developed for lower Mill Creek and presented here apply from the Upper Diversion Dam at River Mile (RM) 5.4 downstream to the confluence with the Sacramento River.

MILL CREEK WATERSHED

The Mill Creek watershed comprises approximately 134 square miles (347 km^2; Figure 1). Mill Creek originates on the slopes of Lassen Peak and flows approximately 60 miles (96.6 km) west until it joins the Sacramento River near the town of Los Molinos, Tehama County. Elevations in the watershed range from 8,000 feet (2,438 m) in Lassen Volcanic National Park to 200 feet (61 m) at the confluence with the Sacramento River. Upper Mill Creek is mostly confined within a narrow canyon, except for some alluvial meadows around the 5,000 foot (1,524 m) elevation, prior to flowing into the valley floor where it flows for eight miles (12.9 km) through irrigated agricultural lands (SRWP 2010). There are two major water diversion dams on Mill Creek: Upper Diversion Dam (RM 5.4), and Ward Diversion Dam (RM 2.8). Los Molinos Mutual Water Company operates both diversion dams.

Mill Creek's hydrology is extremely variable because of the large influence of rainfall and snowmelt, which affects the timing and amount of runoff in the watershed. Annual average precipitation ranges from 60 inches (152 cm) in the upper watershed to 20 inches (50.8 cm) in the lower watershed (SRWP 2010). Average daily flows, mean monthly flows, and average annual peak flows are all variable with the lowest flows and least variability in September (USGS gage 11381500; Kondolf et al. 2001).

Upper Mill Creek, upstream of the Upper Diversion Dam, provides ideal cold water holding pools and spawning habitat for SRCS and steelhead. However, insufficient stream flows in the lower reaches, due to diversions during key migration periods, may impede migration into the upper watershed (Reynolds et al. 1993; McEwan and Jackson 1996; Armentrout et al. 1998). Insufficient flows can also impede or block adult FRCS and LFRCS migration to their spawning habitat in the valley floor of Mill Creek, and may adversely influence the outmigration of juvenile salmonids (Armentrout et al. 1998; USFWS 2000; Johnson and Merrick 2012; Notch 2017).

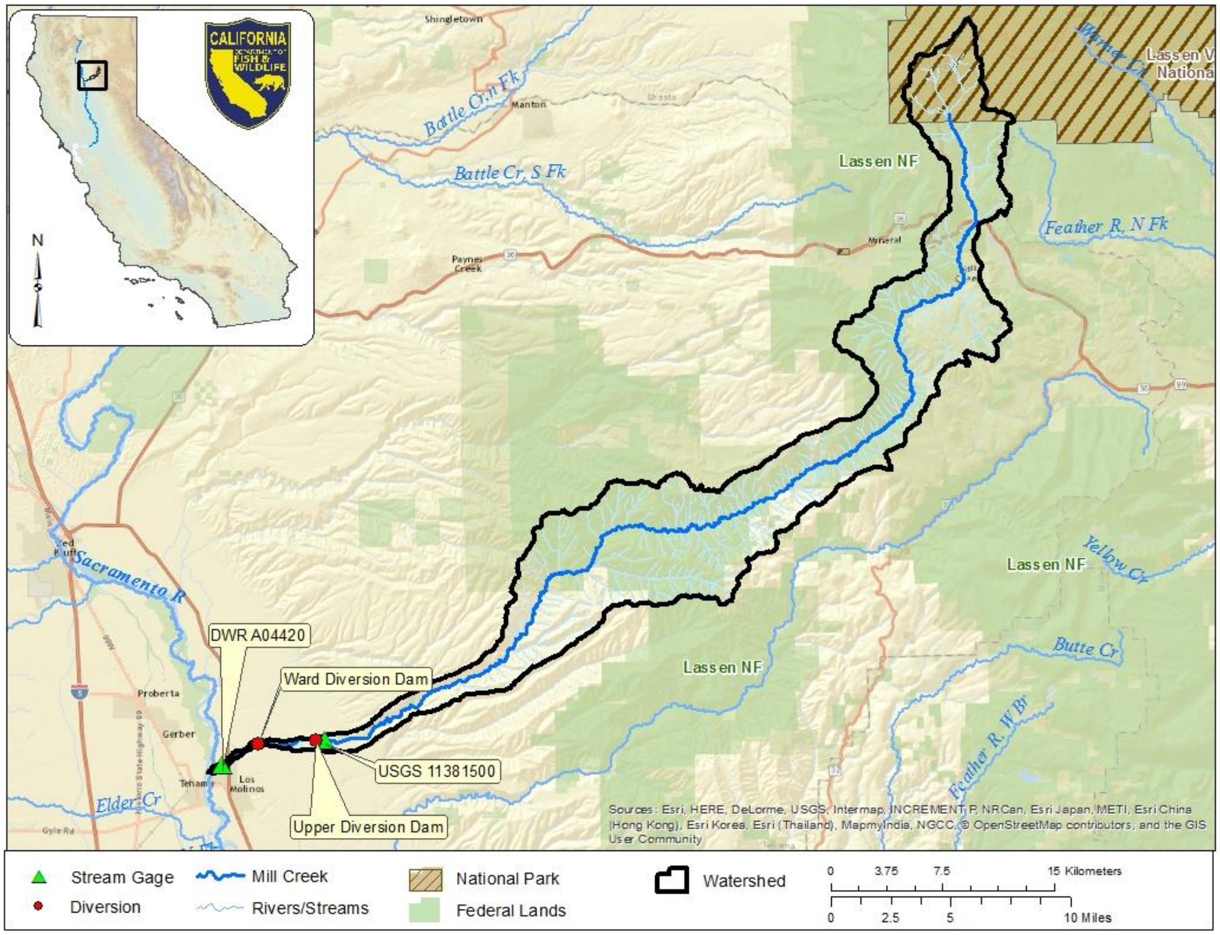

Figure 1. Mill Creek watershed map.

Fisheries Resource

SRCS are State and federally listed as threatened. Migrating adult SRCS enter Mill Creek from late February through early August (Table 1), holding in deep pools in the upper watershed until spawning occurs. The Mill Creek SRCS adult population averaged 882 fish from 1960 to 2003 (DWR 2005). More recently, a video monitoring station installed at Ward Diversion Dam indicates a declining SRCS population, with an average of 517 fish between 2011 and 2015 (Killam 2012; Killam and Johnson 2013; Killam, Johnson and Revnak 2014, 2015, 2016).

Steelhead are federally listed as threatened. Steelhead typically enter Mill Creek from late-September through June with peaks in October-November and January-March (Table 1). According to the video monitoring station installed at Ward Diversion Dam, an average of 151 steelhead migrated into upper Mill Creek between the 2011 and 2015 migration periods (Killam 2012; Killam and Johnson 2013; Killam, Johnson and Revnak 2014, 2015, 2016).

Central Valley FRCS and LFRCS are designated as California Fish Species of Special Concern. FRCS adults enter Mill Creek from late-September through December and spawn primarily in the valley floor (Table 1). The FRCS population estimate in Mill Creek averaged 1,619 fish between the 2011 and 2015 migration periods (Killam 2012; Killam and Johnson 2013; Killam, Johnson and Revnak 2014, 2015, 2016). Documentation of LFRCS in Mill Creek was limited prior to installation of the video monitoring equipment at Ward Diversion Dam. However, spawning LFRCS adults have been observed in the lower reaches of Mill Creek (Reynolds et al. 1993). LFRCS counted at the video monitoring station averaged nine fish between the 2011 and 2015 migration periods (Killam 2012; Killam and Johnson 2013; Killam, Johnson and Revnak 2014, 2015, 2016).

WRCS are State and federally listed as endangered. A recent study supports the occurrence of WRCS using lower Mill Creek for non-natal rearing. Phillis et al. (2017) evaluated the natural variation in otolith strontium isotopes to identify freshwater rearing habitats associated with Sacramento River WRCS. Four isotopically unique juvenile WRCS rearing habitat groups, including a “Lassen Tributaries” group comprising Mill, Battle, and Deer creeks, were identified. This research revealed that 44 to 65 percent of Sacramento River WRCS adults surviving to spawn produced juveniles that reared for at least three weeks in non-natal stream habitats; 7 to 34 percent of these fish reared in the “Lassen Tributaries” group (Phillis et al. 2017). Rotary screw trap investigations conducted on the Sacramento River at the Red Bluff Diversion Dam from 2002 through 2012 showed that weekly passage of WRCS fry consistently begins in July, builds through September, and peaks in early October (Poytress et al. 2014). This timing suggests that juvenile WRCS could utilize lower Mill Creek rearing habitat beginning in late summer. The Department began conducting focused surveys for juvenile WRCS in August 2017. These surveys may provide additional documentation of WRCS juvenile presence and timing in lower Mill Creek.

Table 1. Adult migration and juvenile presence timing for Mill Creek salmonids. Shading indicates timing span, with darker shading indicating months of peak movement.

