Kaweah Project, FERC Project No. 298

AQ 8 – Fish Passage
Draft Technical Study Report

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SOUTHERN CALIFORNIA EDISON®
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Southern California Edison Company
Regulatory Support Services
1515 Walnut Grove Avenue, Rosemead, CA 91770

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List of Acronyms

°C	degrees Celsius
FERC	Federal Energy Regulatory Commission
FL	fork length
ft	feet
lengths/sec	lengths per second
mm	millimeter
Project	Kaweah Project
PSP	Proposed Study Plan
RM	River Mile
RSP	Revised Study Plan
SCE	Southern California Edison Company
SNP	Sequoia National Park
TSP	Technical Study Plan
TSR	Technical Study Report
USFWS	U.S. Department of Fish and Wildlife Service

1 INTRODUCTION

This Technical Study Report (TSR) describes the data and findings developed by Southern California Edison Company (SCE) in association with implementation of the AQ 8 – Fish Passage Technical Study Plan (AQ 8 – TSP) for the Kaweah Project (Project). The AQ 8 – TSP was included in SCE's Revised Study Plan (RSP)[1] (SCE 2017a) and was approved by the Federal Energy Regulatory Commission (FERC) on October 24, 2017 as part of its Study Plan Determination for the Project (FERC 2017). Specifically, this report provides a description of the methods and results of AQ 8 – TSP completed in 2018.

2 STUDY OBJECTIVES

The AQ 8 – TSP included two study objectives, as follows:

- Document the location, nature, and characteristics of fish barriers in bypass river reaches[2].
- Identify Project facilities and operations (e.g., diversion structures, instream flow releases) that may affect fish passage.

3 EXTENT OF STUDY AREA

The study area includes the bypass river reaches and Project diversion dams (Map AQ 8-1).

4 STUDY APPROACH

- Identification and classification potential fish passage barriers in bypass river reaches was accomplished using the following approach:
  - The AQ 1 – Instream Flow TSP mesohabitat mapping data were used to identify the location and nature (natural or Project-related) of potential barriers (e.g., natural falls, tributary junctions, road crossings, shallow riffles, and diversion or dam structures) in the bypass river reaches.
  - Potential barriers were revisited after the mesohabitat mapping study and each of the potential barriers were classified into the falls, chute, and cascade types defined by Powers and Orsborn (1985) or as critical riffles (Thompson 1972).
  - Because much of the East Fork Kaweah River is too narrow and steep to be accessible, we were only able to visit the first potential natural barrier on the downstream end of the river (i.e., near the Kaweah River confluence) and a potential natural barrier on the upstream end (i.e., near the bridge crossing and Kaweah No. 1 Diversion). Other potential natural barriers on the East Fork Kaweah were identified from aerial photographs.
  - Fish passage assessment data were collected at each of the barriers visited in the field. The data included fall height, plunge pool depth, water velocity, photographs, and field biologist observations. The specific measurements are shown in Figure AQ 8-1. An example of the field data sheet that was used is shown in Appendix A. In addition, the barriers were also assessed qualitatively for fish passage by the field biologist at flows not present during the field visit

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1 SCE filed a Proposed Study Plan (PSP) on May 24, 2017 (SCE 2017b). Three comments were filed on the PSP, however, they did not result in revisions to any of the study plans. Therefore, SCE filed a Revised Study Plan (RSP) on September 19, 2017, which stated that the PSP, without revision, constituted its RSP. The FERC subsequently issued a Study Plan Determination on October 24, 2017 approving all study plans for the Kaweah Project.

2 A bypass reach is a segment of a river downstream of a diversion facility where Project operations result in the diversion of a portion of the water from that reach. Typically the diverted water re-enters the river through a powerhouse at the downstream end of the bypass reach.

(e.g., high flows) by visually determining if there were obvious passage routes through or around the barrier that would be present at a different flow that would allow passage.

- Fish passage at the potential Project-related and natural fish barriers was evaluated typically during the low-flow period (some sites were visited at higher flows) using the swimming and leaping capabilities of trout (particularly rainbow trout) and minnows/suckers (hardhead, Sacramento pikeminnow, Sacramento sucker). Barriers were classified as impassable if at both low and high flow it was determined that fish could not traverse the barrier and partial if at some flow (e.g., high flow) a pathway was likely to exist that would provide passage. The general upstream fish passage assessment methodology outlined in Powers and Orsborn (1985) and Thompson (1972) was used to evaluate passage at potential vertical barriers (falls), high velocity chutes, and/or critical riffles based on field measurements of the barriers. Appendix B provides a detailed discussion of the analysis approach and methods and the literature sources of the quantitative fish performance data.
- A range of swimming velocity was used for the trout (high and low swimming estimates). Minnow and sucker swimming capability was set at the lower end of the trout swimming range. Figure AQ 8-2 shows the assumed swimming capabilities of fish. Burst swimming velocity was used to determine the leaping ability of fish (i.e., their ability to navigate vertical barriers). Prolonged and sustained swimming capability was used to determine the ability of fish to navigate high velocity water in chutes and riffles (Powers and Orsborn 1985). Burst swimming (less than 0.1 minute) was assumed to range between 8 and 12 body lengths/second (lengths/sec) for salmonids (trout) (Beamish 1978; Reiser and Peacock 1985; Videler 1993). Burst swimming for cyprinids (minnows and catastomids (suckers) was set on the lower end of the trout range (8 body lengths/sec). The sixty-minute sustained swimming velocity was assumed to be between 2 and 4 body lengths/sec for trout (Brett and Glass 1973; Beamish 1978; Reiser and Peacock 1985) and approximately 2 body lengths/sec for minnows/suckers[3] (Myrick and Cech 2000; Berry and Pimentel 1985). Prolonged swimming (0.1–60 minutes) was assumed to vary between burst and sustained swimming speed logarithmically (Videler 1993).
- Barriers were analyzed for passage by a 12-inch (305 mm [millimeter]) trout or minnow (e.g., hardhead, Sacramento pikeminnow) at a typical late Spring / early Summer water temperature of 15°Celsius (°C) (e.g., temperature when spawning/post-spawning movement would potentially occur). The 12-inch (305 mm) fish size was used for the analysis to represent a large trout in the system. During the fish population sampling (AQ 2 – Fish Population Study), the largest trout measured was 8.5 inches (216 mm fork length [FL]) and the largest trout observed (snorkeling) was in the 10 to 12-inch size class. For fish in the approximately 12-inch and less size, empirical fish leaping data from the literature indicate that smaller fish (e.g., 6 inches) can leap as high as larger fish (e.g., 8+ inches) (Kondratieff and Myrick 2006). This is partly because the maximum swimming speed per body length is higher for smaller fish (e.g., <12 inches) than it is for larger fish (e.g., ≥12 inches) (see compilation of data in Kondratieff and Myrick 2006). As a result, we used the leaping and swimming ability of a 12-inch fish as reasonable representation for the passage capabilities of various sized fish in the Project area. The same fish size was used for hardhead, Sacramento pikeminnow, and Sacramento sucker.
- The vertical and horizontal leaping relationships based the maximum burst swimming velocity that was used in the analysis are shown in Figure AQ 8-3. The leaping ability was used to assess passage at falls. Burst and prolonged swimming velocity versus duration relationships were used to evaluate water velocity versus fish swimming distance for the chute passage analysis

[3] Critical swimming velocity data (a laboratory measure of prolonged swimming capacity) for hardhead, Sacramento pikeminnow, Colorado pikeminnow, and Sacramento sucker (Myrick and Cech 2000; Berry and Pimentel 1985) were compared to data for rainbow trout (Beamish 1978; Hawkins and Quinn 1996; Jain et al. 1997). Minnow/sucker species swimming velocities were comparable to the lower range observed for trout (typically about 2 body lengths/sec).

(Figure AQ 8-4). Water depth in the plunge pool, crest of a falls, or in a chute was also used to assess falls and chute passage. The details are provided in Appendix B.

- Historical data on potential fish barriers (SCE 2007) collected within the Sequoia National Park (SNP), but outside the relicensing study area were included in this report to provide context to the location and frequency of natural barriers in the Kaweah River watershed. The historical data extends from the SNP boundary near RM 9.5 (Map AQ 8-1) upstream to approximately 1,500 feet (ft) above the Marble Fork Diversion and Middle Fork Diversion within the SNP. Only barriers documented by SCE (2007) that were classified as impassable barriers or high severity barriers were incorporated. We assumed the impassable barriers were impassable and the high severity barriers were assumed in this report as partial barriers. SCE (2007) described them as not passable under low flow conditions and potentially passable with substantial difficulty at higher flows.

