LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

FISH PASSAGE FACILITIES ALTERNATIVES ASSESSMENT
WORKSHOP NO. 5

MAY 19, 2016

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project
Reintroduction/Fish Passage Assessment Framework
Plenary Group - Meeting No. 5

Thursday, May 19, 10:00 am to 12:00 pm
MID Office, 1231 11th Street, Modesto, California
Conference Line: 1-866-583-7984; Passcode: 814-0607
Join Lync Meeting: https://meet.hdrinc.com/jenna.borovansky/3D64F0F5

Meeting Objectives:

1. Discuss and seek approval of the field studies planned for 2016.
2. Progress update on the Reintroduction Goals Subcommittee activities.
3. Introduce development of temperature criteria.

TIME	TOPIC
10:00 am – 10:10 am	Introduction of Participants (All)
10:10 am – 10:30 am	Opening Remarks (All) Review Agenda and Meeting Objectives (All) Overview of Activities (since the January 27, 2016, Workshop No. 4) (Districts/All)
10:30 am – 11:15 am	Reintroduction Assessment Framework 2016 Study Program (All) Summary and Discussion of the following 2016 studies: a. Habitat Mapping and Macroinvertebrate Assessment b. Spawning Gravel Mapping Study c. Instream Flow Study d. Regulatory Context for Reintroduction Assessment e. Socioeconomic Scoping Study f. Hatchery and Stocking Practices Review
11:15 am – 11:30 am	Reintroduction Goals Subcommittee – Progress Update (All)
11:30 am – 11:50 am	Water Temperature Criteria (All) a. Introductory discussion – collaborative development of suitable criteria
11:50 am – 12:00 pm	Next Steps (All) a. Schedule for Workshop No. 6 b. Action items

La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Workshop No. 5
Modesto Irrigation District
1231 11th Street, Modesto, California

Thursday, May 19, 2016
10:00 am to 12:00 pm

Final Meeting Notes

On May 19, 2016, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted Workshop No. 5 for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document includes a list of attendees, the meeting agenda, and study plans distributed by the Districts on May 10.

Mr. Bao Le (HDR, consultant to the Districts) said today's meeting is the fifth Workshop of this process and the second Workshop in 2016. Workshop No. 4, held on January 27, 2016 (meeting notes are available on the La Grange Project Licensing Website here), focused on the two primary drivers of the Framework, which are to (1) develop a study program to collect information about the upper Tuolumne River relevant to a possible reintroduction program and (2) develop the goals of the reintroduction program. As described in the Framework, later this year an analysis will be conducted to evaluate whether, based on the results of the study program, it is feasible to meet the goals for reintroduction.

Mr. Le said at Workshop No. 4, meeting attendees decided to form a Technical Committee to take the lead on developing the study program. The Technical Committee has since developed several study plans and later in the meeting, each study lead will provide a brief overview of his or her study. The objective of this discussion is to reach consensus on moving forward with implementing the studies. Later in this meeting, a brief update will be provided on the progress made developing reintroduction program goals. Finally, the need for understanding what water temperature criteria should be used, and how this group may collaboratively develop these criteria, will be discussed. Mr. Le asked if there are any questions. There were none.

Mr. Le summarized progress made by the Technical Committee since Workshop No. 4. On February 16, the Technical Committee met to identify a preliminary list of studies that may be implemented to support the Framework. That list was refined and on March 16, the Districts sent draft study plans to the Technical Committee for review and comment (the Districts sent the draft Upper Tuolumne River Instream Flow Study Plan to the Technical Committee on April 12). On March 18 and April 18, the Technical Committee met by conference call to discuss the draft study plans (March 18 notes are available here, April 18 notes are available here). Based on feedback received from the Technical Committee, the Districts revised the study plans. These revised study plans were forwarded to the Technical Committee on May 4. No additional comments were received and on May 10, the Districts sent the study plans to the Plenary Group. Mr. Le said the Districts anticipate fieldwork will start in mid-July, and would like to get consent from the Plenary Group to proceed with the studies. Mr. Le noted that meeting notices and draft study plans were sent out via email by Ms. Rose Staples (HDR); any attendees who have not been receiving these emails should contact Ms. Staples at Rose.Staples@hdrinc.com.