Species/Life Stage	Oct		Nov		Dec		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep	
Spring-run Chinook Salmon																								
Adult SRCS[1,2,3]										light	light	dark	dark	dark	dark	dark	dark	dark	light	light	light			
Juvenile SRCS[4,5]	light	dark	dark	dark	dark	light	light	light	dark	dark	dark	dark	dark	dark	dark	light	light	light	light	light	light	light	light	light
Fall-run Chinook Salmon																								
Adult FRCS[1,2,3]	light	dark	dark	dark	light																			light
Juvenile FRCS[4,5]						light	light	dark	dark	dark	dark	dark	dark	dark	light	light	light	light						
Late Fall-run Chinook Salmon																								
Adult LFRCS[1,2]					light	dark	dark	dark	light	light	light													
Juvenile LFRCS[4,5]											light	light	dark	dark	dark	dark	light	light	light	light				
Steelhead																								
Adult steelhead[1,2]	light	dark	dark	dark	light	light	light	dark	dark	dark	dark	dark	light	light	light	light	light	light						light
Juvenile steelhead[4,5]	light	dark	dark	dark	light	light	light	light	light	light	light	dark	dark	dark	dark	light	light	light	light	light	light	light	light	light

Mill Creek Hydrology

Two stream gages currently collect flow and water temperature data on Mill Creek. The downstream gage is operated by the Department of Water Resources (DWR), DWR A04420[6], and is located below both major diversions at RM 0.8. The station is rated for low flow only; the highest rated flow for this gage is 462 cubic feet per second (cfs; D. Ables, DWR, pers. comm. 2015). The U.S. Geological Survey (USGS) operates the upstream gage, USGS 11381500[7], which is located at RM 5.8 above Ward Diversion Dam and Upper Diversion Dam. Due to its location, USGS 11381500 can be considered to represent the unimpaired flow conditions for lower Mill Creek (Figure 2). DWR (2007) defines unimpaired flow as “the runoff from a basin that would have occurred had man not altered the flow of water in the basin” (p.4).

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[1] Van Woert (1964), Killam (2012), Killam and Johnson (2013), Killam, Johnson and Revnak (2014, 2015, 2016)
[2] CDFW Mill Creek Video Station. Adult spring-run Chinook Salmon counts. Office Files 2009-2010 and 2015 through 2016.
[3] Needlam, Hanson, and Parker (1943)
[4] Johnson and Merrick (2012)
[5] CDFW Red Bluff Fisheries Office, Office Files. Lower Mill Creek juvenile salmonid snorkel investigation field notes 2012 through 2016.
[6] California Data Exchange Center Station ID: MCH for Mill Creek below HWY 99
[7] California Data Exchange Center Station ID: MLM for Mill Creek near Los Molinos

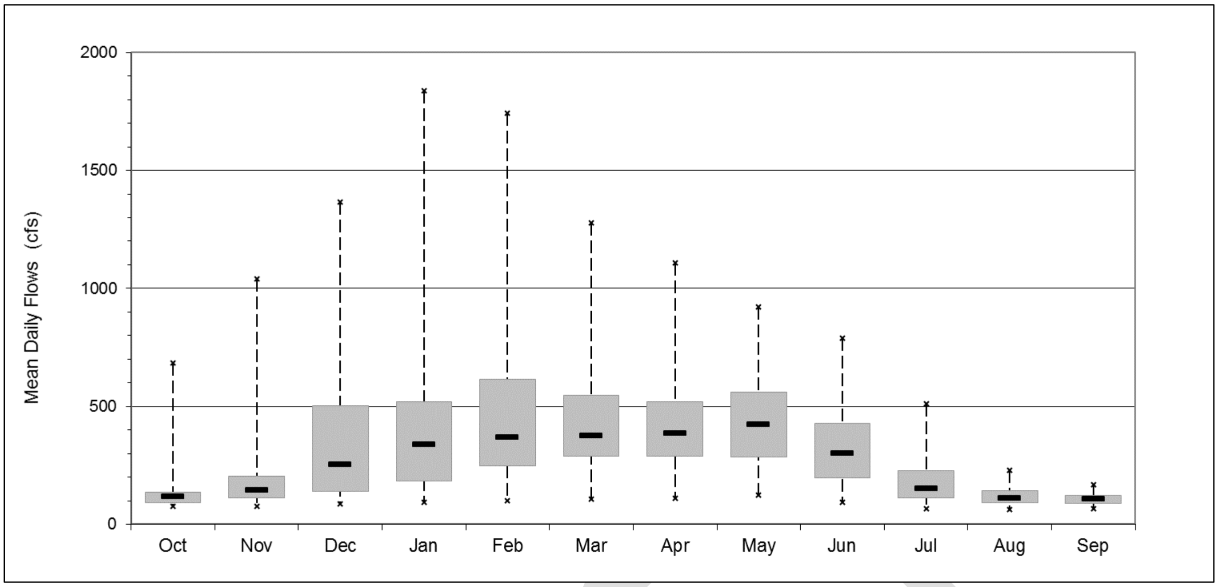


Figure 2. Box plot of Mill Creek mean daily flow (cfs) at USGS 11381500 between October 1, 1928 and September 30, 2015. The horizontal line represents the median flow, the box comprises the 25th to 75th percentile flow, and the whiskers represent the range of flow per month (i.e., the minimum and maximum daily average flow recorded per month).

Monthly unimpaired flows by water year type classification were estimated by computing the median monthly flow for five water year type classes: critical (C), dry (D), below normal (BN), above normal (AN), and wet (W) using the daily discharge data reported by USGS 11381500. Water year types were defined using the Sacramento Valley Water Year Index, reported by the DWR update to Bulletin 120, Historic Water Supply Indices (DWR 2016). The Sacramento Valley Water Year Index was originally specified in the 1995 State Water Board Water Quality Control Plan and is used to determine water year types implemented in Water Board Decision 1641. DWR maintains a forecast of water year type for the upper Sacramento River watershed beginning in February. Final determination is based on the May 1, 50 percent exceedance forecast.

The Sacramento Valley Water Year Index value is calculated as 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 value. If the previous water year’s index value exceeds 10.0, then 10.0 is used. The Sacramento Valley Water Year Hydrologic Classifications are defined as follows:

Year Type	Water Year Index[8]
Wet	Equal to or greater then 9.2
Above Normal	Greater than 7.8, and 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

The median unimpaired flow for each month was computed for each water year type using flow data from USGS 11381500 for the period of October 1, 1928 through September 30, 2015 (Table 2). The median flow represents the 50 percent unimpaired exceedance flow and characterizes the flow in cubic feet per second predicted to be present in lower Mill Creek at least 50 percent of the time. Median monthly unimpaired flow (cfs) was calculated as the median of individual daily mean flows (cfs) for all complete months during the period of record.

[8] Millions of acre-feet (MAF)

Table 2. Median monthly unimpaired flows in cubic feet per second (cfs) computed from USGS 11381500 between October 1, 1928 and September 30, 2015.

Water Year Type	Water Years	Median Monthly Flow (cfs)												
	(1929-2015)	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul (1-15)	Jul (16-31)	Aug	Sep
Critical	'29, '31, '33, '34, '76, '77, '88, '90, '91, '92, '94, '08, '14, '15	91	98	113	135	164	215	218	207	136	104	87	75	75
Dry	'30, '32, '39, '44, '47, '49, '55, '60, '61, '64, '81, '85, '87, '89, '01, '02, '07, '09, '13	108	124	142	151	199	290	297	296	193	124	106	92	90
Below Normal	'35, '36, '37, '45, '46, '48, '50, '59, '62, '66, '68, '72, '79, '04, '10, '12	104	123	130	194	241	306	400	405	272	161	125	104	97
Above Normal	'40, '51, '54, '57, '73, '78, '80, '93, '00, '03, '05	104	133	152	341	347	386	420	481	331	205	150	122	111
Wet	'38, '41, '42, '43, '52, '53, '56, '58, '63, '65, '67, '69, '70, '71, '74, '75, '82, '83, '84, '86, '95, '96, '97, '98, '99, '06, '11	118	147	307	392	419	432	506	580	466	303	213	150	127

INSTREAM FLOW STUDY

The instream flow study conducted by the Department and summarized in the Technical Report (CDFW 2017b) was completed with assistance from USFWS between 2012 and 2015. Passage conditions based on water temperature and depth were investigated for anadromous salmonids through lower Mill Creek, Tehama County (Figure 3). The instream flow study evaluated depth-limiting passage impediments through use of a two-dimensional (2D) hydraulic habitat model and Critical Riffle Analysis (CDFW 2017a). Water temperature regimes were evaluated using a predictive stream temperature model. Additionally, a low flow threshold necessary to sustain ecological function was determined using the wetted perimeter method.