- The AQ 8 – Fish Passage Study Plan contemplated that if there were any stream crossings identified that were potential barriers (e.g., culverts), then the stream crossings would be evaluated for fish passage consistent with Flosi, et al. (2010). In addition, if any Project-related barriers were identified, which potentially required hydrodynamics modeling to assess fish passage over a range of flows, this would be completed in collaboration with resource agencies. Only barriers that prevented access to sections of river with important spawning or rearing habitat (as determined in collaboration with the resource agencies) would be considered for modeling.

5 STUDY RESULTS

Map AQ 8-1 shows the barriers identified during the 2018 surveys and barriers that were previously documented upstream of River Mile (RM) 9.5 in the SNP boundary as part of another study (SCE 2007). Pictures and details of barriers surveyed in 2018 are summarized in Table AQ 8-1 and Appendix C.

5.1 Fish Passage Barriers in Kaweah River

In the Kaweah River there were two Project-related barriers identified, including the Kaweah No. 2 Diversion Dam (RM 8.9) and Kaweah No. 2 Diversion Dam Gage Pool Weir (RM 8.8). The Kaweah No. 2 Diversion Dam was identified as an impassable barrier and the Kaweah No. 2 Diversion Dam Gage Pool Weir was identified as a partial barrier to fish passage (Map AQ 8-1; Table AQ 8-1; Appendix C).

Additionally, one partial natural barrier was documented on the Kaweah River below Kaweah No. 2 Powerhouse at RM 3.8 and another impassable natural barrier within the SNP at RM 9.5 approximately 0.6 mile upstream of the Kaweah No. 2 Diversion Dam.

The Kaweah No. 2 Diversion Dam at RM 8.9 precludes upstream fish passage into the river reach from RM 8.9–9.5. Above the impassable natural barrier at RM 9.5, SCE (2007) documented numerous upstream migration partial barriers, one additional impassable barrier in the Kaweah River (below the confluence of the Middle Fork Kaweah River and Marble Fork Kaweah River), and several impassable barriers in the Middle Fork Kaweah and Marble Fork Kaweah rivers upstream of their confluence (natural and manmade).

5.2 Fish Passage Barriers in East Fork Kaweah River

In the East Fork Kaweah River, there were two Project-related barriers, including the Kaweah No. 1 Diversion Dam and Kaweah No. 1 Diversion Dam Gage Pool Weir (Map AQ 8-1; Table AQ 8-1; Appendix C). Both structures create impassable fish barriers at approximately RM 4.7.

Downstream of the Project-related barriers there were two natural barriers that were surveyed – an impassable natural barrier on the East Fork Kaweah River near the confluence at RM 0.2 and an impassable natural barrier at RM 4.4 below the Kaweah River Bridge. Analysis of aerial photographs and topographic maps of the river stretch between these natural barriers suggest many similar impassable barriers in this section of river, however, ground surveys are unsafe due to steep terrain.

5.3 Potential Barriers Requiring Hydrodynamic Modeling

No stream crossings were identified that created fish passage barriers. No Project-related fish passage barriers were identified where further study (e.g., hydrodynamics modeling) appeared warranted to understand passage over a wide range of flows. The Project-related impassable were large enough to be barriers over a wide range of flows (low to high) (i.e., additional hydrodynamics modeling would not change the conclusion). The natural barrier on the Kaweah River at RM 3.8 (partial barrier) is located below the Project (below Powerhouse No. 2 tailrace); therefore, the Project does not influence flows at this barrier. The lower flows that affect passage at this barrier are a product of natural hydrology in the Kaweah River Watershed.

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Tables

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Table AQ 8-1. Potential Fish Passage Barriers

Barrier ID	River Mile	Barrier Type	Barrier Class	Physical Characteristics					Passable at Low / High Flows		Barrier Limitation
				Height of Barrier (ft)	Horizontal Distance or Length (ft) (Measured or Calculated)[2]	Plunge Pool / Chute Depth (ft)	Water Velocity[3] (ft/s)	Flow at Visit (cfs)	Trout	Minnows[4]	
Kaweah River											
Downstream of National Park Foothills Visitor Center	9.5	Natural	Falls	10.0[1]	12.0[1]	-	-	-	NO / NO	NO / NO	Fall Height
Kaweah No. 2 Diversion Dam	8.9	Project	Falls	9.2	16.0	5.0	2.2	338	NO / NO	NO / NO	Fall Height
Kaweah No. 2 Diversion Dam Gage Pool Weir	8.8	Project	Falls	1.0	3.0	5.2	2.2	315	NO[5] / YES	NO[5] / YES	Fall Height
Downstream of Kaweah No. 2 Powerhouse	3.8	Natural	Falls	1.8	20.0	2.3	0.6	169	NO / YES	NO / YES	Fall Height
East Fork Kaweah River											
Kaweah No. 1 Diversion Dam	4.7	Project	Falls	11.5	15.0	8.0	2.5	188	NO / NO	NO / NO	Fall Height
Kaweah No. 1 Diversion Dam Gage Pool Weir	4.7	Project	Falls/ Chute	7.2	11.2 / 17.0	2.5/0.5	3 / >12	122	NO / NO	NO / NO	Fall Height, Chute Velocity, and Length
East Fork Kaweah Downstream of Kaweah River Bridge	4.4	Natural	Falls	9.0	20.0	6.0	4.0	195	NO / NO	NO / NO	Fall Height
East Fork Kaweah above Confluence with Kaweah River	0.2	Natural	Falls/ Chute	5.7/9.7	15.0 / 35.8	4.0/0.5	3.8 / 12.2	47	NO / NO	NO / NO	Fall Height, Chute Velocity, and Length

1 Measurement estimated from online kayaker video.
2 Horizontal leap distance required to clear falls and/or swimming length of chutes.
3 Velocity at crest of falls / Velocity in chute.
4 "Minnows" include hardhead, Sacramento pikeminnow, and Sacramento sucker.
5 Passable at measured flow, but not at low flow.

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Figures

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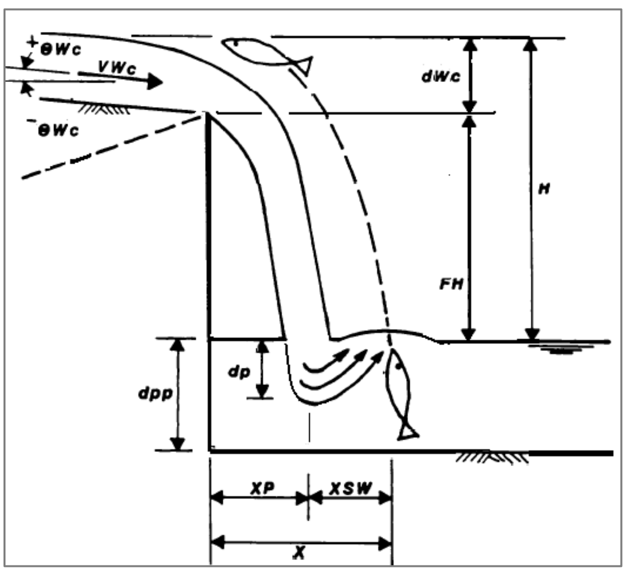
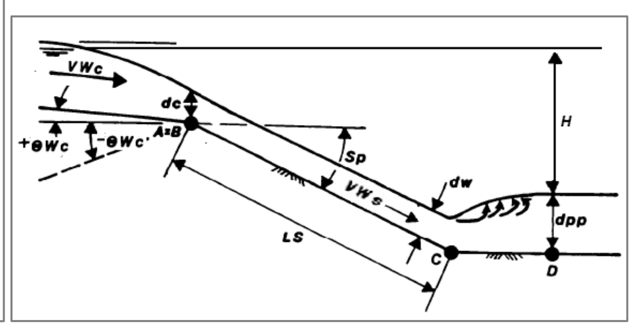
Fish Passage Parameters Measured (Abbreviations Shown on Schematics[1] Below)			
Falls	**Chutes**	**Cascades**	**Critical Riffles**
Width of channel/water at top of crest	Width of water at crest and in chute	Also measure the following for each chute/ fall	Width of riffle
Water depth at crest (dWc)	Water depth at crest (dWc)	Resting pool width, length, and depth if resting pools are present.	Depth across riffle
Water velocity at crest (VWc)	Water velocity at crest (VWc)	Air entrainment %	Velocity across riffle
Angle of water at crest (± θWc)	Angle of water at crest (± θWc)	Turbulence (passable or not)	
Fall height (FH)	Chute height (H)		
Depth of plunge pool (dpp)	Depth of water in chute (dW)		
Depth of plunging water (dp)	Velocity of water in chute (VWs)		
Distance from crest to plunge (Xp)	Length of chute slope (LS)		
Distance from plunge to standing wave (XSW)	Slope of chute passage area (Sp)		
	Depth of plunge pool (dpp)		

[1] Powers, P.D. and J.F. Orsborn. 1985. Analysis of Barriers to Upstream Migration: An Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls. BPA Report No. DOE/BP-36523-1.