Mr. John Buckley (Central Sierra Environmental Resource Center) said one of the questions raised at a previous meeting was whether Chinook salmon currently exist in the upper Tuolumne River. Mr. Buckley asked if that question has been answered or if information on that topic has been provided to the Plenary Group. Mr. Buckley asked if it would be possible to study the genetics of Chinook that may exist in that reach of the river. Mr. Le said there have been discussions about stocking practices in Don Pedro Reservoir and whether these practices have resulted in a landlocked Chinook population. Ms. Gretchen Murphy (California Department of Fish and Wildlife [CDFW]) added that there is some anecdotal evidence about the possible existence of a landlocked Chinook population in Don Pedro Reservoir. This evidence is documented in Perales et al. 2015, a copy of which Ms. Murphy provided to this group in February (available online here). Mr. Le said the Districts had an action item from the March 18 Technical Committee meeting to contact Mr. Steve Holdeman (U.S. Forest Service [USFS]) about data the USFS may have regarding Chinook in Don Pedro Reservoir or in the upper Tuolumne River. The Districts sent an inquiry to Mr. Holdeman, who replied that he is aware of several anecdotal observations of Chinook in this reach, but he did not know of any formal studies or data that are available. Mr. Le said the Hatchery and Stocking Practices Review will help us better understand the effects of past and current stocking practices. Mr. Buckley said determining whether or not salmon are already present in the upper Tuolumne River seems like an important piece of information to have before significant resources are spent on studies. Mr. Buckley said the NGOs previously shared anecdotal evidence that salmon in Don Pedro Reservoir moved upstream to spawn. Mr. Ron Yoshiyama (consultant to City and County of San Francisco [CCSF]) said that past records indicate that fall-run Chinook have been stocked in Don Pedro Reservoir. These records provide annual stocking statistics. Mr. Yoshiyama said the paper described by Ms. Murphy states that Chinook have been found upstream of Don Pedro Reservoir. Mr. Yoshiyama said he is also aware of anecdotal observations of Chinook by Dr. Moyle and his graduate students, and that it would be possible to request more information about these observations from Dr. Moyle.

Mr. Peter Drekmeier (Tuolumne River Trust) asked if historical records are available about the existence of *O. mykiss* in the upper Tuolumne River. Mr. Le said he is aware of a report from the 1980s that notes the existence of *O. mykiss* in the Clavey River. Mr. Le said the Hatchery and Stocking Practices Review aims to provide additional information about this topic.

Mr. Jason Guignard (FISHBIO, consultant to the Districts) reviewed the goals, study area, methodology, and schedule for the Upper Tuolumne River Habitat Mapping and Macroinvertebrate Assessment. Mr. Guignard noted that originally the study team planned to begin the fieldwork in June, but given the snow pack this year, the study team will instead begin fieldwork in mid-July. Mr. Guignard said the study team plans to use the peaking flows to raft between sites and will collect the data during the low flow following each pulse.

Mr. John Wooster (National Marine Fisheries Service [NMFS]) asked how many sites will be sampled for macroinvertebrates. Mr. Guignard said drifting and benthic macroinvertebrates will be collected at seven sites. Mr. Guignard said that although the actual habitat units have not yet been identified, the study team plans to collect samples at a suitable habitat unit nearby to where the study team will camp each night.

Mr. Larry Byrd (Modesto Irrigation Districts [MID]) asked how it is known whether a fish is natural or introduced. Mr. Le said the only way to determine where a fish comes from is by looking at its genetics. Mr. Le noted that genetics testing is not part of the Districts' studies to be completed in 2016 but that NMFS is conducting a genetics study in the upper reach.

Ms. Dana Ferreira (Office of U.S. Congressman Jeff Denham) asked if Mr. Wooster would provide an update on both the genetics study and the habitat and carrying capacity study being completed by NMFS. For the genetics study, Mr. Wooster said 700 *O. mykiss* samples were collected last summer in the upper Tuolumne River basin. Those samples have been processed and analyzed by the National Oceanic and

Atmospheric Administration Southwest Fisheries Science Center. NMFS will be completing a second round of sampling this year with a focus on higher elevation sites in the upper Tuolumne River and upper Merced River. NMFS aims to collect another 700 samples during this round of sampling. These new samples will be processed this winter, and a final report should be available in the spring of 2017.