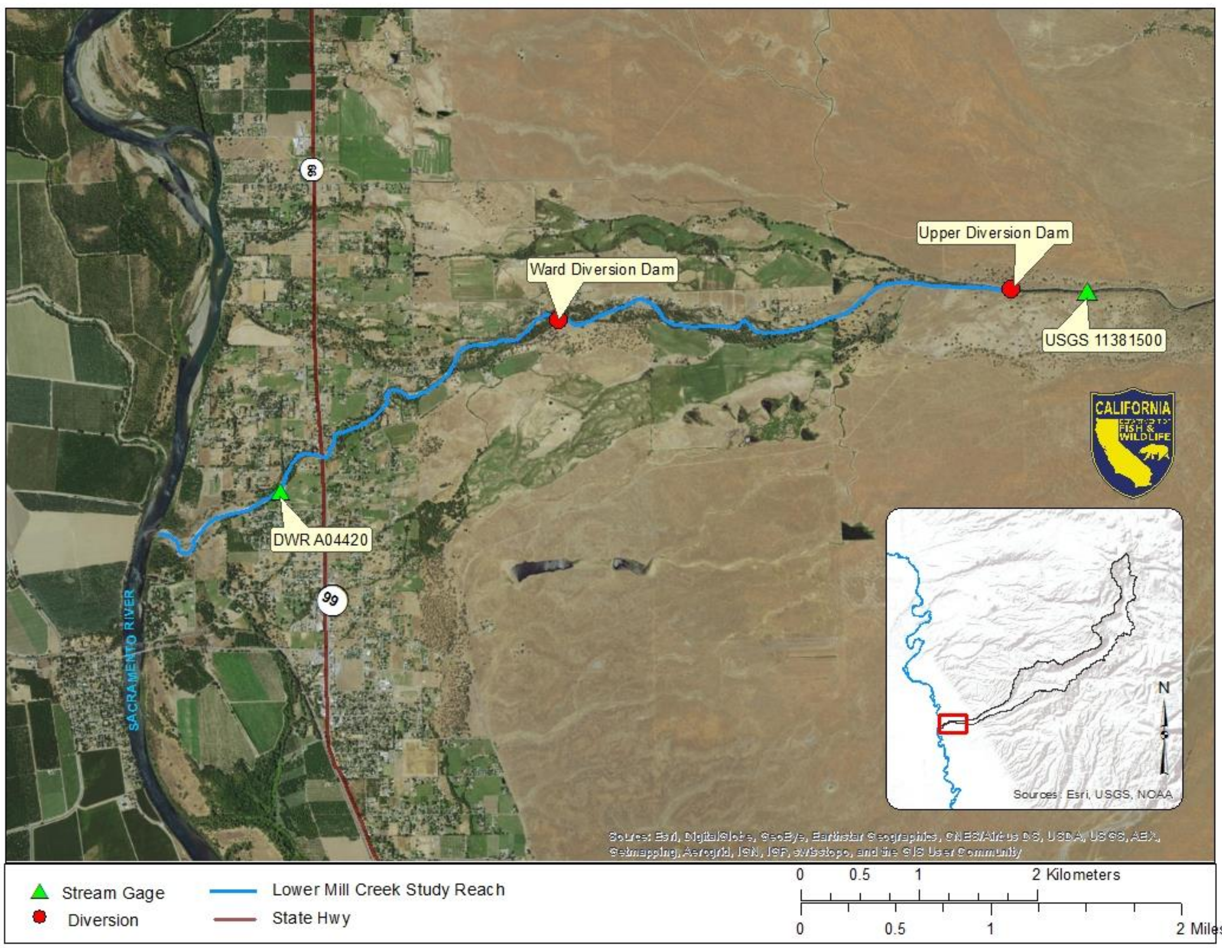


Figure 3. Lower Mill Creek instream flow study overview map.

Critical Riffle Evaluation

Critical riffles are considered the shallowest riffles in a stream channel and are particularly sensitive to changes in flow. As flow diminishes in a stream channel, the critical riffle will contain the shallowest water depths. Changes in stream flow and associated water depth can reduce the channel’s overall hydraulic connectivity, which restricts the movement of aquatic species and often impedes fish passage (CDFW 2017a).

The Department developed a Standard Operating Procedure (SOP) for Critical Riffle Analysis for Fish Passage in California (CDFW 2017a). The Department SOP was developed to identify stream flow rates necessary for the passage of salmon and trout through critical riffles and promote overall riverine connectivity in Californian streams and rivers. Procedurally, the SOP is based on concepts from Thompson (1972) and methods used by the Oregon Department of Fish and Wildlife. The Thompson (1972) criteria, based on percent of critical riffle transect length, is combined with species-specific depth criteria adopted by the State Water Board (SWRCB 2014) to ensure the SOP’s applicability to California.

Critical Riffle Analysis (CRA) involves developing a predictive relationship of flow and percent critical riffle transect length. The relationship is dependent upon the depth required by the fish species and life stage under consideration; larger fish require more depth and consequently higher flow levels for successful passage through a critical riffle. A transect is established across each critical riffle, following the shallowest course from bank to bank. Water depth data are collected along the transect at a minimum of three representative flow levels. Each data collection event must contain at least one measurement that meets the minimum depth criteria required by the target species and life stage. The stream flow rate (i.e., discharge) and correlating feet of transect meeting the minimum depth criteria are plotted to determine the flows necessary for salmonid passage (CDFW 2017a). The minimum depth criteria used in CRA are based on the water depth (ft.) needed for a salmonid to navigate over a critical riffle with sufficient clearance underneath it, so that contact with the streambed and abrasion are minimized (SWRCB 2014). The minimum water depth criteria for adult Chinook Salmon and adult steelhead passage are 0.9 feet and 0.7 feet, respectively (CDFW 2017a).

Stream flow rates for salmonid passage, herein called passage flows, are achieved when a target species and life stage water depth criterion is attained over a defined percent of the identified critical riffle transect. The following percentage of critical riffle transect length (i.e., width criteria) have been adopted for development of passage flows for salmon and trout (Thompson 1972; CDFW 2017a):

1. At least 10 percent of the maximum wetted transect length must be contiguous for the minimum depth criterion; and

2. A total of at least 25 percent of the maximum wetted transect length must meet the minimum depth criterion.

In lower Mill Creek, critical riffles were identified through surveys conducted between the Sacramento River confluence (RM 0.0) and the Upper Diversion Dam (RM 5.4). Riffles were identified in the lower Mill Creek study reach, numbered, and photographed, and the location was recorded. The greatest depth (i.e., the thalweg) along the shallowest path from bank to bank was measured at each riffle to an accuracy of 0.1 ft. (3 cm). Depth-sensitive riffles were identified for CRA sampling based on results of the surveys as well as historical documentation of critical riffle locations (e.g., Harvey-Arrison 2009).

Critical Riffle site number two (CR2) was identified as the critical riffle with the greatest potential to impede adult salmonid passage. Previous observations also identified CR2 as a passage impediment (Harvey-Arrison 2009). CR4 was identified as the second most limiting location to adult salmonid passage. CR3 and CR7 were identified for study based on their shallow depth measurements, and were added to increase the sample size. All four of the critical riffles identified were located downstream of the Ward Diversion Dam (Figure 4). Critical riffle sites CR3, CR4, and CR7 were evaluated consistent with the Department CRA SOP (CDFW 2017a) and are discussed in detail in the Technical Report. Due to unique site characteristics, CR2 was evaluated using a two-dimensional hydraulic habitat model, River2D. An overview of CR2 analysis is presented below; details pertaining to data collection, model development, calibration and validation can be found in the Technical Report (CDFW 2017b).

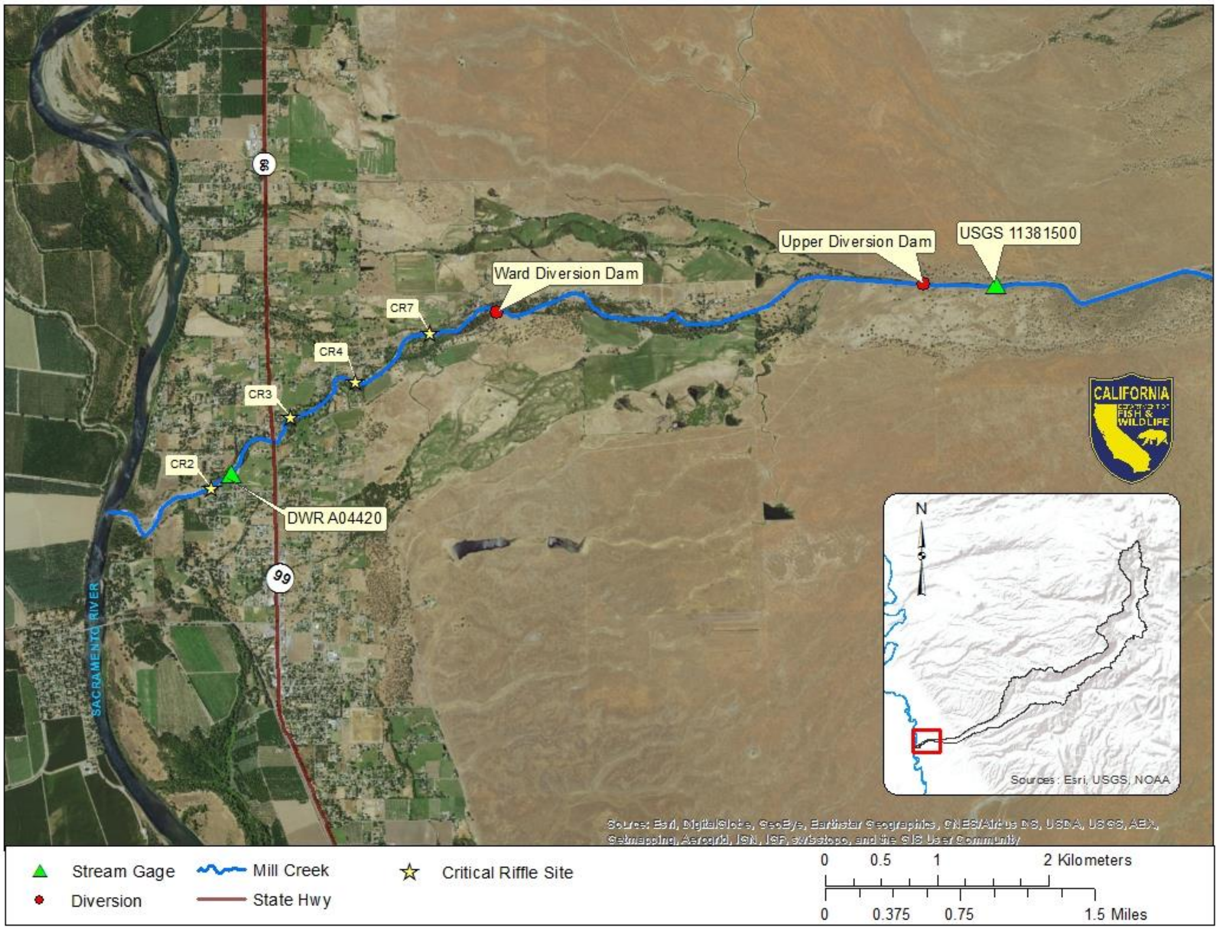


Figure 4. Critical riffle locations in lower Mill Creek.