Fall Measurements



Chute Measurements

Figure AQ 8-1. Summary of Parameters Measured at Each Potential Barrier during 2018 Field Visits.

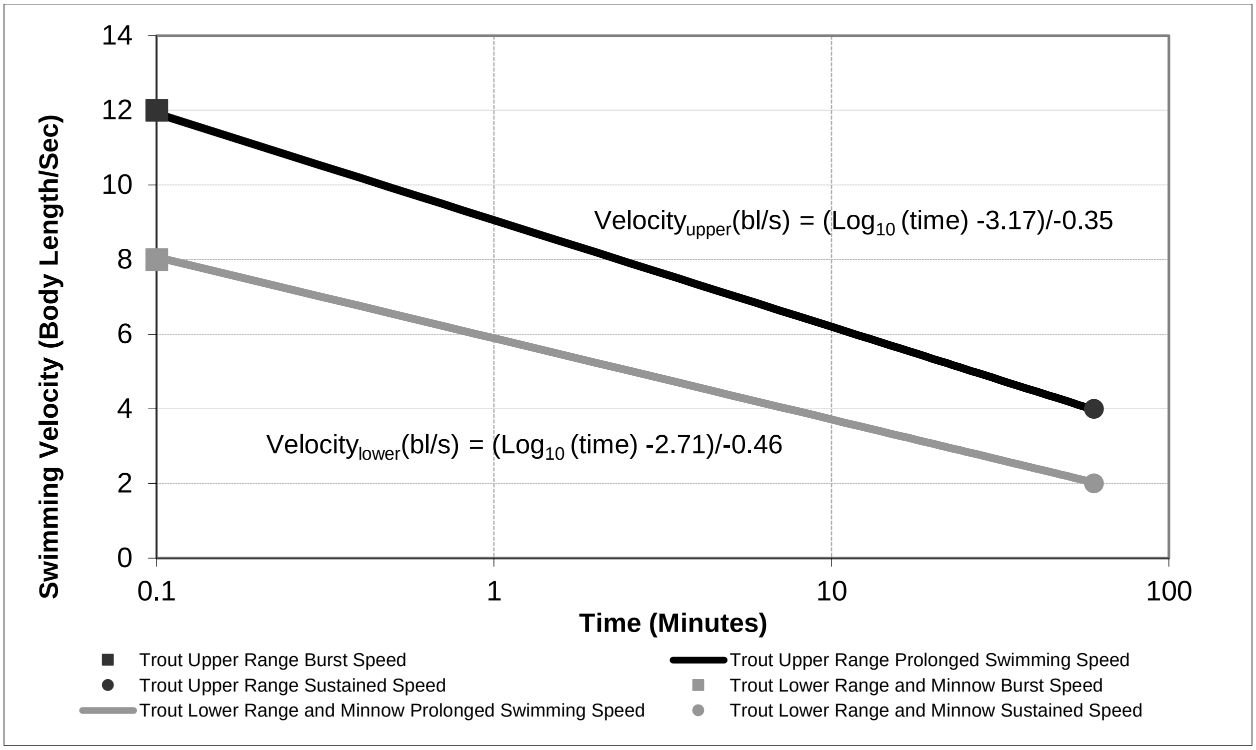


Figure AQ 8-2. Fish Swimming Speed vs. Time.

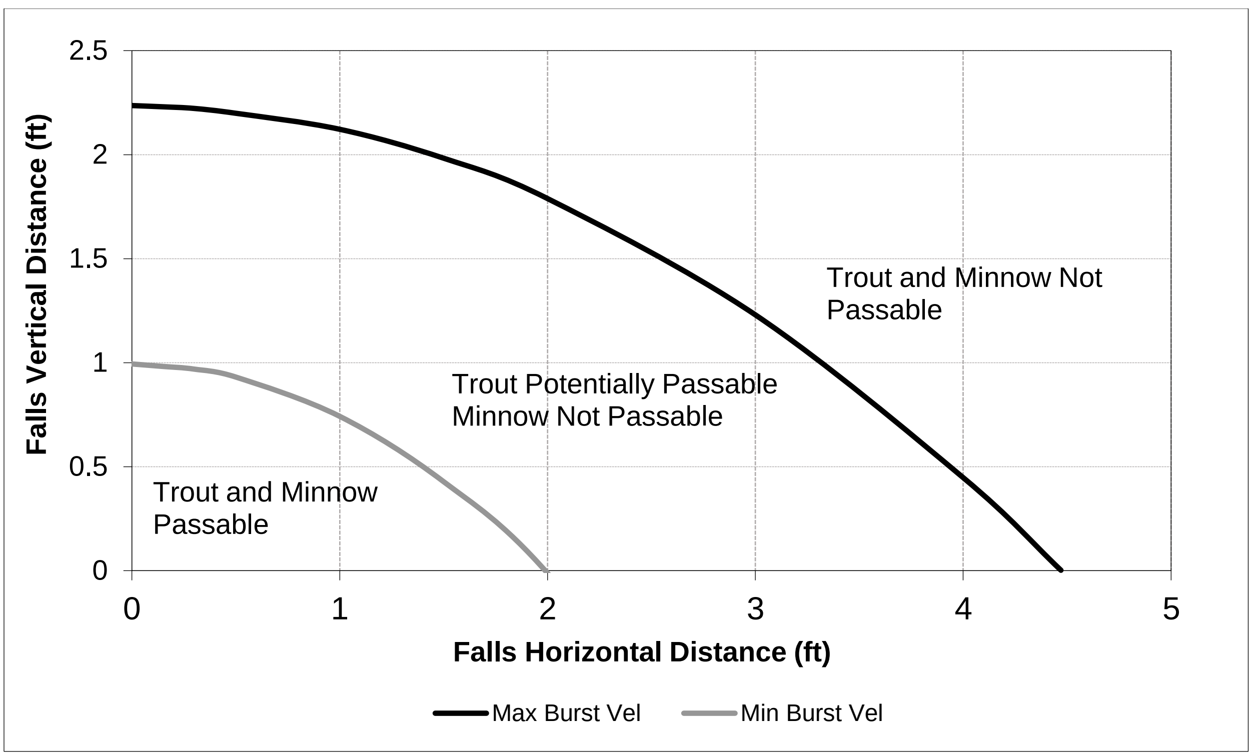


Figure AQ 8-3. Fish Vertical and Horizontal Leaping Ability.

