Appendix 6.1

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PRUNUSKE CHATHAM, INC.

TECHNICAL MEMO

Date: October 30, 2017

To: Mary Ann King, Trout Unlimited

From: Lauren Hammack, Prunuske Chatham, Inc.

Subject: Mill Creek Dam Fish Passage Monitoring – Post-construction

Introduction

This memo describes the post-construction fish passage monitoring conducted by Prunuske Chatham, Inc. (PCI) at the Mill Creek Dam Fish Passage Project (Project) in Sonoma County, California. The Project's objective was to remediate the highest priority barrier for coho salmon within the Russian River, as identified in the National Marine Fisheries Service's Recovery Plan for the Central California Coast Coho Salmon ESU (NMFS 2012), and to restore juvenile and adult coho salmon (Oncorhynchus kisutch) and steelhead (Oncorhynchus mykiss) access to approximately 11.2 miles of high-quality spawning and rearing habitat in Mill Creek and it's upper tributaries. The Project was implemented by Trout Unlimited with funding from NOAA Restoration Center, California Department of Fish and Wildlife (CDFW), and the Sonoma County Water Agency. Funding for this monitoring effort was through a CDFW Fisheries Restoration Grant (#P1530400).

The Project improved fish passage at a 5-foot high concrete flashboard dam on Mill Creek by constructing 200 feet of new channel: a roughened ramp up to the dam crest and a side channel excavated into the right bank around the dam abutment (Figure 1). The Project was designed in consultation with the NMFS fish passage engineer, David White, and the two-channel design satisfied all adult and most juvenile fish passage criteria, in addition to the long list of site constraints. The completed main-channel roughened ramp has a slope of 6% in the lower 50 feet and a slope of 8% from the confluence with the side channel up to the dam. The side channel is 100 feet long and has a slope of 3%. Low fish passage flows are designed to be concentrated in the side channel while higher flows are designed to be split between the main and side channels. The roughened ramp was built with a framework of 4-6 ton boulders with smaller boulders, cobble, and gravel between. The boulders protruding through the bed creates multiple flow pathways during low flows and mimics a steep section of Mill Creek downstream of the project site.

Construction was completed by Prunuske Chatham Inc. (PCI) in summer 2016. The project was constructed in significant accordance to the plans with all changes approved by the NOAA-NMFS engineer and the CDFW project manager. The fish passage and engineering construction monitoring point, as-built documentation spreadsheet is included as Attachment 1 to confirm that the channel bed was built to plan.

Figure 1. View of Mill Creek Dam Fish Passage Project less than one month after construction completion (looking downstream). Constructed side channel with 3% slope is in the foreground with pre-existing dam and the main channel roughened ramp in center of photo.

Monitoring Approach

To evaluate actual fish passage conditions through the Project's roughened ramps at typical flows during salmonid migration periods we measured depth and velocity at multiple locations within cross sections and along longitudinal profiles that mimicked fish swim pathways. While the simplified 1-D hydraulic model used in the design process indicated that fish passage criteria would likely be met at the full range of fish passage flows (Table 1), the actual constructed channel form is very different than that modeled. It is assumed that adult and juvenile fish can navigate roughened channels over a wide range of flows because the constructed channels simulate natural stream conditions, however this design approach is considered new technology and is unproven compared to other standard passage structures such as concrete fish ladders or weirs where the hydraulics are controlled structurally and are non-deformable (NMFS 2011).

Table 1. Predicted fish passage conditions in Project based on 1-D hydraulic model of design.

				NMFS/CDFW Criteria			Side Channel			Main Channel		
Flow Condition	Total Flow (cfs)	Side Channel Flow (cfs)	% Flow in Side Channel	Max Velocity (fps)	Min Depth (ft)	Max hydraulic Drop (ft)	Max Velocity (fps)	Min Depth (ft)	Max hydraulic Drop (ft)	Max Velocity (fps)	Min Depth (ft)	Max hydraulic Drop (ft)
Juvenile Low Flow (JLF)	1	1	100%	1	0.5	0.5	0.9	0.4	0	1.2	0.3	0
Adult Low Flow (ALF)	6.4	6.3	99%	6	1	1	1.4	0.7	0	1.8	0.6	0
Juvenile High Flow (JHF)	111	45	41%	1	0.5	0.5	3.1	1.4	0	4.0	1.9	0
50% Adult High Flow (50% AHF)	385	132	34%	6	1	1	4.6	2.3	0	4.8	3.8	0
Adult High Flow (AHF)	770	280	36%	6	1	1	5.9	3.5	0	5.6	5.5	0

The Project had funding to conduct two one-day monitoring sessions. A flow on the receding limb of a storm during the late winter was selected to represent an adult migration flow, and a late spring flow was selected when juveniles are thought to be redistributing themselves within the watershed. During each visit discharge was measured at the main channel weir and the side channel weir with a Marsh-McBirney flow meter. The two discharge values were added together to determine total discharge.

Three cross-sections were established to monitor depth and velocity repeatedly at the same locations, and allow comparisons between flows. The cross-sections were sited to represent the channel at the various bed slopes (3%, 6%, and 8%). Capped rebar markers were installed to indicate the start and end points of each cross-section. The first cross-section spans the main channel to the bifurcation island where the slope is 8%. The second cross-section extends from the island to the right edge of the side channel where the slope is 3%. The third cross-section is located below the confluence of the two channels within the 6% slope zone. See maps below (Figure 2 and Figure 3) for the locations of the cross-sections. A measuring tape was extended between the two markers and velocities and depths were measured at multiple points across the section where water was flowing between boulders.