Critical Riffle 2

CR2 is a long, broad crested transverse riffle approximately 0.7 miles (1.1 km) upstream of the mouth, and 2.1 miles (3.4 km) downstream of the Ward Diversion Dam. This was the widest critical riffle of the four studied, having a maximum transect length of 319 feet (Figure 5). CR2 was found to be the most limiting critical riffle for salmonid passage and is the first major passage impediment for salmonids migrating through lower Mill Creek. Facing upstream, the left bank of CR2 is unconfined, consisting of a broad gravel bar that lacks an abrupt bed to bank transition (Figure 6). The impact of the unconfined bank is that as flow levels increase and inundate the cobble bar, a corresponding increase in water depth along the crest of CR2 does not occur. This results in shallower depths occurring over a greater width at higher flows, as opposed to increased depth as would be expected at more confined riffle sites.

The complex characteristics of CR2 are well suited to two-dimensional (2D) modeling. River2D is a 2D depth averaged finite element hydrodynamic model that has been customized for fish habitat evaluation studies. The flow in defined stream segments, such as critical riffles, can be simulated over a range of flows using 2D depth averaging models like River2D. A 2D hydraulic model simulates depths that vary both longitudinally (upstream and downstream) and laterally (from left bank to right bank). As such, it is a good choice for evaluating depth in a complex critical riffle.

River2D inputs include bed topography, bed roughness height, and Water Surface Elevation (WSEL). The CR2 River2D study site was bounded by two transects, one at each end (i.e., upstream and downstream) of the passage assessment area. Transects are positioned where the flow is perpendicular to the transect line, relatively undisturbed, and where the WSEL is expected to be uniform across the transect over the range of flow levels sampled. The relationship between WSEL measurements and discharge measurements must be established. Discharge is measured at a minimum of three well-spaced flow levels; WSEL measurements are recorded at the upstream and downstream transects at the same time. The data collected from these measuring events are used to generate a hydraulic rating curve that predicts stage and flow in River2D over the modeled study site.

Figure 5. CR2 at approximately 65 cfs, facing downstream.

Figure 6. CR2 at approximately 45 cfs, looking upstream.

Within the River2D model study site, the critical riffle transect was identified as the shallowest course from bank to bank. The minimum body depth criteria for adult Chinook Salmon (0.9 ft.) and steelhead (0.7 ft.) were applied to the results of the CR2 River2D model to estimate the relationship between flow, percent total passable width, and percent contiguous passable width along the critical riffle transect. Flow simulations were generally run at 10 cfs intervals under 200 cfs, and at 20 cfs intervals over 200 cfs.

Passage flows occur when the minimum depth criteria is achieved over both 25 percent total and 10 percent contiguous portions of the critical riffle maximum transect length. A flow of 260 cfs acheives a depth of 0.9 ft. along a 25 percent total portion of the maximum critical riffle transect length. A flow of 220 cfs achieves a depth of 0.9 ft. along a 10 percent contiguous portion of the maximum critical riffle transect length. Therefore, the passage flow for adult Chinook Salmon through CR2 is 260 cfs (Figure 7).

In addition to determining the passage flow, River2D was evaluated for ancillary flows. These flows allow for an assessment of the minimum depth criteria along the critical riffle transect, with consideration of water availability. While the ancillary flows do not meet the passage flow width criteria, they do allow for a beneficial portion of the riffle to be passable to salmonids when water availability might naturally be less than the passage flow. Evaluation of ancillary flows indicated that when flow increases from 170 to 180 cfs in lower Mill Creek, the contiguous width maintaining a depth of 0.9 ft. for adult Chinook Salmon passage through CR2 increases abruptly from 2 to 6 percent, and the total passable width increases from 4 to 8 percent. Accordingly, a flow of 180 cfs provides a significant benefit to adult Chinook Salmon passing through CR2. Finally, the CR2 River2D model indicates that a flow of 140 cfs is required to generate the smallest increment of two feet total width and two feet contiguous width[9] meeting the depth criteria for adult Chinook Salmon (0.9 ft.). Therefore, flows below 140 cfs would not provide any portion of the critical riffle transect through CR2 sufficient to meet the minimum adult Chinook Salmon passage depth criteria of 0.9 ft.

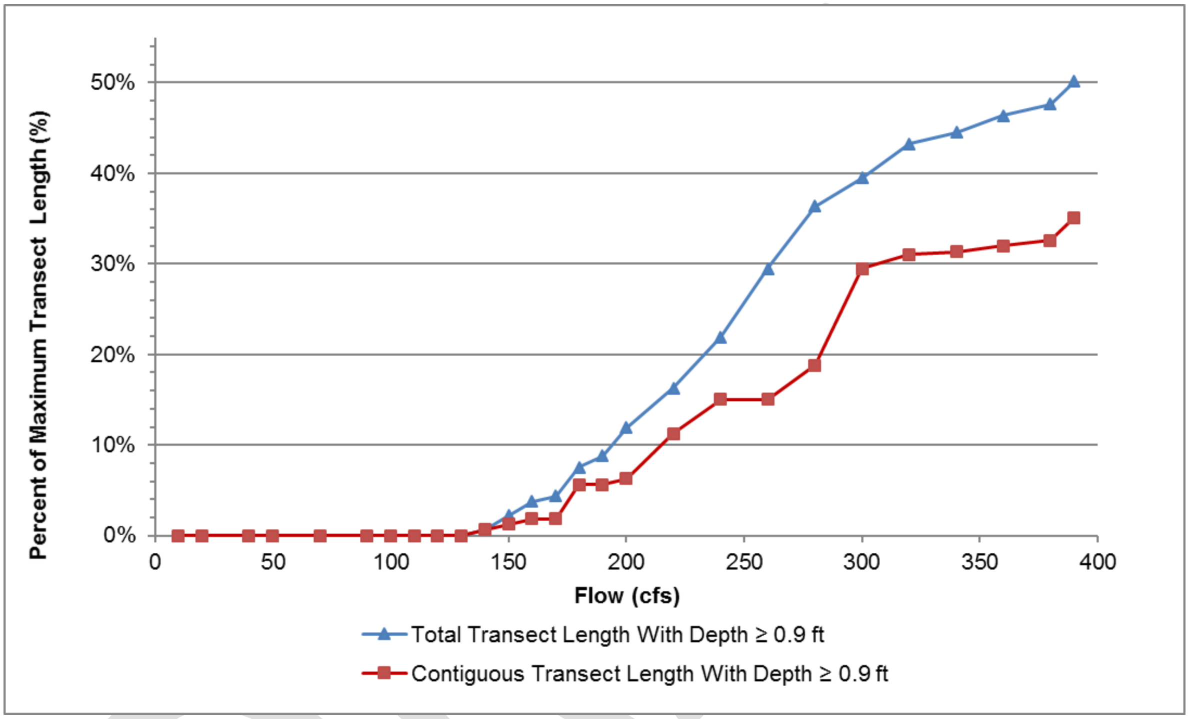


Figure 7. CR2 flow versus percent of maximum transect length with depth ≥ 0.9 ft.

While adult SRCS are the largest anadromous species reliant on flows for migration into upper Mill Creek, adult steelhead must also migrate through the lower watershed to reach their spawning areas above Upper Diversion Dam. Using the width criteria described above, a flow of 190 cfs achieves a depth of 0.7 ft. along a 25 percent total portion of the critical riffle maximum transect length (Figure 8). A flow of 160 cfs achieves a depth of 0.7 ft. along a 10 percent contiguous portion of the maximum transect length. Therefore, the passage flow for adult steelhead through CR2 is 190 cfs. A flow of 90 cfs is required to generate the smallest increment of two feet total width, and one foot contiguous width[10] meeting the 0.7 ft. depth criteria.

[9] Although the CR2 River2D model assessed passable widths using one foot increments, both the total and contiguous passable width jumped from zero feet at 130 cfs to two feet at 140 cfs for adult Chinook Salmon.

[10] Although the CR2 River2D model assessed passable widths using one foot increments, the total passable width jumped from zero feet to two feet and the contiguous passable width jumped from zero feet to one foot at 90 cfs for adult steelhead.