Mr. Wooster said he has not seen any results or conclusions from the analysis completed on the 2015 samples. Mr. Wooster said he thinks part of the goal of collecting additional samples this year is to try to understand the variability and relationships between samples collected at higher elevation locations, which, in terms of reintroduction, are not hydrologically connected. NMFS is trying to understand what is native to this stretch of the river. The study has compared the 2015 samples to known hatchery strains. Mr. Wooster said based on the results so far, there does not appear to be a strong relationship between the samples collected in 2015 and known hatchery strains. Mr. Yoshiyama asked if Mr. Wooster can provide more details about what hatchery strains the samples were compared to. Mr. Yoshiyama asked if the 2015 samples were compared to samples of Central Valley hatchery strains, California hatchery strains, or a broader suite of west coast hatchery strains, given that an evaluation of genetic origin is important and should be robust. Mr. Wooster said he did not know the answer to that question. Mr. Wooster said the 2015 paper by Pearce and Garza (available online here) about Central Valley *O. mykiss* contains a genetic tree diagram, and he thinks the hatchery strains included on that diagram may be the strains that were used in the comparison.

Mr. Wooster said *O. mykiss* samples were also collected from the Clavey River. Samples were collected at river miles 8 and 16. Mr. Wooster estimated that about 100 samples in total were collected from these two sites.

Mr. Wooster said the NMFS Upper Tuolumne Habitat and Carrying Capacity Study (NMFS Carrying Capacity Study) is behind schedule. NMFS is still in the process of generating bathymetry from the hyperspectral imagery. This needs to be completed before habitat units can be generated. Once the habitat units are delineated, carrying capacity can be calculated. Mr. Wooster said NMFS hopes the development of bathymetry data will be completed soon.

Mr. Greg Dias (MID) said imagery from the NMFS Carrying Capacity Study will be very helpful for informing the Districts' 2016 fieldwork. Mr. Dias said given the Districts are on a tight schedule to complete these studies, the Districts would be interested in helping the NMFS Carrying Capacity Study move forward. Mr. Wooster said the current bottleneck in the study is running the algorithms to translate the photo data into depth data (i.e., hyperspectral data to bathymetry). Mr. Wooster said the individual who had been completing this work recently left the project, and now the work is on-hold until another individual with suitable training and expertise is found who can step in and resume this effort. Mr. Wooster noted that he is not directly involved with this work, but if the Districts are offering to provide programming assistance, he will relay the Districts' offer to the team working on this task. Mr. Dias confirmed the Districts are offering to make computer/GIS support available to help process the photos, if that would help keep the study on schedule. Mr. Wooster thanked Mr. Dias for his offer and said he will follow up with the appropriate individuals. Ms. Ferreira said it would be helpful if the Districts and NMFS can find a way to collaborate on these studies since they are complementary to the Districts' studies.

Mr. Jay Stallman (Stillwater Sciences, consultant to the Districts) reviewed the goals, study area, methodology, and schedule for the Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study. Mr. Buckley said on a recent field visit to Wards Ferry, he observed high amounts of fine sediment in the river. Mr. Buckley said the current high flows in the river are the first flows of this magnitude since the Rim Fire occurred, and these flows are washing down sediment produced by the fire. Mr. Buckley said this sediment has the potential to fill in gaps around the gravel, which could affect results from this study. Mr. Buckley asked if this is a concern, and if the team should consider conducting another round of study next year. Mr. Stallman said the point is well taken and this topic has been discussed by the study team. Mr. Stallman said he does not believe there will be an opportunity in 2017 to repeat this study, so the study team will need to do the best they can with this effort. Mr. Stallman said he believes the overall distribution of gravel deposits will not change significantly as a result of the recent sediment delivery, but the surface grain size distribution may be affected by fine sediment deposits in some locations. This will be a consideration as the study progresses. Mr. Wooster said in his previous fieldwork, he observed gravel completely buried by sediment. Mr. Stallman said the study team will be probing with a silvey rod, but will need to consider how to interpret gravel covered by fine sediment. Mr. John Devine (HDR) said the underlying question here is whether data collected this year is representative of other years and whether the data collected this year would have been significantly different if the Rim Fire had not occurred.

Mr. Drekmeier asked if anything relevant to this study had been learned from the recent pulse flow in the upper reach. Mr. Bill Sears (CCSF) said crews have not been in the field since the recent high flows. Mr. Sears said post-flood monitoring upstream of Early Intake is scheduled for July or August. This monitoring is part of the standard ongoing annual monitoring that is completed related to the Rim Fire and experimental releases from O'Shaughnessy Dam. Mr. Sears said he thinks next steps should be for the Districts to complete the 2016 work and at a future workshop the results can be discussed. Mr. Sears said that given these are the first flows of this magnitude and duration since 2011, it is unknown what may be happening on the river. Mr. Devine said it is known that a flood of this magnitude has the ability to mobilize sediment, but it is unknown how the sediment will be redeposited.