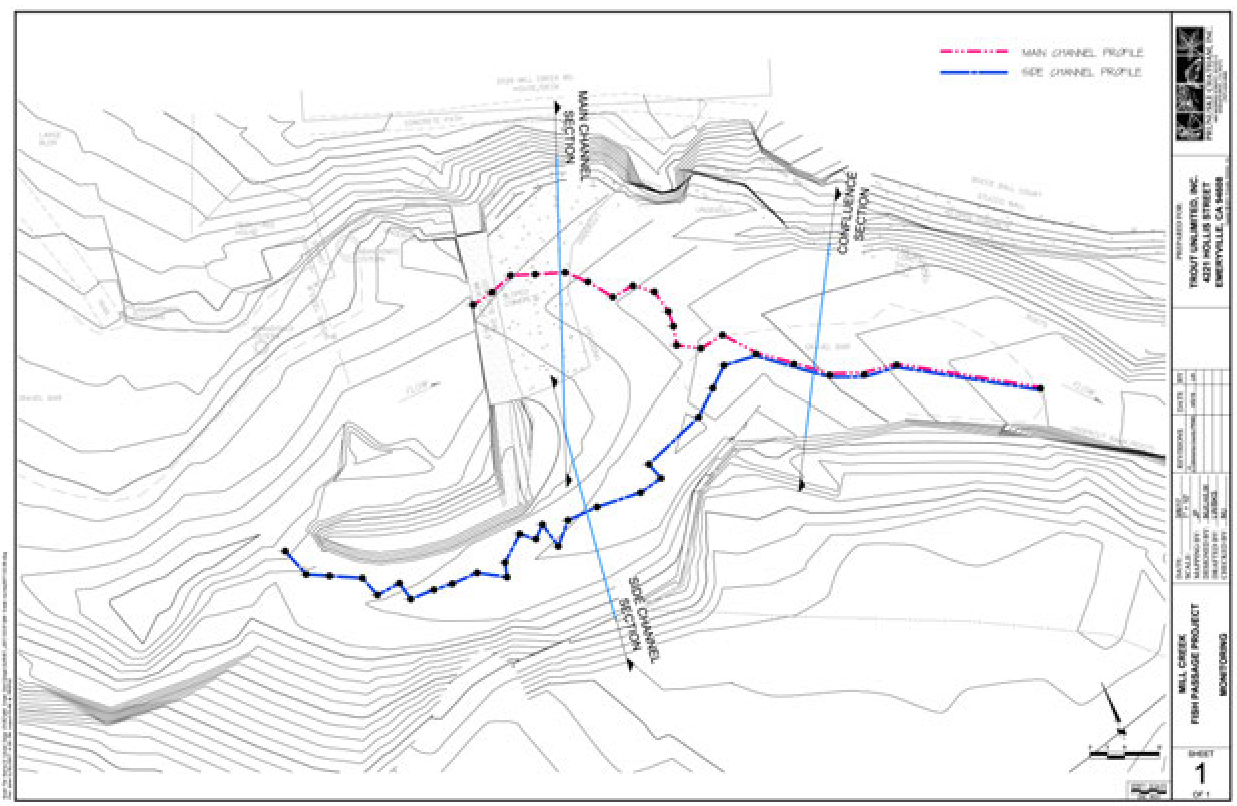

Figure 2. Plan view of where the mid-range flow monitoring data was collected (profiles and cross-sections).

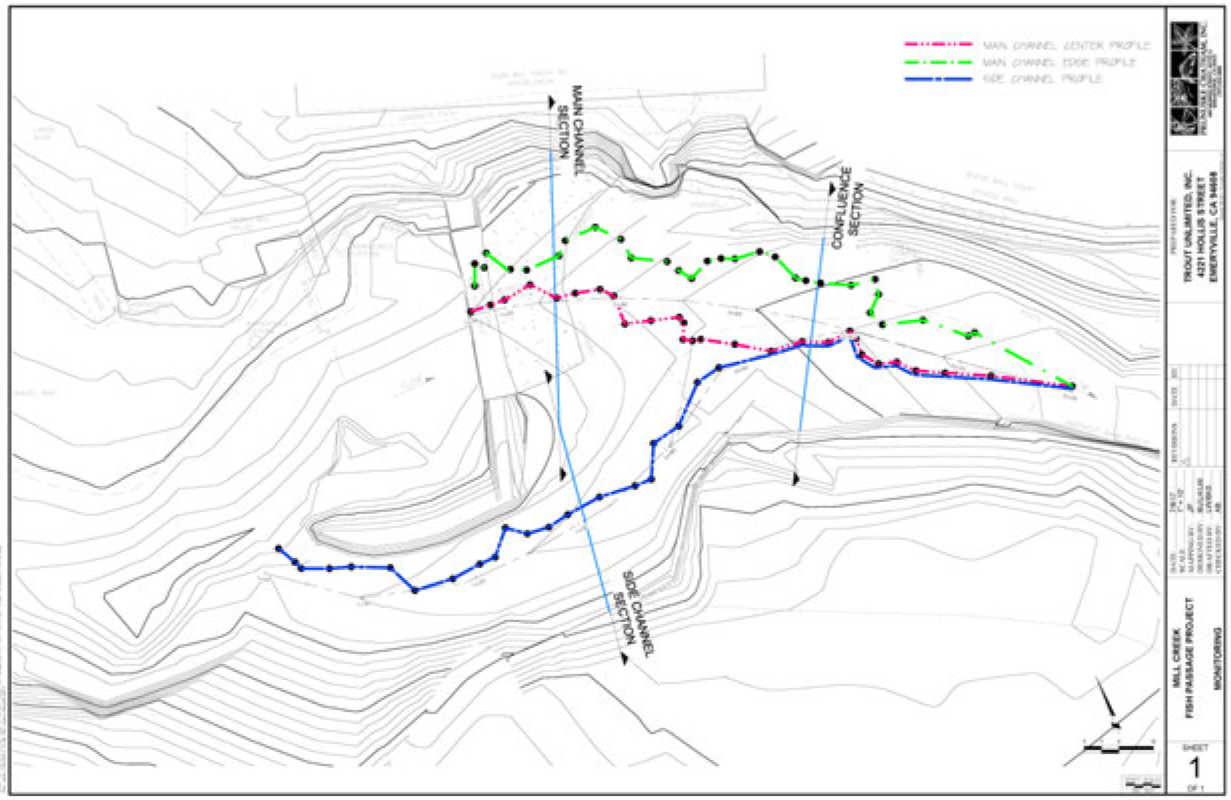

Figure 3. Plan view of where the low flow monitoring data was collected (profiles and cross-sections).