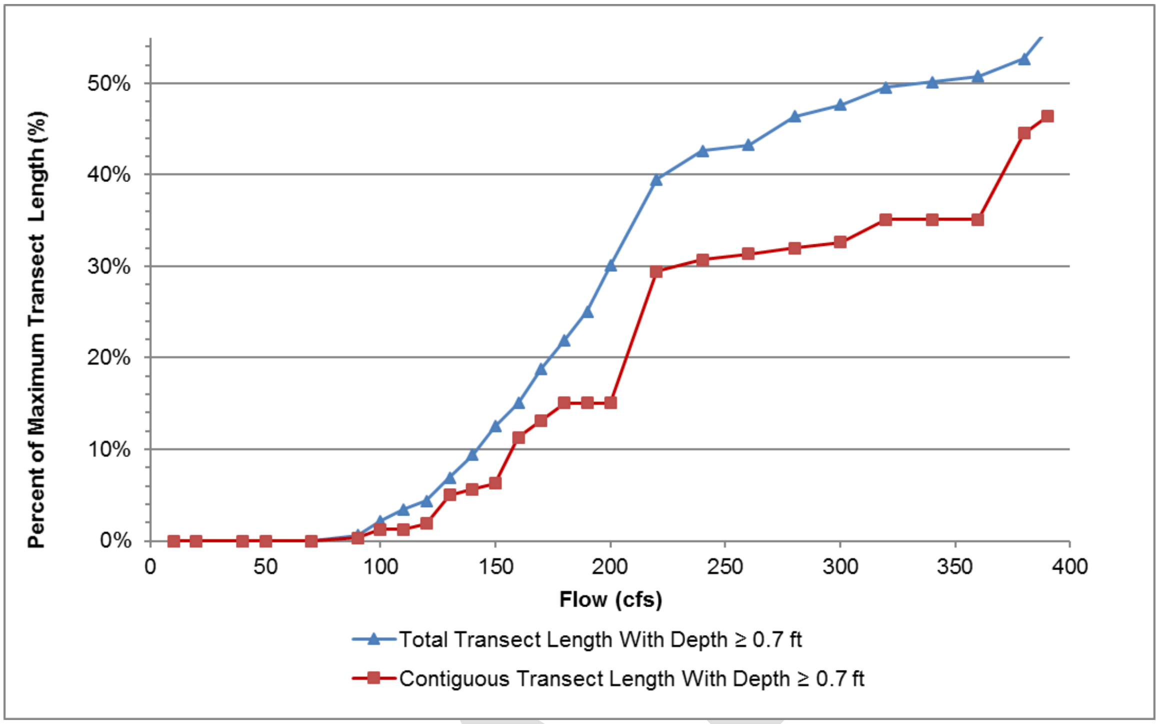


Figure 8. CR2 flow versus percent of maximum transect length with depth ≥ 0.7 ft.

Water Temperature

The temperature component of the instream flow study focused on determining the difference in water temperature between impaired and unimpaired flows. Climate data (i.e., air temperature, relative humidity, daily wind speed, cloud cover during daylight), monitoring data from DWR A04420 and USGS 11381500, and data collected from pressure transducers, flow measurements, and water temperature data loggers were combined to create a predictive water temperature model. The commercially available software program StreamTemp (Payne and Associates 2005) was used to simulate impaired and unimpaired water temperature conditions in lower Mill Creek during the spring and summer for water years 2008 through 2014.

StreamTemp model results indicated mean daily water temperature values were generally lower for unimpaired flows versus impaired flows in the latter half of the SRCS migration period. Further, the difference between impaired and unimpaired water temperatures was exacerbated in dry years versus wet in Reach 1, which extends upstream from the confluence of Mill Creek with the Sacramento River to the Ward Diversion Dam (Figure 9). In 2008, a critically dry year, the mean daily water temperature of impaired and unimpaired flows began to diverge by at least 1°F in early April, while in 2011, a wet year, the mean daily water temperature did not diverge until mid-July.

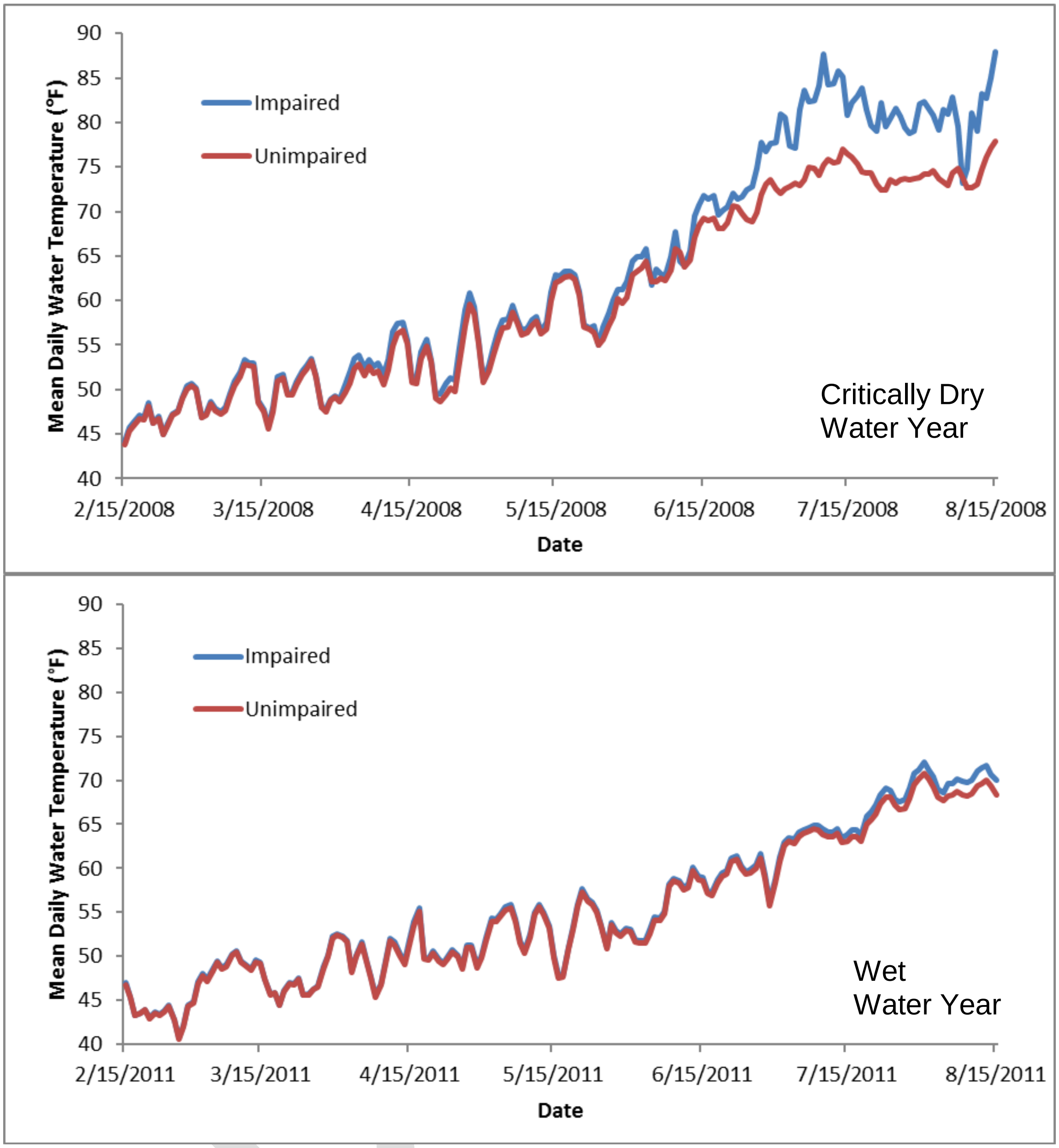


Figure 9. Predicted mean daily water temperature at the downstream end of Reach 1 for impaired and unimpaired flows during SRCS migration in a critically dry year (2008; top) versus a wet year (2011; bottom).

Water temperature guidance criteria for salmonids were published by the U.S. Environmental Protection Agency (EPA) in 2003 for the Pacific Northwest (EPA 2003). The EPA criteria use the metric 7DADM, or seven-day average of the daily maximum temperature. The EPA has established thresholds of 7DADM for various species and life stages of salmonids including passage of Chinook Salmon (EPA 2003). These are not rigid thresholds, but represent criteria to protect cold water salmonids; adverse temperature effects to salmonids are more likely to occur above these temperatures (EPA 2003). The EPA criteria indicate that under summer maximum temperatures, for areas where non-core (i.e., low density) juvenile rearing may occur along with adult migration, the 7DADM is 64°F (18°C). In areas where only adult migration occurs, the 7DADM is 68°F (20°C). Evaluation of the EPA criteria relative to stream temperatures observed, monitored, and modeled can help ascertain when temperatures for adult fish passage might become problematic. While the intended use of StreamTemp in the technical study (CDFW 2017) was to predict the difference in average daily water temperature between unimpaired and impaired flows within the study reach, maximum daily water temperatures were also predicted to examine trends in 7DADM for the years simulated.

The model StreamTemp can estimate both mean daily and maximum daily water temperature. The shortest time increment or time step the model can process is one day as opposed to half days or hours. The inability of StreamTemp to consider diurnal fluctuations over the course of a day limits its applicability to accurately predict maximum daily water temperature. The calibrated StreamTemp model met the Kimmerer and Carpenter (1989) validation criteria for predicted mean daily water temperatures of an average error for each reach of less than 1.8°F (1°C) and a maximum error for each reach of less than 2.7°F (1.5°C). These criteria were not met for the predicted maximum daily temperatures that were used to calculate the 7DADM. However, a comparison of 2014 measured 7DADM to StreamTemp predicted 7DADM indicates that while the model underpredicts the maximum temperature it maintains the overall trend (Figure 10).