Mr. Wooster confirmed the NMFS LiDAR and hyperspectral data was flown after the Rim Fire, in late September and early October 2014. In August 2014, NMFS photographed gravel cobble bars using suspended cameras. Mr. Wooster said during that fieldwork, he observed sediment in the river, presumably from the fire. Mr. Wooster said he observed less sediment in the river during the NMFS 2015 fieldwork. Mr. Wooster said the photos from 2014 may be helpful, even though these photos were not taken prior to the fire. Mr. Dias agreed that the photos could be helpful for that purpose. Mr. Wooster said he will check on what documentation exists for the photos. Mr. Sears said CCSF has provided 2007 color aerial photos to the study team. Mr. Sears said photogrammetry associated with that 2007 flight was also developed.

Mr. Wooster said the study plan states the minimum patch size for *O. mykiss* is six square meters. Mr. Wooster said he thinks that six square meters is large compared to the minimum patch size used in previous studies completed by NMFS and the Districts, as well as studies completed on the McCloud River, which used a minimum patch size of two square meters. Mr. Wooster said that on similar studies, NMFS typically uses five square meters for a minimum patch size for Chinook and two square meters for a minimum patch size for steelhead. Mr. Stallman said the criteria were based on criteria used in studies previously completed on the Tuolumne River, McCloud River, and other rivers. Mr. Dirk Pedersen (Stillwater Sciences) said the study team felt that using a slightly larger minimum patch size than might appear in the literature would be helpful from a logistical standpoint. Given the resolution of the existing aerial photos, the study team was not confident a smaller patch size could be accurately mapped. Noting that the study plan currently assumes a 12 square meter patch size Chinook, Mr. Wooster asked if the study plan could be revised to instead assume a 6 square meter patch size for Chinook similar to for steelhead. Mr. Le said the Districts will consider this request.

Mr. Le asked if there were any concerns, besides those previously voiced, to the Districts moving forward with the study. There were no objections.

Mr. Jarvis Caldwell (HDR) reviewed the goals, study area, methodology, and schedule for the Upper Tuolumne River Instream Flow Study. Mr. Wooster asked about the projected cost of the study. Mr. Caldwell said given that the study team is still finalizing the fieldwork logistics, the budget has not yet been finalized. Mr. Devine said the budget can be provided once it is finalized.

Mr. Buckley asked if the model will be able to show how alternative future flows may help prevent dewatering caused by Holm peaking. Mr. Devine said the model will consider existing conditions only.

Mr. Le asked if there were any concerns with the Districts moving forward with the study. Mr. Wooster said it does not appear that the cost/benefit analysis warrants this study. Mr. Wooster said the study will likely be very expensive and there are documented shortcomings related to this type of study. Mr. Wooster said he thinks data on habitat availability at different stages and flow releases could be collected in a much more cost efficient manner. There were no other objections.

Ms. Jenna Borovansky (HDR) reviewed the goals, study area, methodology, and schedule for the Regulatory Context for Reintroduction. Mr. Buckley said whether or not salmon or steelhead currently exist in Don Pedro Reservoir and/or the upper river may have an effect on what regulations come into play. Ms. Borovansky said the study will consider applicable regulations in a broad context including if landlocked populations do exist or do not exist.

Ms. Borovansky reviewed the goals, study area, methodology, and schedule for the Socioeconomic Scoping Study. Mr. Drekmeier asked if the study will also consider the potential positive benefits of reintroduction such as a revived sport fishery. Ms. Borovansky said the study will consider current uses and how these uses may be affected, both positively and negatively, if fish are reintroduced. Ms. Jennifer Shipman (Manufacturer's Council of the Central Valley) asked if recreational boating activities on the reservoir would be considered since this is currently a significant activity. Ms. Borovansky said the boaters are a key stakeholder group for Don Pedro Reservoir. This study will include outreach to the boaters.