In addition to the cross-sections, velocity and depth profiles were measured along the length of each channel by collecting readings with the Marsh McBirney flow meter at multiple points while travelling upstream. This method aimed to mimic a path that fish might travel and record the range of the depth and velocity conditions present. A total station was used to survey in each measurement location to spatially orient the points. On both monitoring dates, a profile was measured in both the side channel and the main channel. During the low flow monitoring visit two main channel pathways were surveyed: one travelling up the center of the channel and one closer to the edge. The goal of this additional profile was to measure the variability in depths and velocities available in different parts of the channel during the same flow event. See maps above (Figure 2 and Figure 3) for the locations of the profiles on each monitoring date.

The mid-range flow monitoring took place on March 1st, 2017 (Figure 4). On this date, the two channels had a combined discharge of 63 cubic feet per second (cfs), which is a flow rate between the adult low fish passage flow of 6 cfs and the juvenile high fish passage flow of 111 cfs (Table 1). The side channel was carrying approximately a third of the flow (21 cfs), and the main channel at the dam was carrying 42 cfs. The May 30th, 2017 field visit captured a low flow event (Figure 5). Total discharge was 7 cubic feet per second, with the majority (6 cfs) flowing down the main channel over the dam and the remaining 1 cfs flowing in the side channel.[1] The total discharge of 7 cfs is close to the adult low fish passage flow (6 cfs), and the 1 cfs flow in the side channel represents the conditions at the low juvenile fish passage flow. The monitoring effort was fortunate to hit these critical mid-range and low flow conditions during the two monitoring sessions.

Figure 4. The site during the mid-range flow on March 1, 2017. Left: Looking upstream at the confluence cross section (Q_{total}=63 cfs). Right: Looking downstream at the side channel cross section (Q=21 cfs).

Figure 5. The site during low flow on May 30, 2017. Left: Looking upstream at the confluence cross section (Q_{total}=7 cfs). Right: Looking downstream at the side channel cross section (Q=1cfs).

[1] Note: This proportioning of the discharge during low flows—majority of flow going down main channel—is not how the project was designed. A landowner adjacent to the Project dammed the side channel inlet, forcing the majority of flows down the main channel. Under design conditions the ratio of side to main channel flow would have been reversed with the majority of flow going down the side channel. Also, a small landslide blocked the right side of the side channel inlet, which reduced the proportion of flow going down the side channel during higher flows (i.e. ratio documented in early 2017 does not match the design ratio shown in Table 1).

Results and Discussion

To expedite the engineering review process fish passage criteria for design has, by necessity, been simplified to very specific average hydraulic conditions that represent thresholds for passability (See Table 2 below for the NMFS and CDFW criteria). However, the ability of salmonids to navigate the complex array of hydraulic conditions within their natural stream environment is not driven by simplified thresholds. While there are optimal or preferred velocity ranges for sustained swimming efforts for adults and juveniles of each species, they also have the ability to move (dart) short distances through higher velocities and/or shallow flows. The varied hydraulics of steep roughened channel reaches, whether the feature naturally formed or was built, requires a more nuanced consideration of passage conditions than the average channel thresholds put forth in the fish passage design criteria.

We attempted to collect data on and present the complexities of the passage conditions within the Project's roughened ramps using a practical approach with limited resources. We have analyzed the depth and velocity data by computing the average conditions within each of the different channel reaches and compared it to the engineering fish passage design criteria listed in Table 2. We also present the data in graphical format so that location-specific velocities and depths can be viewed together in detailed cross section and long profile format. The measured velocities are shown relative to sustained swimming abilities in feet per second (fps) of both adult and juvenile coho salmon as stated in the U.S. Department of Transportation's "Design for Fish Passage at Roadway-Stream Crossings Report" (U.S. DOT 2007). We were unable to find information on darting velocities for coho adults and juveniles with a cursory literature search.

Table 2. Fish Passage Design Criteria

Criteria	Adult Salmonids	Juvenile Salmonids
Average minimum water depth	>1.0 foot	>0.5 foot
Average maximum velocity	<6.0 fps	<1.0 fps
Maximum hydraulic drop	<1.0 foot	<0.5 foot

Adult Fish Passage Flow

As described above, the discharge of 63 cfs on March 1st is representative of a mid-range flow that is within the range for both adult and juvenile migration. To determine how the flow on March 1st compared to the flows on days that coho were documented moving up Mill Creek we used stage data from a gage established by CEMAR and maintained by TU that is located downstream of the Project site that reasonably represents flows at the dam and PIT tag antenna array readings from UC Cooperative Extension/California Sea Grant's monitoring sites upstream and downstream of the Project. Figure 6 shows that coho transited the site when the stage was between 2.1 and 2.6 feet and that PCI's mid-range flow monitoring site visit on March 1, 2017 corresponds to a stage value of 2.1 feet at the gage site. Thus 63 cfs is representative of the range of flows that coho chose to migrate upstream in early winter.