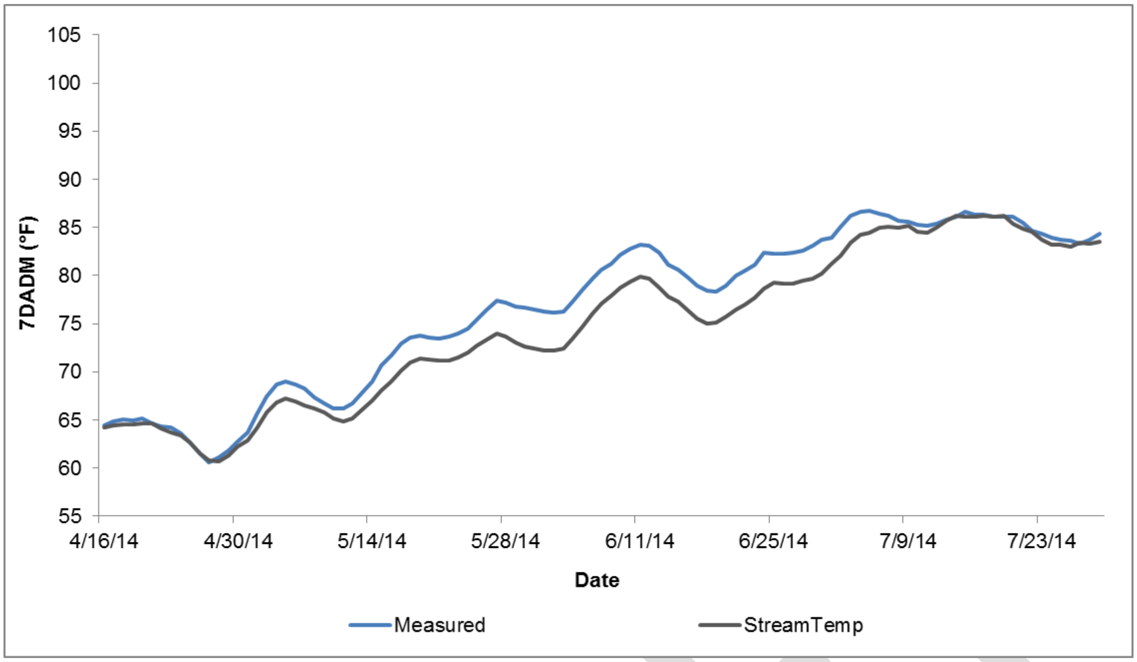
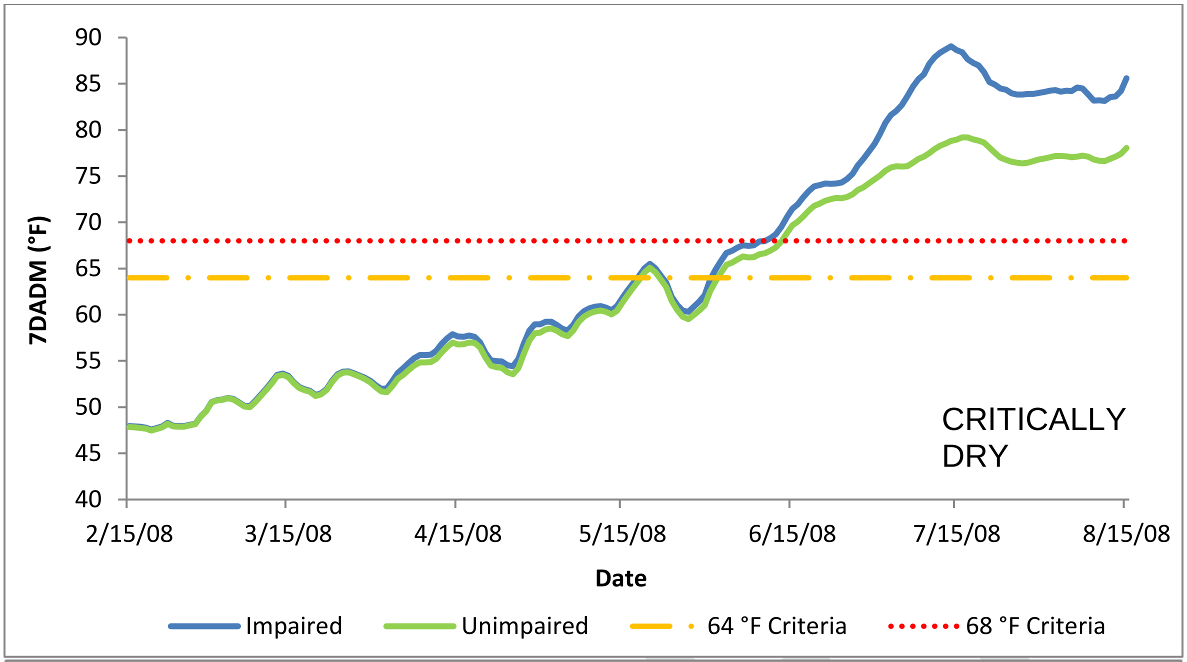


Figure 10. 7DADM StreamTemp model predictions compared to measured maximum daily temperatures (°F) at the downstream end of Reach 1 in 2014.

Simulated 7DADM values at the downstream end of Reach 1 were generated to compare maximum temperature trends between impaired and unimpaired flow conditions, and between water year types (Figure 11). Generally, the simulations indicated that 7DADM values were exceeded earlier in drier water year types compared to wet water year types. The difference between impaired and unimpaired water temperatures was again greater in dry years versus wet; 7DADM values are reached earlier under impaired conditions.



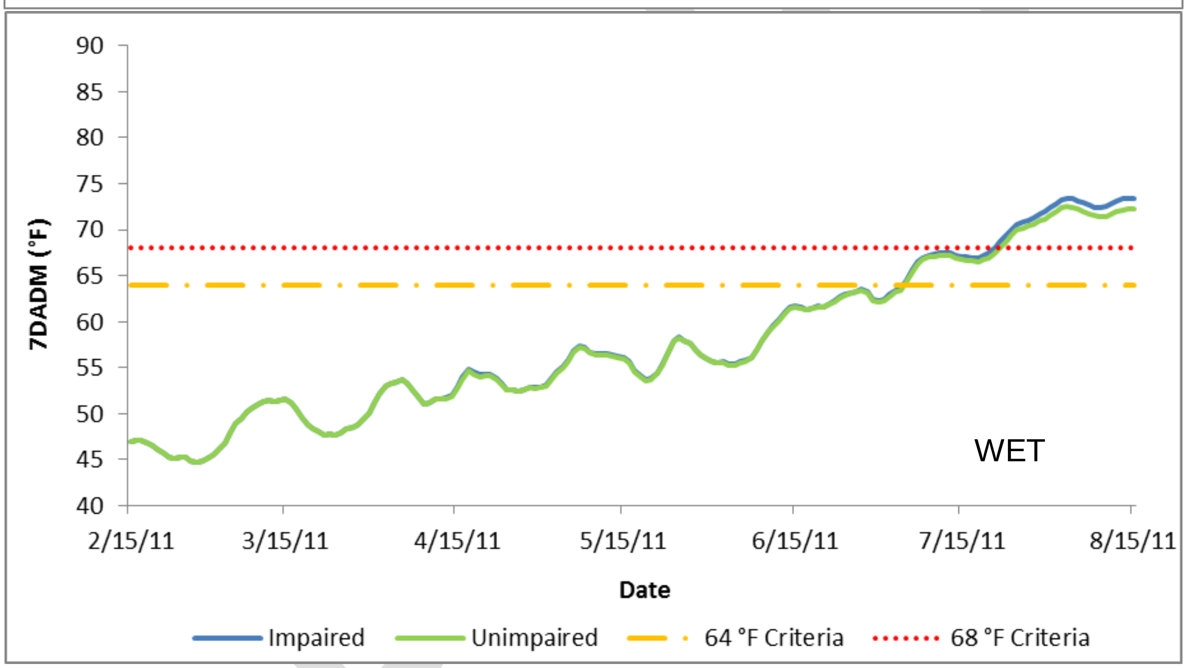


Figure 11. Predicted 7DADM at the downstream end of Reach 1 for impaired and unimpaired flows during SRCS migration in a dry year (2008; top) versus a wet year (2011; bottom).

Low Flow Threshold

A low flow threshold is recognized as an important part of any flow regime. Low flow thresholds are applied to conserve and protect aquatic resources during critically low flow periods. In Mill Creek, low flow thresholds should be applied during the summer months when migration has ceased and flows for adult salmonid passage are no longer required. It is widely recognized that maintaining a low flow threshold preserves ecosystem structure and function in riverine ecosystems that support fish populations (DFO 2013). Furthermore, flow levels less than 30 percent of the Mean Annual Discharge (MAD) have a heightened risk of ecological impact; this is identified as the "zone of highest risk" when using only a hydrology-based approach (DFO 2013). Applying the 30 percent MAD to USGS 11381500 discharge data (cfs) for water years 1982 to 2015 equates to a low flow threshold of 90 cfs.

MAD does not often reflect seasonal patterns in hydrology, so hydrological low flow thresholds can be improved using site-specific approaches. The Department assessed ecological function and benthic macroinvertebrate flow needs using site-specific data from Mill Creek. The wetted perimeter method utilizing Manning's equation for open channel flow was selected as the most appropriate method for establishing the low flow threshold (CDFW 2017b). Wetted perimeter transects were established in 2014 on four riffle sites at flows ranging between 41 and 56 cfs (Figure 12). The four wetted perimeter sites varied in geomorphic shape; sites were selected based on their structure and representativeness of riffle habitat types in lower Mill Creek.