Mr. Don Swotman (citizen) said he has been very active on Don Pedro Reservoir and the Tuolumne River since the dam was built. As many as 4,000 families visit Don Pedro Reservoir on a summer weekend. Over 250 houseboats provide base income for the area year-round. The area also hosts several bass tournaments. Mr. Swotman said many millions of dollars are being spent on extremely detailed investigation and this money would be better spent elsewhere. Mr. Swotman questioned what is accomplished by taking water away from farmers as many acres are now fallow because water is being used for other purposes. Mr. Swotman said many of the houseboats must be removed, but it is unknown where they should be relocated or when a new marina will be built. Mr. Swotman said the focus should be on the global picture. It is not economically feasible to release 30 to 40 percent of water for fish when so few fish will be benefited.

Mr. Le reviewed the goals, study area, methodology, and schedule for the Hatchery and Stocking Practices Review. Mr. Le asked if there were any concerns with the Districts moving forward with the study. There were no objections.

Mr. Le thanked the Technical Committee members for taking time out of their busy schedules to participate. Mr. Le noted that participation is completely voluntary, and it takes a lot of effort and time to follow up on action items and review draft study plans. He said the Districts appreciate the Technical Committee's voluntary participation.

Mr. Le summarized progress made by the Reintroduction Goals Subcommittee. On April 13, the Reintroduction Goals Subcommittee, which includes the Districts and representatives from the agencies and NGOs, discussed the importance of developing goals for reintroduction and how such goals fit into the Framework. The Districts have an action item from that meeting to draft a preliminary reintroduction goals statement and circulate this to the Subcommittee, as the means for kicking off discussion. Mr. Le noted that as work began on this task, the Districts quickly realized it is extremely difficult to develop a concise goal in just one or two sentences that is representative of all participants' interests. Mr. Le said the Districts will aim to complete a draft goals statement in the next two weeks, and will send the draft out with a Doodle poll for future discussion.

Mr. Lonnie Moore (citizen) asked who is in charge of developing the goals statement. Mr. Le said Districts staff, HDR staff, and other consultants are working on developing this initial goals statement. Mr. Moore asked who is in charge of this process. Mr. Devine said he is the lead of the process, but he is not the decision maker. Mr. Dias added that he is the lead for Modesto Irrigation District and Mr. Steve Boyd is the lead for Turlock Irrigation District. Mr. Dias said the Districts welcome individuals to submit their ideas or comments on the goals. Mr. Dias said individuals are also welcome to submit their comments anonymously if they prefer. Mr. Devine said the Districts' initial draft of a goals statement is just the opening step to getting feedback. The Districts look forward to receiving comments from everyone.

Mr. Le asked if there are any objections to moving forward with the six studies presented for consideration. Ms. Ferreira and Ms. Shipman specifically asked for the representatives of NMFS and the U.S. Fish and Wildlife Service (USFWS) to indicate whether they object to the studies. Mr. Wooster said all the studies are supported by NMFS except for the Instream Flow Study. Mr. Zac Jackson (USFWS) said he has no concerns moving forward with the suite of studies.

Mr. Le said the Districts' Initial Study Report (ISR) contained several statements about temperature in the upper river. NMFS's ISR comment letter correctly noted that no temperature criteria as it relates to habitat suitability currently exist for the upper Tuolumne River. Mr. Le said that point was well taken by the Districts, and thus in their ISR comment response letter, the Districts stated it would be important that these criteria be developed through a collaborative process. Mr. Le asked if NMFS had ideas or thoughts about moving forward with developing temperature criteria related to the reintroduction program. Mr. Tom Holley (NMFS) said that a very similar effort was completed for the Yuba Salmon Forum, and that reviewing the results from that effort may be a good place to start. Mr. Le noted that Mr. Paul Bratovich (HDR) was central to the development of temperature criteria on the Yuba. He is also a team member on this process and would be well-qualified to develop a summary of Yuba temperature criteria. Mr. Le said the Districts will develop a document summarizing how water temperature criteria were developed for the Yuba River, as well as similar efforts at other Central Valley reintroduction programs if they exist. Mr. Holley said that seemed like a reasonable place to start. Mr. Devine said the Districts will also reach out to Mr. Peter Barnes at the State Water Resources Control Board to get his input on temperature criteria. Mr. Devine said once the information is collected, the Districts will send out a Doodle poll to schedule a meeting to discuss the information.

Meeting attendees discussed a date for the next Workshop. Meeting attendees agreed the next Workshop will be on Thursday, September 15, from 10:00 am to 12:00 pm. Ms. Rose Staples (HDR) will send out a save-the-date email. Mr. Le confirmed there are no meetings currently scheduled for the Technical Committee or Reintroduction Goals Subcommittee.