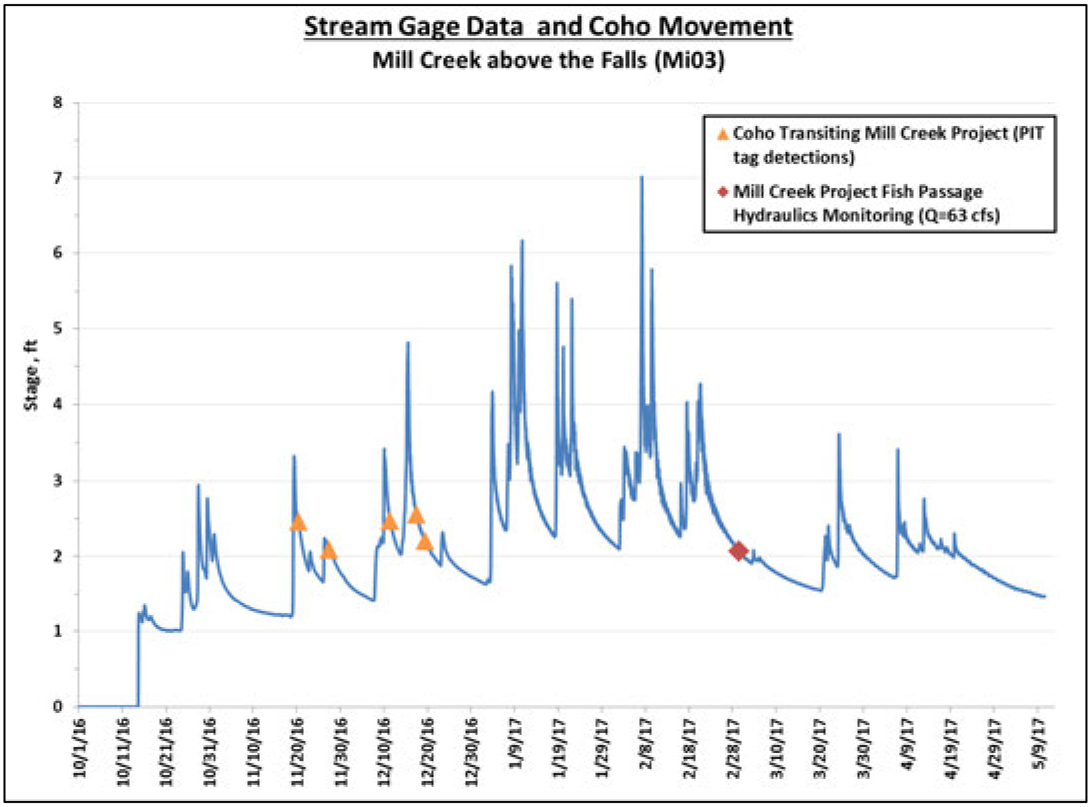

Figure 6. Stage data from downstream gage site on Mill Creek, with dates and flow conditions when coho migrated through the project site and the March 1st monitoring shown.

During the mid-range flow event on March 1, 2017 all measured sections and profiles had average velocities that were well below the fish passage guidelines for adult salmonids (<6.0 fps) as shown in Table 3. The average velocities were all above the 1.0 fps threshold for juvenile passage. Average depths measured in the reach were all greater than one foot, meeting minimum depth requirement for both adult and juvenile salmonids.

Table 3. Average fish passage conditions on March 1, 2017. Total discharge was 63 cfs. See Table 2 for comparative criteria.

	Side Channel X-Section	Main Channel X-Section	Confluence X-Section	Side Channel Profile	Main Channel Profile
Average Velocity [fps]	1.5	2.1	2.3	2.6	2.7
Average Depth [ft]	1.2	1.4	1.6	1.8	1.8

While the average depth and velocity calculations provide a generalized evaluation of the passage conditions it does not provide the complete picture. Examination of the variations in velocity along the profile and across individual cross sections within the topographically complex channel provides a more accurate picture. See Figure 7, Figure 8, and Figure 9 below for a graphical display of the point specific velocity and depth measurements, with coho swim velocity ranges shown for reference.

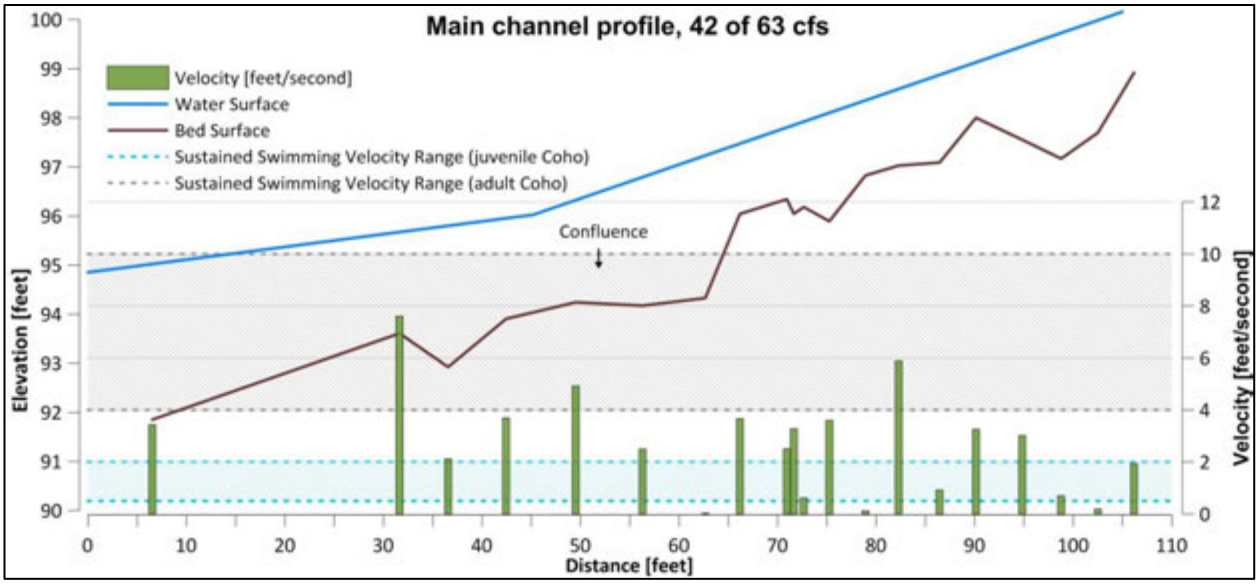

Figure 7. Measured depths and velocities in the main channel on March 1, 2017.