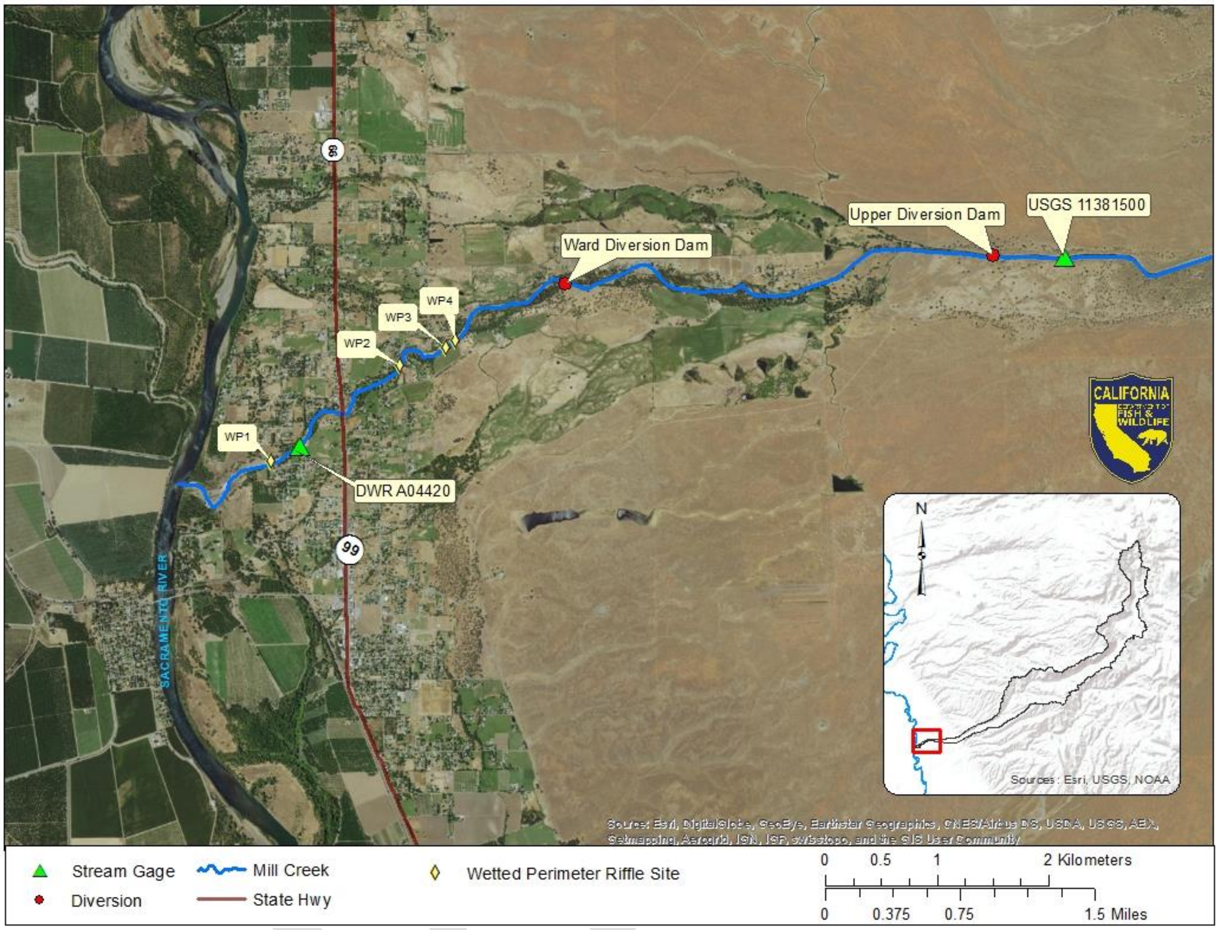


Figure 12. Wetted perimeter riffle site locations on lower Mill Creek.

The wetted perimeter method can be used to determine the low flow component of a flow regime necessary to maintain ecological function and benthic macroinvertebrate production (CDFW 2013). The flow identified as the incipient asymptote of the wetted perimeter-discharge curve (i.e., the second inflection point) provides the upper threshold for riffle food production (CDFW 2013). The mean incipient asymptote flow of the four riffle sites in lower Mill Creek is 58 cfs (CDFW 2017b).

The flow associated with the breakpoint (i.e., the first inflection point) on the wetted perimeter-discharge curve is assumed to protect the food producing riffle habitats at a level sufficient to maintain resident fish populations (Annear et al. 2004). The breakpoint flow is the threshold below which aquatic habitat conditions necessary to support benthic macroinvertebrates rapidly declines (CDFW 2013). Annear et al. (2004) recommends that when using the wetted perimeter method to define a low flow threshold, the breakpoint be used as long as it provides at least 50 percent of the wetted perimeter in streams less than 50 feet wide and between 60 and 70 percent of the wetted perimeter in streams wider than 50 feet. If the breakpoint flow identified provides less than the required percent wetted perimeter, then the flow that covers the recommended percentage of wetted perimeter is used in its place.

The average breakpoint flow may better represent the overall characteristics of the entire reach for lower Mill Creek (CDFW 2017b). All four wetted perimeter sites were wider than 50 feet. For three of the four wetted perimeter sites analyzed, the breakpoint flow was higher than the 60 percent wetted perimeter flow. The fourth site had a breakpoint flow providing only 57 percent wetted perimeter and required an additional three cfs to achieve inundation of at least 60 percent of the wetted width (CDFW 2017b). Considering the Annear et al. (2004) recommendation to maintain at least 60 percent of the wetted perimeter, the average breakpoint flow in lower Mill Creek is 30 cfs.

FLOW CRITERIA

An objective of the Department is to manage salmonid populations for optimum production of naturally spawning adult fish. Increased production of SRCS and steelhead in Mill Creek requires unobstructed access to over-summer holding pools and spawning grounds located above the Upper Diversion Dam. FRCS and LFRCS require flows that provide access to their spawning habitats in the valley floor. In addition, a low flow regime that maintains ecological function year round is necessary for benthic macroinvertebrate production, a food source for juvenile salmonids. It is assumed that flows necessary to support adult salmonid passage into Mill Creek will also support co-occurring species, other salmonid life stages present, and other ecological functions.

Monthly Criteria Considerations

The selected flow criteria outlined below accounts for natural variability in Mill Creek’s hydrograph and water year type. Median monthly unimpaired flow values were calculated from daily mean data recorded at USGS 11381500 for the period October 1, 1928 through September 30, 2015 (Table 2). Median monthly unimpaired flows (i.e., 50 percent exceedance flows) were used as an indication of natural water availability and were considered when developing the monthly flow criteria. Additionally, results from the temperature analysis completed in the Department’s instream flow study (CDFW 2017b) were considered.

The temperature analysis indicated a strong relationship between air temperature and stream temperature. Impaired and unimpaired mean daily water temperatures stay comparable in wet water year types but diverge in dry water year types (Figure 9). Additionally, 7DADM values were exceeded later in wet water year types compared to drier water year types (Figure 11). These findings suggest that stream temperatures should remain acceptable for migrating salmonids longer in wet years compared to drier years. Further, when evaluating individual water year types using EPA guidance criteria to protect cold water salmonids (EPA 2003), temperatures appear to remain suitable for adult salmonid passage in wet years though early July (e.g., Figures 9 and 11; water year 2011). Although adverse temperature effects to salmonids are more likely to occur above the EPA guidance criteria (EPA 2003), salmonids can and have migrated into lower Mill Creek at temperatures above 68°F (CDFW 2017b).

The principal species and life stage requirements considered by the Department when determining monthly flow criteria are described below. It is assumed that co-occurring species, life stages, and aquatic life will be protected when flows that allow for passage of the most depth-limited species through CR2, are provided. A low flow threshold is also identified to maintain ecological function outside of migration periods.

1) <u>October and November</u>

Adult FRCS and adult steelhead migrate into Mill Creek during October and November. Although steelhead are present, FRCS have greater body depths and are therefore more limited in terms of passage. Flow levels necessary for adult FRCS migration are considered protective for adult steelhead and all other life stages and species present.

Evaluation of the Mill Creek unimpaired hydrograph (Figure 2; Table 2) indicates that while the average unimpaired daily flow level during October and November can be low, storm events frequently occur and increase the daily flow for short periods. High and low stream flows provide cues for certain salmonid life cycle events, such as spawning movements, rearing, and migration (Annear et al. 2004). Salmonids use high streamflow events to cue migration into lower Mill Creek from the Sacramento River. Therefore, maintaining high streamflow events for adult FRCS and adult steelhead to migrate into lower Mill Creek during the October and November migration period is essential.

A flow of 260 cfs through CR2 meets the passage flow criteria for adult Chinook Salmon. However, median monthly unimpaired flows during this period are much lower than 260 cfs in all water year types (Table 2). A flow of at least 140 cfs is required to achieve the minimum depth criteria of 0.9 ft. for adult Chinook Salmon. Due to the variability of flow and presence of adult FRCS and steelhead in these months, a daily base flow level is recommended when the unimpaired flow is less than 140 cfs. Richter et al. (2011) found that daily flow alterations greater than 20 percent were found to result in moderate to major changes in the natural structure and function of the ecosystem. A maximum daily flow alteration of 20 percent or less (i.e., 80 percent unimpaired flow or more) has therefore been recognized as precautionary (Richter et al. 2011). To preserve the natural structure and function of lower Mill Creek, 80 percent of the unimpaired flow should be considered the base flow level required for October and November.

When the unimpaired flow reaches 140 cfs (i.e., because of a storm event or a general increase in precipitation), the full amount of unimpaired flow is recommended to allow for adult FRCS and steelhead migration. Once the unimpaired flow drops below 140 cfs, a declining ramping flow schedule should be followed; such that each adjustment in flow reduction does not exceed 10 cfs, with a minimum 3-hour period between adjustments, until a return to base flow level (i.e., 80 percent unimpaired flow) is reached. An incremental flow reduction is recommended to minimize potential stranding of migrating salmonids. The Department recommends use of USGS 11381500 to evaluate unimpaired flow conditions in lower Mill Creek. In accordance, USGS 11381500 should be used to calculate the daily base flow level of 80 percent unimpaired flow when flows are less than 140 cfs.