Meeting adjourned.

ACTION ITEMS

1. The Districts will contact Dr. Peter Moyle at UC Davis and ask for any data he and his classes have collected regarding Chinook salmon in Don Pedro Reservoir and in the Tuolumne River upstream of Don Pedro Reservoir.
2. Mr. Wooster will relay to the appropriate individuals the Districts' offer to assist on the NMFS Carrying Capacity Study. (complete)
3. Mr. Wooster will check on what documentation exists for the photos NMFS took in August 2014 of gravel cobble bars. (complete)
4. The Districts will consider NMFS' request to revise the Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study Plan to state that the minimum patch size for Chinook is 6 square meters (the study plan currently states the minimum patch size for Chinook is 12 square meters).
5. The Districts will provide to NMFS the final budget for the Upper Tuolumne River Instream Flow Study Plan.
6. The Districts will develop a document summarizing how water temperature criteria were developed for the Yuba River, as well as how criteria were developed at other reintroduction programs.
7. The Districts will reach out to Mr. Peter Barnes at the State Water Resources Control Board to get his input on water temperature criteria.
8. Ms. Rose Staples will send out a save-the-date email for Workshop No. 6, which is scheduled for Thursday, September 15, from 10:00 am to 12:00 pm. (complete)

WORKSHOP NO. 5
MAY 19, 2016

MEETING NOTES

ATTACHMENT A

Workshop No. 5 Meeting Attendees		
No.	**Name**	**Organization**
In Person Attendees		
1	Jenna Borovansky	HDR, consultant to the Districts
2	Steve Boyd	Turlock Irrigation District
3	Paul Bratovich	HDR, consultant to the Districts
4	Gavin Bruce	Stanislaus Business Alliance
5	John Buckley	Central Sierra Environmental Resource Center
6	Larry Byrd	Modesto Irrigation District
7	Paul Campbell	Modesto Irrigation District
8	Calvin Curtin	Turlock Irrigation District
9	John Devine	HDR, consultant to the Districts
10	Greg Dias	Modesto Irrigation District
11	Peter Drekmeier	Tuolumne River Trust
12	Leonard Van Elderen	Yosemite Farm Credit
13	Gordon Enas	Modesto Irrigation District
14	Dana Ferreira	Office of U.S. Congressman Jeff Denham
15	Art Godwin	Turlock Irrigation District
16	Kelsey Gowans	Modesto Irrigation District
17	Brenda Herbert	Office of State Senator Anthony Cannella
18	John Holland	Modesto Bee
19	Bao Le	HDR, consultant to the Districts
20	Lisa Mantarro	Office of State Assemblymember Adam Gray
21	Brandon McMillan	Turlock Irrigation District
22	Lacy Monier	Tuolumne River Trust
23	Lonnie Moore	Citizen
24	Marco Moreno	Latino Community Roundtable
25	Gretchen Murphy	California Department of Fish and Wildlife
26	Bill Paris	Modesto Irrigation District
27	Liz Peterson	Tuolumne County
28	Daniel Richardson	Tuolumne County
29	Greg Salyer	Modesto Irrigation District
30	Alfred A. Scuza	Yosemite Farm Credit
31	Jennifer Shipman	Manufacturer's Council of the Central Valley
32	Don Swotman	Citizen
33	Jake Wenger	Modesto Irrigation District
34	Melissa Williams	Modesto Irrigation District
35	Samantha Wookey	Modesto Irrigation District
36	Ron Yoshiyama	City and County of San Francisco
37	Paul Zeek	Office of State Assemblymember Kristin Olsen
Conference Call Attendees		
38	Jarvis Caldwell	HDR, consultant to the Districts
39	Jesse Deason	HDR, consultant to the Districts
40	Jason Guignard	FISHBIO, consultant to the Districts
41	Tom Holley	National Marine Fisheries Service
42	Zac Jackson	U.S. Fish and Wildlife Service
43	Patrick Koepele	Tuolumne River Trust
44	Ellen Levin	City and County of San Francisco
45	Dirk Pedersen	Stillwater Sciences, consultant to the Districts
46	Bill Sears	City and County of San Francisco
47	Chris Shutes	California Sportfishing Protection Alliance
48	Jay Stallman	Stillwater Sciences, consultant to the Districts
49	John Wooster	National Marine Fisheries Service