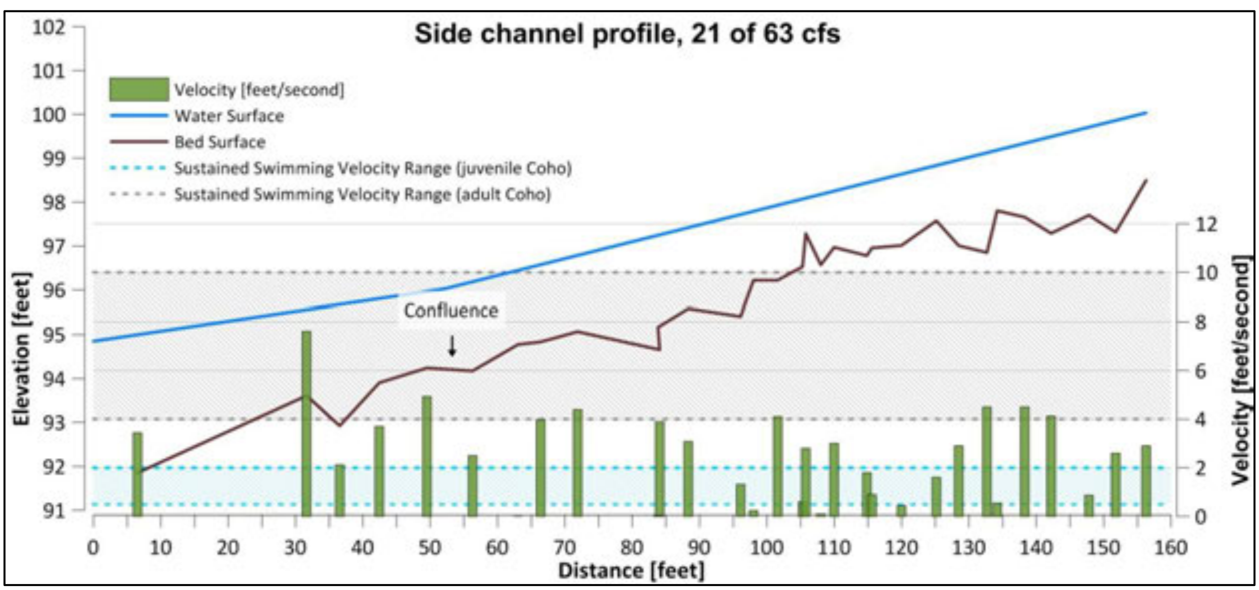

Figure 8. Measured depths and velocities in the side channel on March 1, 2017.

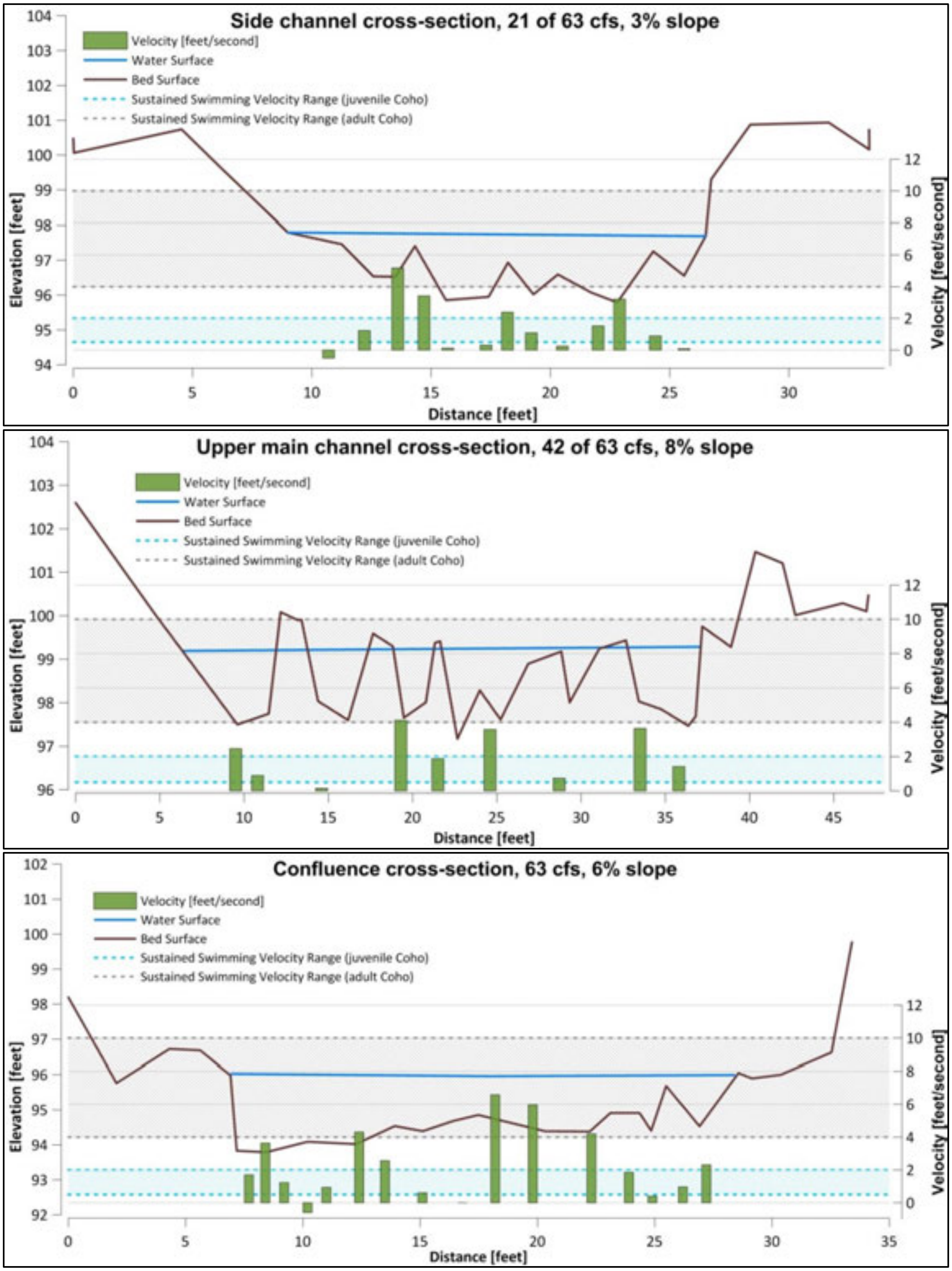

Figure 9. Fish passage conditions in cross sections during the mid-range flow measured on March 1, 2017.