2) December, January, and February

Mill Creek is identified as a high priority watershed in part because of its potential to support threatened Central Valley steelhead. Winter flows are essential for the migration of adult steelhead through lower Mill Creek and into their spawning and rearing habitats located above the Upper Diversion Dam. A flow of 190 cfs is required to meet the passage flow criteria for adult steelhead through CR2. A very small population of LFRCS has been identified in Mill Creek at the video monitoring station (see Fisheries Resource). While a flow of 190 cfs does not meet the passage flow criteria for adult LFRCS through CR2, it does provide nine percent total and six percent contiguous width at a depth of 0.9 ft.

Evaluation of the unimpaired hydrograph indicates a flow of 190 cfs is generally available December through February in wet water year types, January through February in above and below normal water year types, and in February in dry water year types. While the average unimpaired daily flow level may be lower than 190 cfs, storm events frequently occur (Figure 2; Table 2). Therefore, when 190 cfs is not available the full amount of unimpaired flow is recommended to support the peak migration of adult steelhead and LFRCS, as well as peak movement of juvenile SRCS and FRCS present in the lower watershed (Table 1).

3) March through June (critical and dry years) or March through July 15 (below normal to wet years)

These periods are essential for the upstream migration of SRCS through lower Mill Creek into cold holding pools available above the Upper Diversion Dam. While steelhead are present during the spring-run period, SRCS have greater body depths and are therefore more limited in terms of passage. It is assumed that adult Chinook Salmon passage flows will be protective for adult steelhead and all other life stages and species present. For each month of the SRCS migration period, the flow providing the most benefit to SRCS passage, considering water year type and water availability (Table 2), is recommended (see Monthly Flow Criteria, Table 3). If unimpaired flows meeting the monthly flow criteria are not present, the full amount of unimpaired flow is recommended.

A flow of 260 cfs through CR2 meets the passage flow criteria for adult Chinook Salmon. A flow of 220 cfs provides 10 percent contiguous width meeting the depth criteria of 0.9 ft., and a flow of 140 cfs is required to achieve the smallest increment of two feet meeting the 0.9 foot depth criteria. Additionally, both the contiguous passable width and the total passable width available to adult Chinook Salmon increases abruptly at 180 cfs providing 6 percent contiguous and 8 percent total transect length. Therefore, a flow of 180 cfs provides a significant benefit to adult Chinook Salmon through CR2 when water availability may be limited.

4) <u>July through September (critical and dry years) or July 16 through September (below normal to wet years)</u>

A minimum flow threshold is necessary to sustain ecological function during the low flow period in lower Mill Creek. Based on assessment of unimpaired hydrology and considering results of the Mill Creek temperature model, the low flow period in Mill Creek is identified as July 1 through September in critical and dry years, and July 16 through September in normal and wet years.

Stream flow and aquatic species are directly and inexorably linked to the adjacent riparian vegetation (Reynolds et al. 1993). The presence of surface and near-surface water and associated moist soils promote high species diversity, and structural diversities in riparian plant communities, which not only support aquatic arthropod fauna, but also protect banks from erosion through reduction of water velocity and deposition of silt (Reynolds et al. 1993). Additionally, the shading effect of riparian vegetation provides stream temperature-moderating effects to adjacent watercourses (Reynolds et al. 1993).

A low flow threshold preserves ecosystem structure and function in riverine ecosystems that support fisheries (DFO 2013). Recent research demonstrates that endangered Sacramento River WRCS adults surviving to spawn may rear as juveniles in non-natal stream habitats, including Mill Creek (Phillis et al. 2017). Mill Creek is typically disconnected from the Sacramento River in late September and early October during the period of peak passage of WRCS fry at the Red Bluff Diversion Dam (Poytress et al. 2014). Potential WRCS non-natal juvenile rearing in Mill Creek is expected to occur from July through March. Although survey efforts focused on WRCS non-natal rearing in Mill Creek are currently limited, juvenile WRCS were identified in lower Mill Creek in January 2014 (M. Johnson, pers. comm. 2017). Connectivity between Mill Creek and the Sacramento River from July through September could greatly expand opportunities for juvenile WRCS to utilize lower Mill Creek for rearing habitat. Finally, a low flow threshold would also benefit numerous native fish species that are present year-round in lower Mill Creek, including Pacific Lamprey and Hardhead (*Mylopharodon conocephalus*), both listed as California Fish Species of Special Concern.

The average breakpoint flow of 30 cfs, derived through application of the wetted perimeter methodology (CDFW 2017b), represents the threshold below which conditions within the stream are likely to decline. Therefore, 30 cfs is considered the low flow threshold for lower Mill Creek during the low flow period.

Monthly Flow Criteria

The Department is recommending monthly instream flow criteria for lower Mill Creek, from the Upper Diversion Dam downstream to the Sacramento River confluence (Table 3). The flow criteria are based on the results of the instream flow study (CDFW 2017b), analysis of unimpaired hydrologic conditions (USGS 11381500), and consideration of other supporting information provided in this report. The objectives of the Department's flow criteria are to provide flows suitable for adult salmonid migration as well as provide a low flow threshold necessary to sustain ecological function when flows for adult salmonid passage are not required. The Department's criteria will help maintain, rehabilitate, and improve ecosystem processes by recommending a variable inter- and intra-annual flow regime that reflects the natural hydrograph to the greatest extent possible. When average daily flows (cfs) as reported by USGS gage 11381500 do not meet the flow criteria listed, the full amount of unimpaired flow is recommended. Substantial changes in conditions in lower Mill Creek may require the Department to collect additional data and reevaluate the flow criteria.

Table 3. Lower Mill Creek flow criteria in cubic feet per second (cfs).

Month	Water Year Type				
	Critical	**Dry**	**Below Normal**	**Above Normal**	**Wet**
October	< 140 cfs → 80% UF*; ≥ 140 cfs → UF**				
November	< 140 cfs → 80% UF*; ≥ 140 cfs → UF**				
December	190	190	190	190	190
January	190	190	190	190	190
February	190	190	190	190	190
March	180	260	260	260	260
April	180	260	260	260	260
May	180	260	260	260	260
June	140	180	260	260	260
July 1 - 15	30	30	140	140	220
July 16 - 31	30	30	30	30	30
August	30	30	30	30	30
September	30	30	30	30	30

* When USGS 11381500 is less than 140 cfs, 80 percent of the unimpaired flow (UF) is recommended.

** When USGS 11381500 is equal to or greater than 140 cfs, the full amount of unimpaired flow (UF) is recommended. Once flow levels naturally recede below 140 cfs, flow reduction will not exceed 10 cfs with a minimum 3-hour period between adjustments until flow levels return to 80 percent of the UF (i.e., a maximum daily flow alteration of 20 percent or less).

Water Year Type and Flow Monitoring Stations

The Sacramento Valley Water Year Type Index is forecast through May of each year in the Bulletin 120 Water Supply Index (DWR 2016). Bulletin 120 forecasts are issued four times a year: February, March, April, and May. Final Water Year Type determination is based on the 50 percent exceedance forecast issued on May 1. Since the final Sacramento Valley Water Year Type determination is based on the May 50 percent exceedance forecast, it is suggested that the same forecast (i.e., 50 percent exceedance) is used to determine the water year type and associated flow criteria (Table 3) for the months of March and April. For the months of May, June, and July, flow criteria should be selected based on the final Water Year Type determination. The forecast is reported on the California Data Exchange Center website: http://cdec.water.ca.gov/snow/bulletin120/index2.html.

The USGS operated gage 11381500 is located at RM 5.8 above both Ward Diversion Dam (RM 2.8) and Upper Diversion Dam (RM 5.4). No additional streams contribute to flow between the gage and the Upper Diversion Dam or Ward Diversion Dam. Therefore, the Department recommends use of USGS 11381500 to evaluate unimpaired flow conditions in lower Mill Creek.

The stream gage DWR A04420 is located below both major diversions at RM 0.8. Therefore, the Department recommends use of DWR A04420 to monitor compliance of lower Mill Creek flow criteria due to its location. If the DWR A04420 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.

Channel-Forming Flows

Periodic flows that result in alteration of the channel form are essential to maintaining the dynamic nature of alluvial streams (Annear et al. 2004). Channel-forming flows promote renewal of the channel and riparian areas that foster healthy riverine habitats, ecologic function, population health, and species viability (R2 Resource Consultants 2008). Leopold, Wolman, and Miller (1995) estimate a flow level in excess of the 1.5-year instantaneous peak return event will initiate channel-forming processes. Flood frequency analysis involves using observed peak flow data to calculate statistical information, such as recurrence intervals. U.S. federal agencies have adopted Log-Pearson Type III as the probability distribution of choice for flood frequency analysis (Gupta 1989). USGS 11381500 reports the instantaneous annual peak stream flows for the last 88 years. Using the Log-Pearson Type III distribution for Mill Creek, the 1.5-year instantaneous peak return flow is 3,409 cfs. While critical, channel-forming flows are not annual flows. Based on USGS 11381500, flow levels this high occur naturally in Mill Creek and should continue. However, these high flow events are not prescribed as part of these annual criteria.

Climate Change

The Department is committed to minimizing, to the maximum extent practicable, the effects of climate change on the State's natural resources. Surface temperatures are projected to rise; it is very likely that heat waves will occur more often and last longer and extreme precipitation events will become more intense and frequent (IPCC 2014). Changes in temperature and precipitation could result in alteration to existing flow regimes in freshwater systems. In addition, these changes may affect groundwater recharge, lead to over drafting, and affect water diversion projects. Given the uncertainty associated with climate change impacts, the Department reserves the right to modify the instream flow criteria for lower Mill Creek as the science and understanding of climate change evolves.

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