REVISED DRAFT STUDY PLAN

TURLOCK IRRIGATION DISTRICT
AND
MODESTO IRRIGATION DISTRICT

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

Upper Tuolumne River Habitat Mapping and Macroinvertebrate Assessment

May 2016

DRAFT

1.0 BACKGROUND

As part of the La Grange Hydroelectric Project licensing proceeding, the Districts are undertaking the Fish Passage Facilities Alternatives Assessment (Fish Passage Assessment), the goal of which is to identify and develop concept-level alternatives for upstream and downstream passage of Chinook salmon and steelhead at the La Grange and Don Pedro dams. In September 2015, the Districts provided to licensing participants Technical Memorandum No. 1, which identified a number of information gaps critical to informing the biological and associated engineering basis of conceptual design for the Fish Passage Assessment. In November 2015, licensing participants adopted a plan to implement the Upper Tuolumne River Reintroduction Assessment Framework (Framework) intended to develop the information needed to undertake and complete the Fish Passage Assessment and to assess the overall feasibility of reintroducing anadromous salmonids into the upper Tuolumne River (TID/MID 2016). As part of implementing the Framework, a number of environmental studies are planned.

The Upper Tuolumne River Habitat Mapping and Macroinvertebrate Assessment is one of several studies to be implemented in 2016 in support of the Framework. Information collected during this study will be used to characterize habitat distribution, abundance, and quality in the upper Tuolumne River.

2.0 STUDY AREA

The study area will include the mainstem of the upper Tuolumne River from the upstream limit of the Don Pedro Project (approximately RM 81) to Early Intake (approximately RM 105).

3.0 STUDY GOALS

The primary goal of this study is to provide information on habitat distribution, abundance, and quality in the upper Tuolumne River. This information will inform evaluations in the Framework and is critical for assessing the feasibility of anadromous salmonid reintroduction, estimating potential population size and developing engineering alternatives for the upper Tuolumne River. Specific objectives include:

- documenting the number, size and distribution of mesohabitats available in the upper Tuolumne River;
- collecting detailed data on habitat attributes in representative reaches of the upper Tuolumne River;

- documenting potential pool holding habitat for over-summering adult Chinook salmon; and
- collecting drift and substrate samples of macroinvertebrates (salmonid prey organisms).

4.0 STUDY METHODS

For this assessment, habitat mapping will quantify the type, amount, and location of habitat types available to potentially reintroduced anadromous salmonids during their riverine life stages (adult holding/spawning, incubation and rearing). Habitat mapping will be conducted in the field and remotely using standardized methodologies. The frequency and area of each habitat type (e.g., pool, riffle, run) will be tabulated and where potential holding pools for adult Chinook occur, the size and depth of the pools will be measured to determine possible holding capacity. Additional mapping tasks will include assessments of channel gradient, width, habitat areas, etc.

Habitat mapping will consist of mapping all mesohabitat units between Early Intake (RM 105) and the upstream limit of the Don Pedro Project (approximately RM 81), and collecting detailed habitat data in a sub-set of the mapped mesohabitat units.

4.1 Task 1. Mesohabitat Mapping

Reconnaissance level mapping in the summer of 2015 consisted of mesohabitat classifications (Table 1.0) for portions of the reach between Lumsden (Merals Pool at RM 96) and approximately RM 81. In 2016, habitat mapping will be extended up to Early Intake (RM 105), and gaps in mapping between RM 96 and approximately RM 81 will be comprehensively assessed to obtain a more complete dataset. Habitat units will be identified visually by a boat-based survey crew and mapped on pre-existing high-resolution color aerial photographs. Boundaries of mesohabitat units will also be geo-referenced in the field with a handheld GPS unit.

Table 1.0 Mesohabitat mapping units and criteria for the mainstem Tuolumne River.