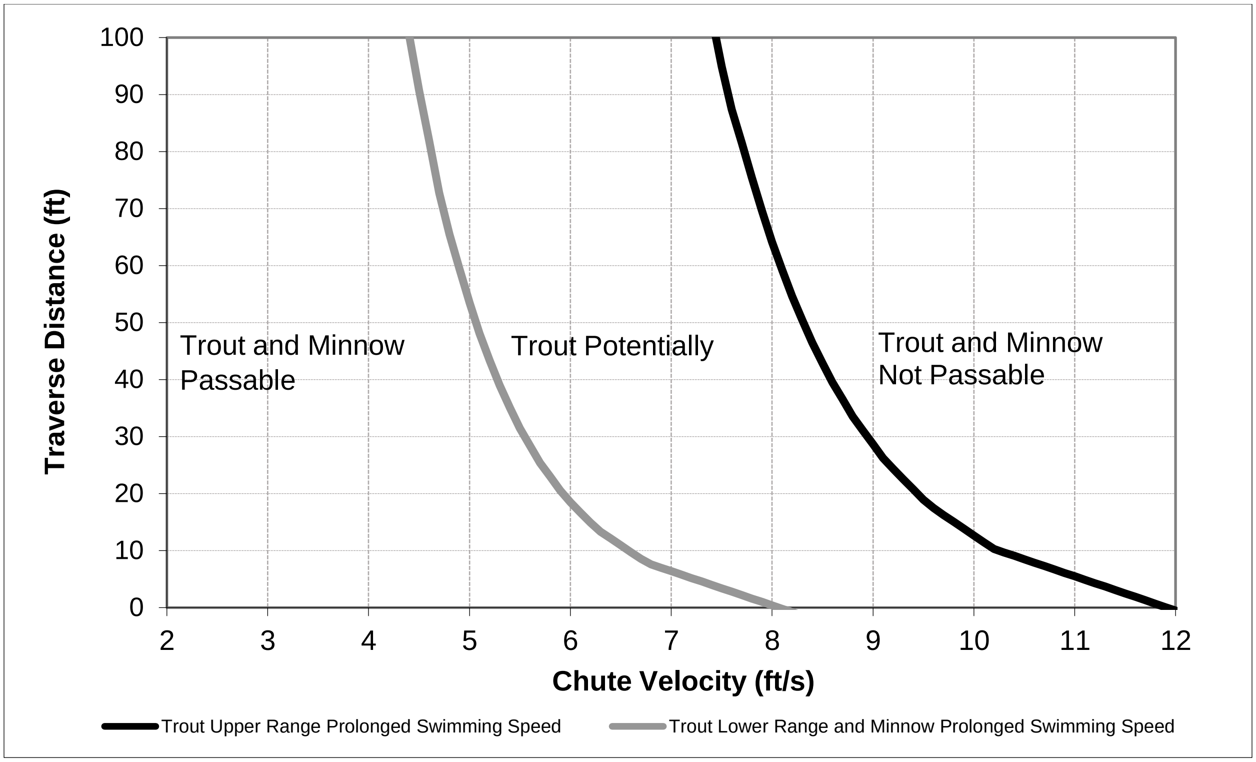


Figure AQ 8-4. Chute Water Velocity vs. Fish Swimming Distance.

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Maps

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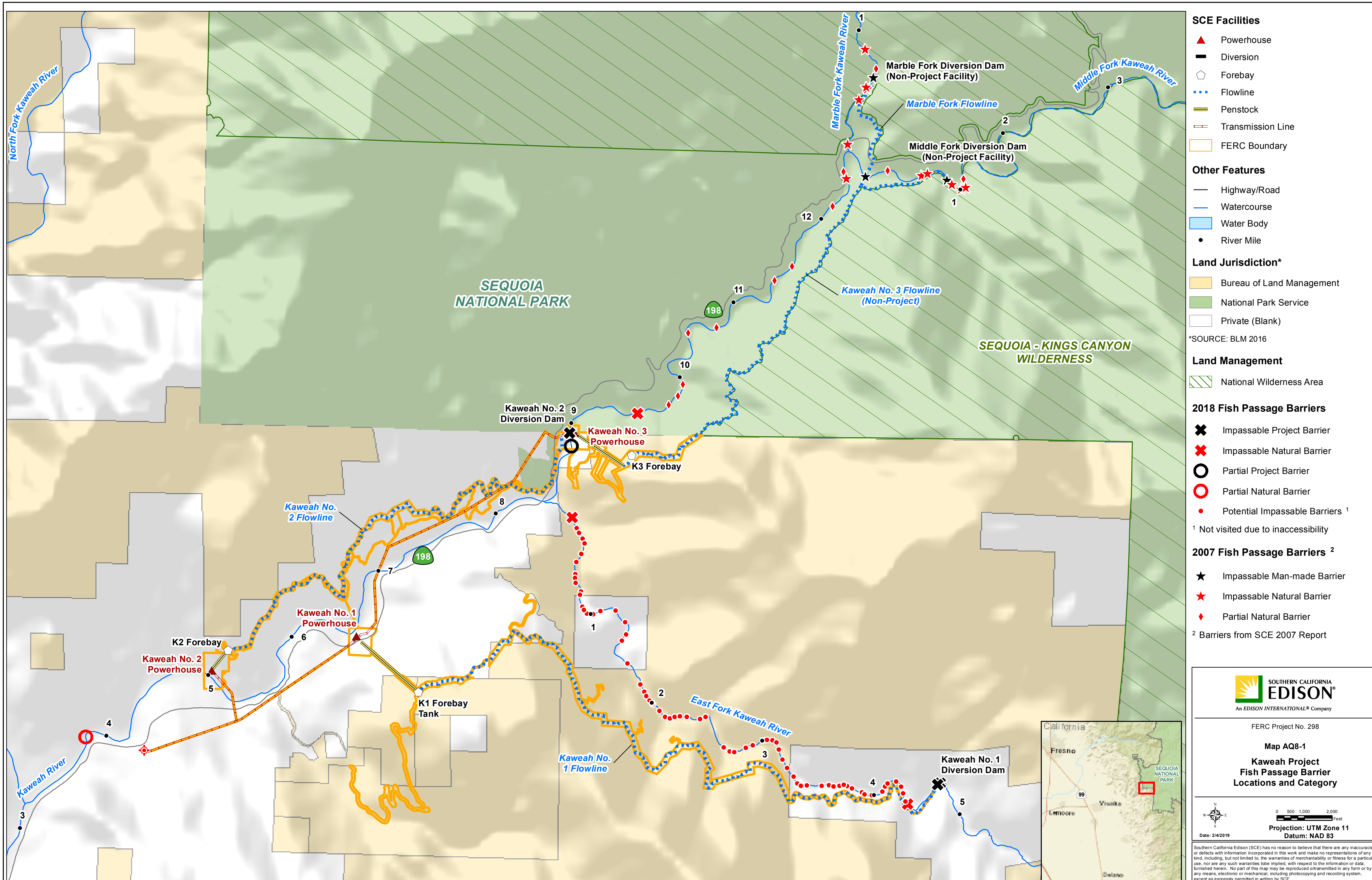

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Appendix A

Quantitative Barrier Assessment Data Sheet

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Fish Passage Data Sheet SCE

River Reach Surveyed: Date: Crew:

Downstream GPS Coordinates:

Upstream GPS Coordinates:

Total Number of Barriers Observed:

General Overview River Photo Numbers:

Detailed Barrier Photo Numbers (list all):

Draw sketch of the river reach or tributary junction surveyed with approximate the location of barriers and photo points labeled. Note: number barriers and photos to correspond to numbers on detailed barrier sheets.

Comments:

River Discharge: ________ cfs

Width (units =)																						
Depth/Elevation (units =)																						
Velocity (units =)																						

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Fish Passage Barrier ID (River Reach and Barrier Number): Date: Crew:

Barrier location (e.g., GPS Coordinates): Detailed Barrier Photo Numbers:

Class (circle): Falls Chute Cascade (combination falls/chutes, boulder, turbulent) Critical Riffle

Discharge: ________ cfs

Critical Riffle Measurements and/or Discharge Measurement (circle one)

Width (units =)																						
Depth/Elevation (units =)																						
Velocity (units =)																						

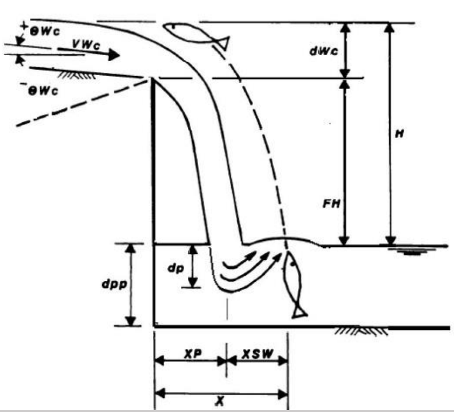
Detailed Barrier Sketch (see images below…use compound falls/chutes or chutes/falls as appropriate). Number each barrier in the order of the measurements recorded below the sketch:

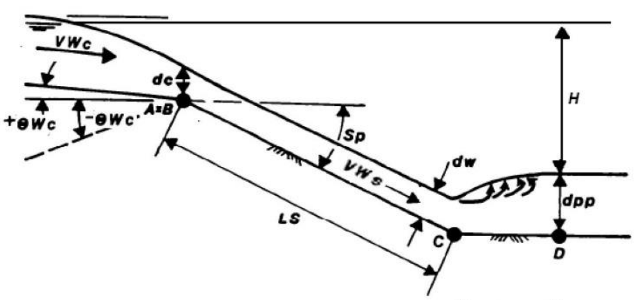
Record the measurements below (with units). Order the measurements as in the sketch if there are multiple chutes/falls.