The profile graphs (Figure 7 and Figure 8) show that point specific velocities vary from near 0 fps to over 4 fps in both the main and side channels, which is due to the chute-pool nature of the bed form and flow patterns. Channel slope does not appear to significantly influence velocity. Velocities at or above 6 fps were measured in the 6% and 8% sloped sections, while the 3% side channel's maximum measured velocity was 4.5 fps. The profile points were taken to represent a fairly straight-line swim path for adult fish to take near the center of the channel. The profile data does not represent the path a juvenile fish would likely take if migrating upstream. Velocities near the channel margins are typically much lower than the center channel, as shown in the cross section plots (Figure 9). The cross-channel velocity variation is similar in scale to the longitudinal variation. However, multiple locations at each cross section had velocities within the preferred range for juvenile coho and had zones of calm water. The zones of calm or low velocity waters are larger in extent in the 3% side channel (Figure 10) than they are in the main channel where the slopes are 6-8% (Figure 11).

Figure 10. Representative flow pattern and zones within the side channel on March 1, 2017. Note short chutes with large flatwater pool features and slow zones behind boulders.

Figure 11. Representative flow and swim conditions in the main channel on March 1, 2017. Note that calm flow zones appear to be smaller and less connected than those in the side channel.

Low Juvenile Fish Passage Flow

On the low-flow monitoring date, May 30, 2017, the total discharge was 7 cfs with the majority of the flow going down the main channel (6 cfs). The side channel had a discharge of 1 cfs. Average velocities were well below the maximum velocity target for adults within all measured areas and met the target for juveniles in the cross sections (Table 4). During this low flow event, average water depths met the minimum depth for juveniles, but were lower than ideal for adult fish passage.

Table 4. Average Fish Passage Conditions on May 30, 2017. Total discharge was 7 cfs. See Table 2 for comparative criteria.

	Side Channel X-Section	Main Channel X-section	Confluence X-Section	Side Channel Profile	Main Channel Profile
Average Velocity [fps]	0.8	1.0	1	1.7	2.2 center, 1.1 edge
Average Depth [ft]	0.5	0.7	0.9	1	0.93 center, 0.7 edge

As for the mid-range flow, velocities during low flow vary longitudinally and cross channel (Figure 12, Figure 13, and Figure 14). At the low adult and juvenile flow represented by the May 30th measurements velocities do not exceed 4 fps anywhere in the channels and are within the preferred velocity range for juveniles in many locations. The edge profile up the main channel shows more favorable passage conditions than the center path profile does, as would be expected. The side channel appears to have only a few points where velocities are above the preferred sustained swimming velocity range for juvenile coho.

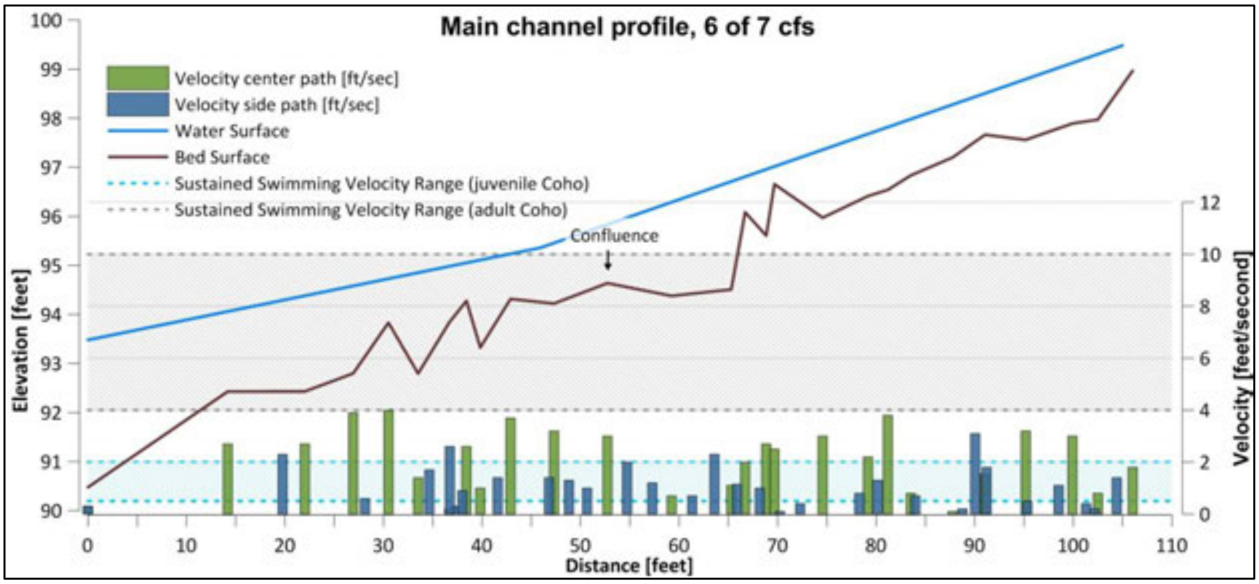

Figure 12. Measured depths and velocities in the main channel on May 30, 2017.