Fall Measurements
Width of channel/water at top of crest:
Water depth at crest (dWc):
Water velocity at crest (VWc):
Angle of water at crest (± θWc):
Fall height (FH):
Depth of plunge pool (dpp):
Depth of plunging water (dp):
Dist. from crest to plunge (Xp):
Dist. from plunge to standing wave (XSW):

Chute Measurements
Width of water at crest and in chute:
Water depth at crest (dWc):
Water velocity at crest (VWc):
Angle of water at crest (± θWc):
Chute height (H):
Depth of water in chute (dW):
Velocity of water in chute (VWs)
Length of chute slope (LS):
Slope of chute passage area (Sp):
Depth of plunge pool (dpp):

Cascade Measurements (Measure each chute/fall)
Also measure the following
Resting pool width:
Resting pool length:
Resting pool depth:
Air entrainment %:
Turbulence (passable or not):





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Appendix B

Quantitative Fish Barrier Evaluation Approach

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B.1 Introduction

Upstream passage was evaluated quantitatively using the swimming and leaping capabilities of trout (particularly rainbow trout) and minnows/suckers (hardhead, Sacramento pikeminnow, Sacramento sucker). The upstream fish passage assessment methodology outlined in Powers and Orsborn (1985) and Thompson (1972) was used to evaluate passage at potential vertical barriers, high velocity chutes, and/or critical riffles based on field measurement of the barriers in the field during base flows. Barriers were analyzed for 12-inch (305-mm) trout and minnows/suckers.

B.2 Fish Swimming and Leaping Capabilities

A range of swimming velocity was used for the trout (high- and low-swimming estimates). Minnow and sucker swimming capability was set at the lower end of the trout swimming range. Burst swimming velocity was used to determine the leaping ability of fish (i.e., their ability to navigate vertical barriers). Prolonged and sustained swimming capability was used to determine the ability of fish to navigate high velocity water in chutes and riffles (Powers and Orsborn 1985).

Burst swimming (less than 0.1 minute) was assumed to range between 8 and 12 body lengths/sec for salmonids (trout) (Beamish 1978; Reiser and Peacock 1985; Videler 1993). Burst swimming for cyprinids (minnows) and catastomids (suckers) was set on the lower end of the trout range (8 body lengths/sec). The 60-minute sustained swimming velocity was assumed to be between 2 and 4 body lengths/sec for trout (Brett and Glass 1973; Beamish 1978; Reiser and Peacock 1985) and approximately 2 body lengths/sec for minnows/suckers[4] (Myrick and Cech 2000; Berry and Pimentel 1985). Prolonged swimming (0.1–60 minutes) was assumed to vary between burst and sustained swimming speed logarithmically (Videler 1993). Figure AQ 8-2 shows the assumed swimming capabilities of fish.

The size of fish used for the analysis was set at a large representative size of 12 inches (305 mm). Throughout the sampled areas (Kaweah River, East Fork Kaweah River, Marble Fork Kaweah River, and Middle Fork Kaweah River), the largest fish measured was about 8.5 inches (216 mm FL). Additionally, snorkel surveys identified one larger rainbow trout in the 10- to 12-inch size class. For fish in the approximately 12-inch and less size, empirical fish leaping data for brook trout indicate that smaller fish (e.g., 6 inches) can leap as high as larger fish (e.g., 8+ inches) (Kondratieff and Myrick 2006). This is partly due to the fact that the maximum swimming speed per body length is higher for smaller fish (e.g., <12 inches) than it is for larger fish (e.g., ≥12 inches) (see compilation of data in Kondratieff and Myrick 2006). As a result, we used the leaping and swimming ability of a 12-inch fish as reasonable representation for the passage capabilities of various-sized fish in the Project Area. The same fish size was used for hardhead, Sacramento pikeminnow, and Sacramento sucker.

A water temperature of 15°C was used to help estimate the approximate 60-minute sustained swimming speed discussed above (Brett and Glass 1973). In general, the effects of water temperature on swimming ability in the range of about 10–20°C are relatively modest (e.g., Myrick and Cech 2000) and water temperature was not used to modify swimming velocity in this analysis.

4 Critical swimming velocity data (a laboratory measure of prolonged swimming capacity) for hardhead, Sacramento pikeminnow, Colorado pikeminnow, and Sacramento sucker (Myrick and Cech 2000; Berry and Pimentel 1985) were compared to data for rainbow trout (Beamish 1978; Hawkins and Quinn 1996; Jain et al. 1997). Minnow/sucker species swimming velocities were comparable to the lower range observed for trout (typically about 2 body lengths/sec).

B.3 Vertical Barriers (Falls)

Passage of vertical barriers (falls) requires fish to leap the vertical and horizontal dimensions of the falls. Passage also requires suitable takeoff conditions at the plunge pool and suitable landing conditions at the falls crest.

B.3.1 Vertical and Horizontal Leaping

In order for a fish to clear a leaping barrier they must be able to leap high enough (H) to reach the crest of the barrier and far enough (X) to cover the distance from the standing wave in the plunge pool (the point of optimal leap) to the crest of the barrier. Leaping ability was based on trajectory equations that convert the burst swimming speed of a fish into X and H components (Powers and Orsborn 1985):

$$H = (Tan\ A)\ X - g\ (X)^2 / 2(VF\ Cos\ A)^2$$

Where VF is the burst speed of the fish (ft/s), A is the leaping angle, and g is a constant acceleration due to gravity (32.2 ft/sec^2). Figure AQ 8-3 shows the vertical and horizontal leaping capability of a 12-inch fish (Note: all potential leaping angles were tested to determine the maximum X distance and H that could be navigated).

Leaping barriers were considered impassable for trout if the barrier could not be cleared at a burst speed of 12 body lengths/sec. Leaping barriers were considered potentially passable for trout if they could be cleared at a burst speed between 8 and 12 body lengths/sec and barriers were considered to be passable if they could be cleared at burst speed of 8 body lengths/sec or less. Leaping barriers were considered impassable for minnows/suckers (e.g., hardhead) if they could not be cleared at a burst velocity greater than 8 body lengths/sec and passable if they could be cleared at a burst velocity of 8 body lengths/sec or less. Table B-1 shows a summary of leaping barrier passability based on fish burst speed.

Table B-1. Leaping Barrier Passability Based on Fish Burst Speed.

	Burst Speed (body lengths /sec) Required to Leap Barrier	
Falls Barrier Rating[1]	**Trout**	**Minnows / Suckers**
Passable	≤8	≤8
Potentially Passable	>8–12	NA
Impassable	>12	>8

Note:

[1] Based on Figure AQ 8-3 and burst speeds listed in this table.

B.3.2 Falls Plunge Pool Conditions

If the plunge pool depth was greater than the full body length of a fish, the leaping ability of a fish was assumed to be unhampered. If, however, the plunge pool depth was between 1½ body lengths and/or the penetration of the plunging water reached the bottom of the pool, the leaping ability was assumed to be reduced and the barrier (all else being passable) was deemed only potentially passable. If the plunge pool depth was less than ½ body length, the barrier was deemed impassable. Table B-2 shows a summary of falls barrier passability based on plunge pool conditions.

Table B-2. Falls Barrier Passability Based on Plunge Pool Conditions and Falls Crest Landing Conditions.

Falls Barrier Rating[1]	Plunge Pool Depth	Falls Crest Landing Conditions[2]
Passable	≥ full body length of a fish	Depth of the crest was ≥1 times the depth of the fish ***or*** the crest ½–<1 times the depth of the fish and sloped downward in the upstream direction ***and*** velocity was < than the fish's burst velocity.
Potentially Passable	½–1 body length ***or*** penetration of the plunging water reached the bottom of the pool	Depth of the crest was between 1–½ times the depth of the fish ***and*** velocity was < than the fish's burst velocity.
Impassable	<½ body length	Depth of the crest <½ times depth of the fish ***or*** water velocity at the crest was > than the fish's burst velocity

Notes:

1 Based on Plunge Pool Depth and Crest Landing Conditions

2 Depth of the fish was 0.22 times fish length.

B.3.3 Falls Crest Landing Conditions

If the water velocity at the crest of the falls was greater than the fish's burst velocity (Figure AQ 8-2), the barrier was classified as impassable. If the crest landing area was deeper than the fish's body depth, the crest was analyzed as a chute / critical riffle (see below). If the depth of the crest was between 1 and ½ times the depth of the fish and passable as analyzed above, it was considered only potentially passable due to the shallow depth, unless the crest sloped downward in the upstream direction in which case the falls was considered passable. If the crest depth was less than half body depth, the falls was considered impassable. The body depth of fish was assumed to be 0.22 times the length of the fish (USFWS 2008). Refer to Table B-2 showing a summary of fall barrier passability based on crest landing conditions.

B.4 Chute and Critical Riffle Barriers

Fish passage assessment of chute and critical riffle barriers required the water velocity to be less than the upstream distance swimming capabilities of the fish and the depth to be great enough to pass fish.

B.4.1 Water Velocity and Chute Length

If the water velocity of the chute or critical riffle was greater than the fish's burst velocity (12 body lengths/sec for trout or 8 body lengths/sec for minnows/suckers), it was considered an impassable barrier. If the water velocity was less than the fish's sustained velocity, 2 body lengths/sec (for both trout and minnows/suckers) the barrier was classified as passable. Otherwise, if the velocity was between the burst and sustained velocity, the prolonged swimming speed equation was used to determine if the fish could pass the length of the barrier (see Figure AQ 8-2). For minnows/suckers, the lower velocity swimming equation was used. For trout, both the high and low velocity equations were used. If the barrier could be navigated with the lower velocity equation, it was considered passable. If the barrier could only be navigated using the higher velocity equation, the barrier was considered potentially passable. Table B-3 shows a summary of chute and critical riffle barrier passability based on water velocity and depth and chute length.

Table B-3. Summary of Chute and Critical Riffle Barrier Passability Based on Water Velocity, Water Depth, and Chute Length.

Chute Barrier Rating[1]	Water Velocity and Length	Water Depth
Passable	Water velocity < fish's sustained velocity (2 body lengths/sec) ***or*** fish's prolonged velocity / swimming distance relationship exceeded velocity / length of chute (see Figure AQ 8-4)	Depth ≥1 times the depth of the fish
Potentially Passable	NA	Depth was ½–1 times the fish's body length
Impassable	Water velocity > fish's burst velocity (8 body lengths/sec for minnows/suckers or 12 body lengths/sec for trout) ***or*** fish's prolonged velocity / swimming distance relationship was < than the velocity / length of chute (see Figure AQ 8-4)	Depth was <½ times fish's body depth

Note:

[1] Based on Listed Water Velocity, Length, and Depth Conditions

B.4.2 Depth

If the water velocity of a chute or riffle was determined to be passable, but the water depth was between 1 ½ times the fish's body depth, swimming ability was assumed to be impaired and the barrier was classified as potentially passable. If the water depth was less than half times the fish's body depth, the barrier was classified as impassable.

B.5 References

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Appendix C

Detailed Fish Passage Barrier Descriptions

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DOWNSTREAM OF NATIONAL PARK FOOTHILLS VISITOR CENTER (NATURAL BARRIER)

Survey Date: November 29, 2018
Survey Time: 1500
Survey Flow: NA
GPS Coordinates: 36.48809, -118.82769
Class: Falls

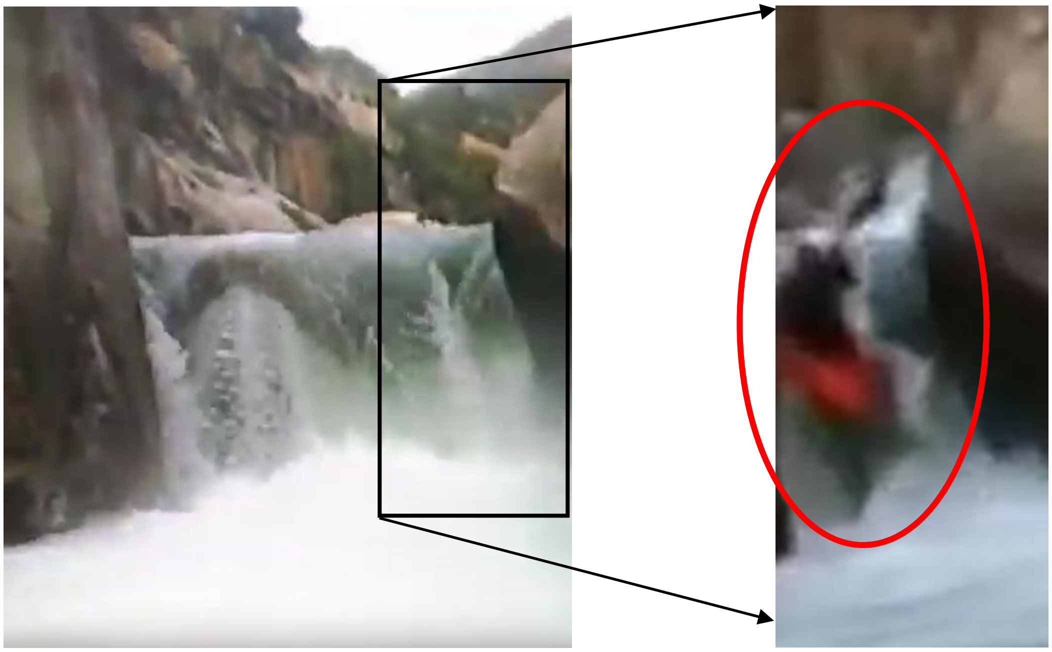
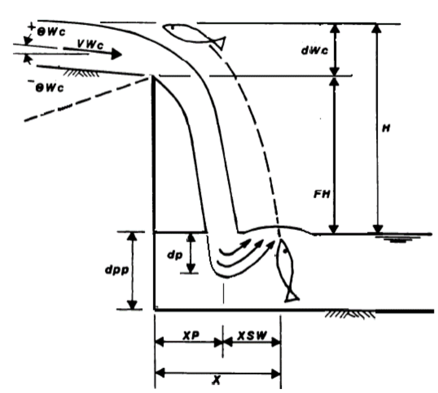


Figure C-1. Left: Image of natural barrier downstream of National Park Foothills Visitor Center. Right: Inset image of a portion of the falls with kayaker for scale.
Notice the rock on right side of both images for orientation. Red circle indicates kayaker.

Table C-1. Downstream of National Park Foothills Visitor Center (Natural Barrier) fall measurements.

Width of channel/water at top of crest in feet:	12
Water depth at crest in feet (dWc):	2
Water velocity at crest in feet per second (VWc):	-
Angle of water at crest (± θWc):	-
Fall height in feet (FH):	10
Depth of plunge pool in feet (dpp):	-
Depth of plunging water in feet (dp):	-
Distance from crest to plunge in feet (Xp):	8
Distance from plunge to standing wave in feet (XSW):	4



Measurements estimated from photographs, too dangerous to access.

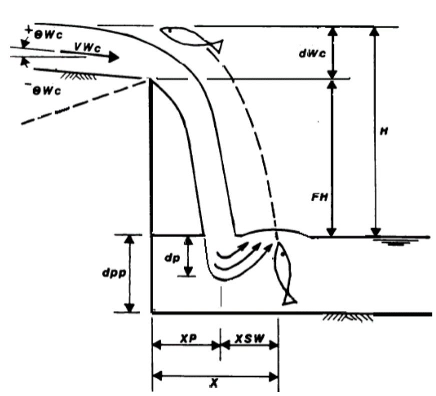
Note: Images obtained from kayaker videos online (URL: https://www.youtube.com/watch?v=zHNBgarNLp4). Date and time when images were taken is unknown.

KAWEAH NO. 2 DIVERSION DAM (PROJECT BARRIER)

Survey Date: November 29, 2018
Survey Time: 1315
Survey Flow: 338 cfs
GPS Coordinates: 36.48597, -118.83603
Class: Diversion Dam Falls

Figure C-2. Image of project barrier at Kaweah No. 2 Diversion Dam.
Staff holding stadia rod on left side of image for scale.

Table C-2. Kaweah No. 2 Diversion Dam (Project Barrier) fall measurements.

Width of channel/water at top of crest in feet:	60	
Water depth at crest in feet (dWc):	0.8	
Water velocity at crest in feet per second (VWc):	2.2	
Angle of water at crest (± θWc):	<1	
Fall height in feet (FH):	9.2	
Depth of plunge pool in feet (dpp):	5	
Depth of plunging water in feet (dp):	5	
Distance from crest to plunge in feet (Xp):	13	
Distance from plunge to standing wave in feet (XSW):	3	

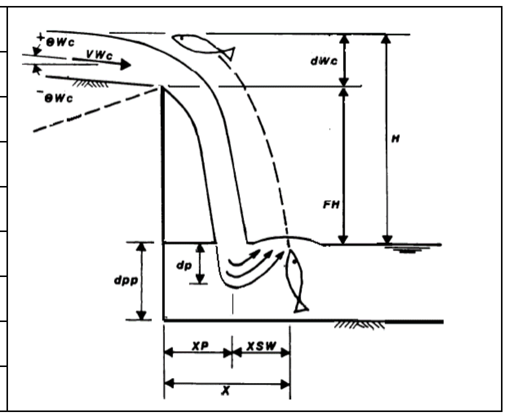
KAWEAH NO. 2 DIVERSION DAM GAGE POOL WEIR (PROJECT BARRIER)

Survey Date: November 29, 2018
Survey Time: 1400
Survey Flow: 315 cfs
GPS Coordinates: 36.484799, -118.835709
Class: Gage Weir Falls

Figure C-3. Image across width of stream at entire project barrier at Kaweah No. 2 Diversion Dam Gage Pool Weir.
Circled portion identifies location of measurements.