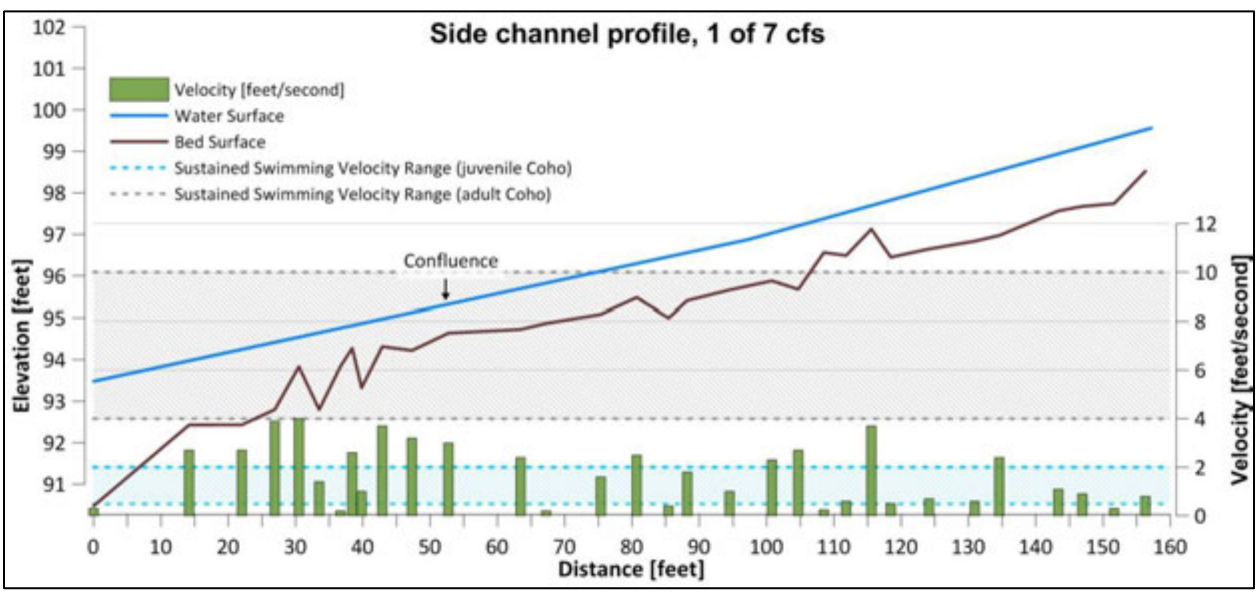

Figure 13. Measured depths and velocities in the side channel on May 30, 2017.

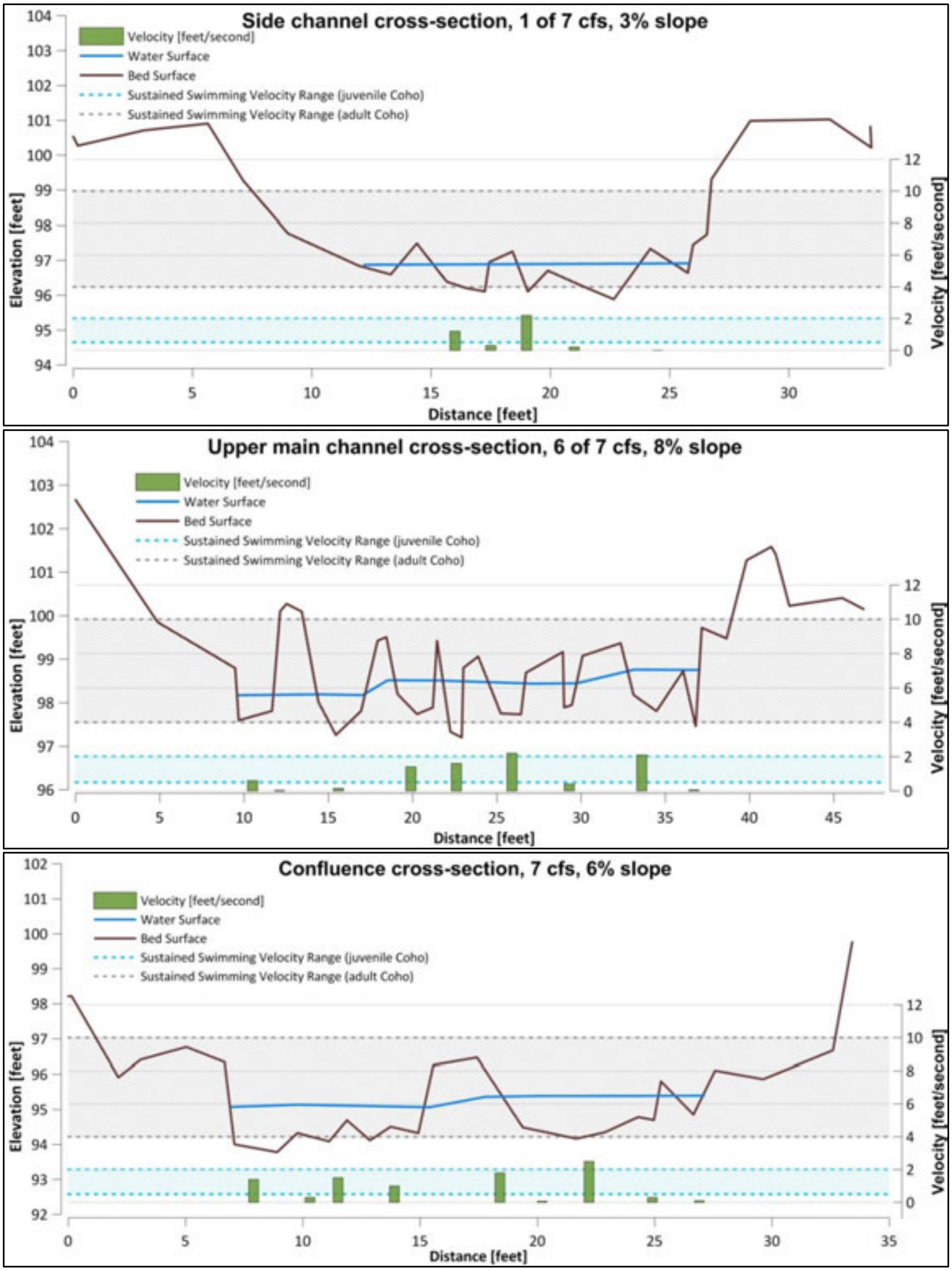

Figure 14. Fish passage conditions at the cross sections during the low flow on May 30, 2017.

Based on the cross section velocity and depth data it is expected that juvenile coho and steelhead can navigate the Project and migrate upstream between early spring storm events and when flows recede in the late spring through early summer (see 2017 hydrograph, Figure 6). The side channel provides abundant low velocity and calm water zones with gravel and meandering flow paths between the boulders. The main channel, with its steeper slope, has less defined flow paths and calm-water resting zones. In the main channel below the dam the interstitial gravel and cobble was largely scoured out, which left small drops and chutes between the boulders that may make navigating the main channel more difficult for juvenile coho (Figure 15).

Figure 15. Flow conditions and paths in the main channel during low flow conditions on May 30, 2017. Flow is 6 cfs. Note the drops and chutes between the boulders.

As evidenced by the PIT tag data, adult salmonids successfully navigated the project reach one month after barrier removal and project completion. The new side channel is providing lower velocity habitat for juvenile salmonids as intended. Together, the two channels create an array of velocity and depth conditions to accommodate passage for both adults and juveniles over a wide range of flows. Future PIT tag monitoring and spawning surveys will further document when salmonids are migrating upstream and whether the Project is meeting its objectives of providing adult and juvenile access to the upper Mill Creek watershed.

References

CDFW. 2002. Culvert criteria for fish passage. Appendix A in California Salmonid Stream Habitat Restoration Manual 3rd edition. California Department of Fish and Wildlife.

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National Marine Fisheries Service (NMFS). 2011. Anadromous Salmonid Passage Facility Design. NMFS, Northwest Region, Portland, Oregon.

Prunuske Chatham, Inc. 2015. Mill Creek Dam Fish Passage Design Report.

U.S. DOT. 2007. Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report. Federal Highway Administration. U.S. Department of Transportation.

<u>Attachment 1</u>

CDFW Construction Monitoring Worksheet for the Mill Creek Dam Fish Passage Project (P1530400)

Mill Creek Dam

Fish passage and engineering - construction monitoring points for as-built documentation

feature	location	measure objective	units	tolerance	units	date measured	observer name	measurement	difference
Main Channel									
Excavation - subgrade bottom	3+47	87.0	feet	minimum	feet	8/8/2016	Ben	86.85	-0.15
Excavation - subgrade bottom	3+55	87.4	feet	minimum	feet	8/8/2016	Ben	87.47	0.07
Excavation - subgrade bottom	3+65	88.0	feet	minimum	feet	8/10/2016	BKS	87.39	-0.61
Excavation - subgrade bottom	3+86	89.3	feet	minimum	feet	8/11/2016	BKS	89.35	0.05
Excavation - subgrade bottom	4+01	90.2	feet	minimum	feet	8/19/2016	BKS	90.17	-0.03
Excavation - subgrade bottom	4+16	91.4	feet	minimum	feet	8/26/2016	BKS	91.15	-0.25
Excavation - subgrade bottom	4+35	92.9	feet	minimum	feet	9/1/2016	BKS	92.92	0.02
ESM finish grade	3+47	92.0	feet	0.25	feet	8/15/2016	BKS	92.25	0.25
ESM finish grade	3+55	92.4	feet	0.25	feet	8/15/2016	BKS	92.37	-0.03
ESM finish grade	3+65	93.0	feet	0.25	feet	9/1/2016	BKS	92.85	-0.15
ESM finish grade	3+86	94.3	feet	0.25	feet	8/25/2016	BKS	94.4	0.10
ESM finish grade	4+01	95.2	feet	0.25	feet	9/1/2016	BKS	95.03	-0.17
ESM finish grade	4+16	96.4	feet	0.25	feet	9/1/2016	BKS	96.47	0.07
ESM finish grade	4+35	97.9	feet	0.25	feet	10/7/2016	BKS	98.04	0.14
Dam notch elevation	4+48	99.0	feet	0.2	feet	10/7/2016	BKS	99.05	0.05
Dam notch width	4+48	10.0	feet	0.5	feet	approved by NOAA engineer and CDFW project manager			
Dam notch side slopes - 10:1	4+48		10:01	Not set					
Side Channel									
Excavation - subgrade bottom confluence	0+00	90.1	feet	minimum	feet	8/19/2016	BKS	90.17	0.07
Excavation - subgrade bottom	0+34	93.2	feet	minimum	feet	9/6/2016	BKS	93.25	0.05
Excavation - subgrade bottom	4+35	93.8	feet	minimum	feet	9/6/2016	BKS	93.69	-0.11
Excavation - subgrade bottom	4+48	94.1	feet	minimum	feet	9/6/2016	BKS	94.19	0.09
Excavation - subgrade bottom	0+90	95.0	feet	minimum	feet	9/13/2016	BKS	94.89	-0.11
ESM finish grade - confluence	0+00	95.1	feet	0.25	feet	9/20/2016	BKS	95.17	0.07
ESM finish grade	0+34	96.2	feet	0.25	feet	9/12/2016	BKS	96.3	0.10
ESM finish grade	4+35	96.8	feet	0.25	feet	9/12/2016	BKS	96.75	-0.05
ESM finish grade	4+48	97.1	feet	0.25	feet	9/12/2016	BKS	97.05	-0.05
ESM finish grade	0+90	98.0	feet	0.25	feet	10/7/2016	BKS	98.02	0.02
Bypass weir concrete	1+00	98.5	feet	0.1	feet	10/7/2016	BKS	98.52	0.02
Bypass weir low flow base rock (2)	1+04.5	98.5	feet	0.1	feet	10/7/2016	BKS	98.21 to 98.63 across opening	N/A - Concrete forms weir and base rock is below
Bypass weir upper debris deflecting rock (3)	1+04.5	100.5	feet	field fit to maximize contact and stability		10/7/2016	BKS	100.67 to 100.30	0.17 to -0.02