Table C-3. Kaweah No. 2 Diversion Dam Gage Pool Weir (Project Barrier) fall measurements.

Width of channel/water at top of crest in feet:	27
Water depth at crest in feet (dWc):	0.6
Water velocity at crest in feet per second (VWc):	2.2
Angle of water at crest (± θWc):	<1
Fall height in feet (FH):	1
Depth of plunge pool in feet (dpp):	5.2
Depth of plunging water in feet (dp):	3
Distance from crest to plunge in feet (Xp):	1.5
Distance from plunge to standing wave in feet (XSW):	1.5



Note: Measurements taken on left bank weir barrier. Barriers in center and right bank are more substantial and were not included in measurements.

DOWNSTREAM OF KAWEAH NO. 2 POWERHOUSE (NATURAL BARRIER)

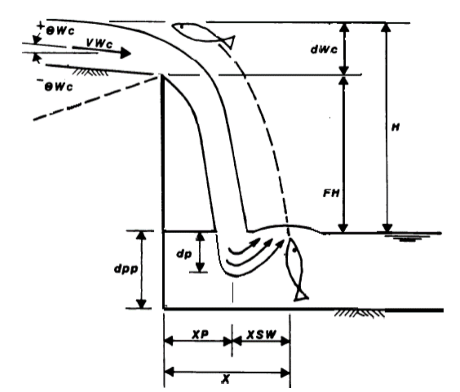
Survey Date: November 30, 2018
Survey Time: 1245
Survey Flow: 169.4 cfs
GPS Coordinates: 36.454732, -118.895203
Class: Falls

Figure C-4. TOP: Overview image of natural barrier downstream of Kaweah No. 2 Powerhouse. BOTTOM: Image of natural barrier downstream of Kaweah No. 2 Powerhouse.

Barrier site consisted of multiple variable size falls and side channels spanning the width of the river. The measurements in Table C-4 only reflect the falls indicated by the red arrows.

Table C-4. Downstream of Kaweah No. 2 Powerhouse (Natural Barrier) fall measurements.

Width of channel/water at top of crest in feet:	3
Water depth at crest in feet (dWc):	1.3
Water velocity at crest in feet per second (VWc):	0.64
Angle of water at crest (± θWc):	<1
Fall height in feet (FH):	1.8
Depth of plunge pool in feet (dpp):	2.3
Depth of plunging water in feet (dp):	2.3
Distance from crest to plunge in feet (Xp):	13
Distance from plunge to standing wave in feet (XSW):	7



Note: Left bank side channel easily passable at mid to high flows behind staff holding stadia rod.

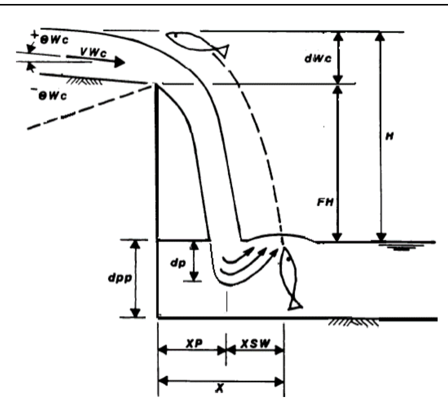
KAWEAH NO. 1 DIVERSION DAM (PROJECT BARRIER)

Survey Date: November 29, 2018
Survey Time: 1035
Survey Flow: 188 cfs
GPS Coordinates: 36.45165, -118.78932
Class: Diversion Dam Falls

Figure C-5. Image of project barrier at Kaweah No. 1 Diversion Dam.
Staff with stadia rod on left bank for scale.

Table C-5. Kaweah No. 1 Diversion Dam (Project Barrier) fall measurements.

Width of channel/water at top of crest in feet:	23
Water depth at crest in feet (dWc):	6
Water velocity at crest in feet per second (VWc):	2.5
Angle of water at crest (± θWc):	<1
Fall height in feet (FH):	11.5
Depth of plunge pool in feet (dpp):	8
Depth of plunging water in feet (dp):	6
Distance from crest to plunge in feet (Xp):	13
Distance from plunge to standing wave in feet (XSW):	2



KAWEAH NO. 1 DIVERSION DAM GAGE POOL WEIR (PROJECT BARRIER)

Survey Date: November 29, 2018
Survey Time: 1230
Survey Flow: 122 cfs
GPS Coordinates: 36.451590, -118.789691
Class: Gage Weir Falls/Chute

Figure C-6. TOP: Image of project barrier at Kaweah No. 1 Diversion Dam Gage Pool Weir. Kaweah No. 1 Diversion Dam project barrier is visible in background. BOTTOM: Image across width of project barrier at Kaweah No. 1 Diversion Dam Gage Pool Weir towards the right bank.

Image shows above angle with left bank falls into immediate chute and larger right bank chute.

Table C-6. Kaweah No. 1 Diversion Dam Gage Pool Weir (Project Barrier) fall measurements.

Width of channel/water at top of crest in feet:	35
Water depth at crest in feet (dWc):	0.8
Water velocity at crest in feet per second (VWc):	3
Angle of water at crest (± θWc):	<1
Fall height in feet (FH):	5.2
Depth of plunge pool in feet (dpp):	0.5
Depth of plunging water in feet (dp):	0.5
Distance from crest to plunge in feet (Xp):	1
Distance from plunge to standing wave in feet (XSW):	0

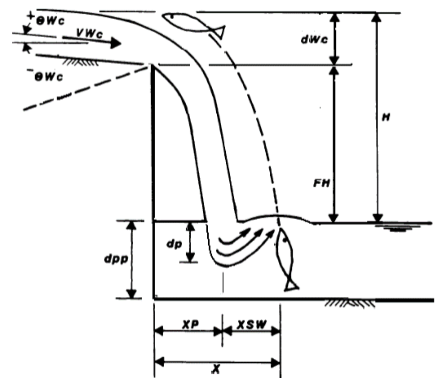


Table C-7. Kaweah No. 1 Diversion Dam Gage Pool Weir (Project Barrier) left bank chute measurements.

Width of water at crest and in chute in feet:	35
Water depth at crest in feet (dWc):	0.5
Water velocity at crest in feet per second (VWc):	-
Angle of water at crest (± θWc):	20
Chute height in feet (H):	2
Depth of water in chute in feet (dW):	0.5
Velocity of water in chute in feet per second (VWs)	>12
Length of chute slope in feet (LS):	10.2
Slope of chute passage area (Sp):	20
Depth of plunge pool in feet (dpp):	2.5

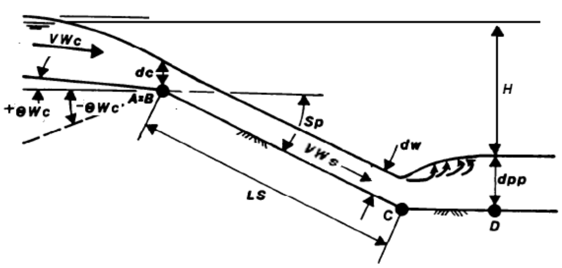
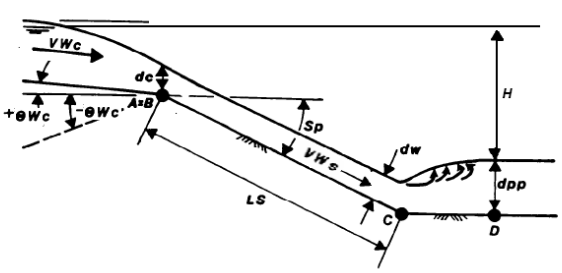


Table C-8. Kaweah No. 1 Diversion Dam Gage Pool Weir (Project Barrier) right bank chute measurements.

Width of water at crest and in chute in feet:	5
Water depth at crest in feet (dWc):	0.5
Water velocity at crest in feet per second (VWc):	>3
Angle of water at crest (± θWc):	<1
Chute height in feet (H):	7.2
Depth of water in chute in feet (dW):	0.5
Velocity of water in chute in feet per second (VWs)	>12
Length of chute slope in feet (LS):	17
Slope of chute passage area (Sp):	48
Depth of plunge pool in feet (dpp):	2.5



Measurements estimated while in the field, chute not safely accessible.

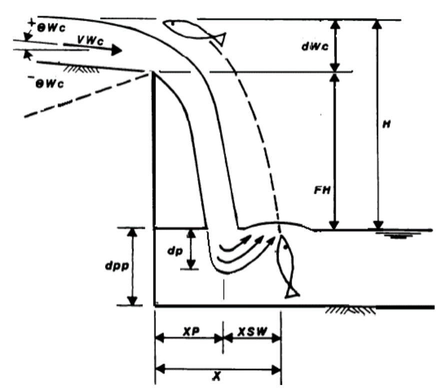
EAST FORK KAWEAH DOWNSTREAM OF KAWEAH RIVER BRIDGE (NATURAL BARRIER)

Survey Date: November 29, 2018
Survey Time: 0950
Survey Flow: 195 cfs
GPS Coordinates: 36.44956, -118.79332
Class: Falls

Figure C-7. **TOP: Overview image of natural barrier on East Fork Kaweah downstream of Kaweah River Bridge. BOTTOM: Image of natural barrier on East Fork Kaweah downstream of Kaweah River Bridge.**
Staff is holding the stadia rod at the base of fall on the surface of the water. The red arrow identifies the 14-foot mark on the stadia rod.

Table C-9. East Fork Kaweah Downstream of Kaweah River Bridge (Natural Barrier) fall measurements.

Width of channel/water at top of crest in feet:	20
Water depth at crest in feet (dWc):	2
Water velocity at crest in feet per second (VWc):	4
Angle of water at crest (± θWc):	<5
Fall height in feet (FH):	9
Depth of plunge pool in feet (dpp):	6
Depth of plunging water in feet (dp):	6
Distance from crest to plunge in feet (Xp):	10
Distance from plunge to standing wave in feet (XSW):	10



EAST FORK KAWEAH ABOVE CONFLUENCE (NATURAL BARRIER)

Survey Date: November 30, 2018
Survey Time: 1050
Survey Flow: 46.5 cfs
GPS Coordinates: 36.47766, -118.83567
Class: Falls/ Chute

Figure C-8. **TOP: Image of natural barrier on the East Fork Kaweah above the confluence with Kaweah River. Right bank falls and the bottom of the left bank bedrock chute in view. BOTTOM: Image of the left bank bedrock chute and the upper section of the right bank falls.**

Table C-10. East Fork Kaweah above Confluence (Natural Barrier) right bank fall measurements.

Width of channel/water at top of crest in feet:	4
Water depth at crest in feet (dWc):	2
Water velocity at crest in feet per second (VWc):	3.8
Angle of water at crest (± θWc):	<3
Fall height in feet (FH):	5.7
Depth of plunge pool in feet (dpp):	4
Depth of plunging water in feet (dp):	4
Distance from crest to plunge in feet (Xp):	11
Distance from plunge to standing wave in feet (XSW):	4

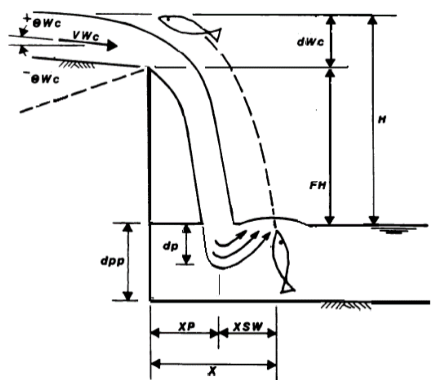
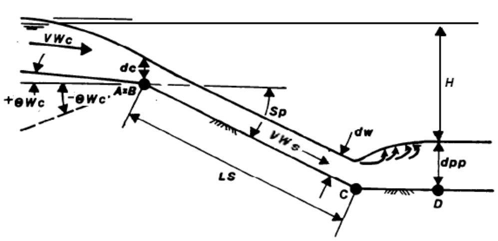


Table C-11. East Fork Kaweah above Confluence (Natural Barrier) left bank chute measurements.

Width of water at crest and in chute in feet:	4
Water depth at crest in feet (dWc):	2
Water velocity at crest in feet per second (VWc):	3.8
Angle of water at crest (± θWc):	<3
Chute height in feet (H):	9.7
Depth of water in chute in feet (dW):	0.5
Velocity of water in chute in feet per second (VWs)	12.2
Length of chute slope in feet (LS):	35.8
Slope of chute passage area (Sp):	22
Depth of plunge pool in feet (dpp):	3



Measurements estimated while in the field, chute not safely accessible.

Appendix D

River Gradient Plots

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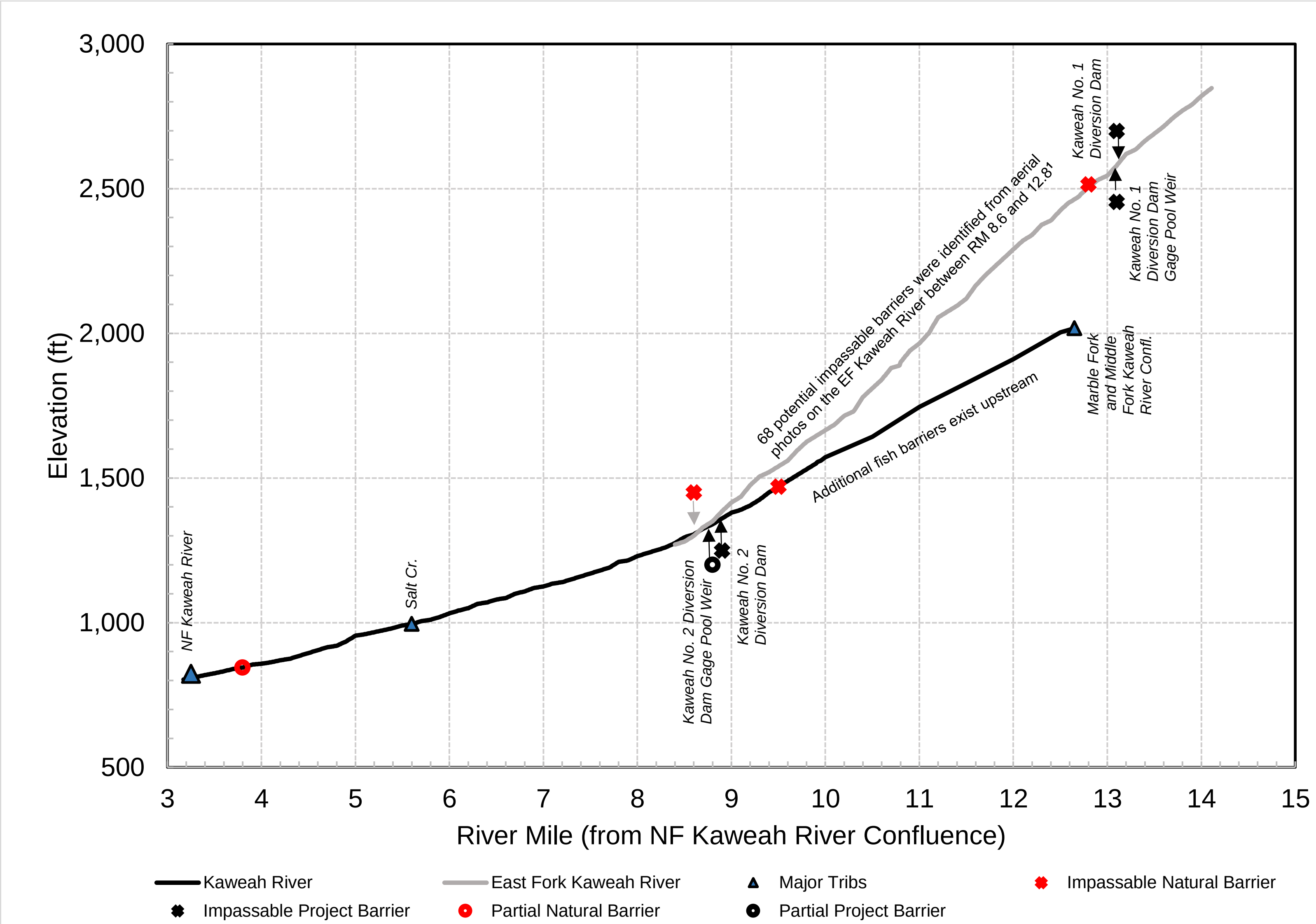

[1]*Additional barriers are shown on Map AQ 8-1*

Figure D-1. Longitudinal Profile of River Gradient and Fish Passage Barriers on the Kaweah River.

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