Mesohabitat types	Definitions/ Criteria
Deep Pool	>6 ft max depth
Shallow Pool	<6 ft max depth
Glide/ Pool tail	Typically in the downstream portion of a pool with negative bed slope where converging flow approaches the riffle crest. Wide, shallow, flat bottom with little to no surface agitation. Substrate type is typically smaller than riffle, but coarser than pool and often provides best salmonid spawning habitat.
Run	Long, smoothly flowing reaches, flat or concave bottom, and deeper than riffles with less surface agitation. Higher velocities than pools.
Boulder Garden/Pocket Water	Moderate to low gradient riffles, runs, and glides with numerous large boulders/obstructions that create scour pockets and eddies with near zero velocity. Often no clear thalweg present due to multiple flow paths.
Cascade/ Chute	>10% gradient, and with air entrainment (particularly in cascades), very large boulders and/or bedrock. Consisting of alternating small waterfalls and can have shallow pools in middle and margin of channel at low flows.
High Gradient Riffle	>4% gradient. Substrate is usually large boulder and bedrock (>24")
Low Gradient Riffle	<4% gradient. Substrate is usually small boulder and large cobble(6-24")
Side Channel	Contains < 20% of total flow. Connected at top and bottom to main channel at low flow.
Backwater	Low to zero velocities. Only connected to main channel from one end.

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Mapped habitats will be digitized and added to the project GIS layer for mapping, as well as for quantitative and spatial analysis. Color maps will be created to depict the type and location of habitats throughout the study area and in relation to important features such as tributaries, potential passage barriers, access points, and water temperature monitoring locations. The frequency and area of each habitat type (e.g., pool, riffle, run) will also be tabulated.

4.2 Task 2. Habitat Inventory Mapping

Additional (remote) mapping tasks will include assessments of channel gradient, width, habitat areas, etc. following the CDFW Level III habitat typing methodology (CDFG 2010). Methods will be similar to habitat typing conducted in the lower Tuolumne River (TID/MID 2013). Sampling units selected for detailed habitat measurements will encompass approximately 10 to 20 percent of the study reach, as recommended in CDFG (2010). The habitat typing field effort will consist of a team of three biologists surveying the river by raft. The study area will be divided into seven sampling reaches, based on length of river rafted daily (two reaches from Early Intake to Lumsden and five reaches from Lumsden to Wards Ferry). Within each individual sampling reach, a one mile section will be randomly selected for habitat typing. Prior to the field assessment, the team will use maps and existing aerial photographs to delineate the specific reaches to be surveyed.

A suite of measurements consistent with the Level III CDFW criteria (Table 2.0) will be made within each mesohabitat type along each of the selected one-mile reaches. Data will be recorded on standardized datasheets to ensure all data are collected in a consistent manner. A photograph of each and GPS coordinates will be recorded at the bottom of each habitat unit. Unit length and width will be measured with a laser range finder. Depths will be measured using a stadia rod or handheld depth finder. Large woody debris (LWD) count will include a count of LWD pieces with a diameter greater than one foot and a length between six and twenty feet, as well as pieces greater than twenty feet in length, within the bankfull width. Percent total canopy will be measured using a spherical densiometer at the upstream end of each habitat unit in the center of the wetted channel, as well as general observations of riparian habitat. The remaining habitat parameters including substrate composition, substrate embeddedness, shelter complexity, and bank composition types will be visually estimated. Within each sampling reach, stream gradient will also be measured using a hand level over a distance of at least 20 bankfull channel widths. In addition, the size and depth of each pool will be collected throughout the study reach to help quantify the amount of potential Chinook salmon adult holding habitat.

Table 2.0 List of data collected as part of Level III CDFW habitat mapping.

Data	Description
Form Number	Sequential numbering
Date	Date of survey
Stream Name	As identified on USGS (U.S. Geological Survey) quadrangle
Legal	Township, Range, and Section
Surveyors	Names of surveyors
Latitude/Longitude	Degrees, Minutes, Seconds from a handheld GPS
Quadrant	7.5 USGS quadrangle where survey occurred
Reach	Reach name or river mile range
Habitat Unit Number	The habitat unit identification number
Time	Recorded for each new data sheet start time
Water Temperature	Recorded to nearest degree Celsius
Air Temperature	Recorded to nearest degree Celsius
Flow Measurement	Available from USGS monitoring stations
Mean Length	Measurement in feet of habitat unit
Mean Width	Measurement in feet of habitat unit wetted width
Mean Depth	Measurement in feet of habitat unit

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Data	Description
Maximum Depth	Measurement in feet of habitat unit
Bankfull Width	Measurement in feet of channel width at bankfull discharge
Bankfull Depth	Averaged unit depth in feet at bankfull discharge
Depth Pool Tail Crest	Maximum thalweg depth at pool tail crest in feet
Pool Tail Embeddedness	Percentage in 25% interval ranges
Pool Tail Substrate	Dominant substrate: silt, sand, gravel, small cobble, large cobble, boulder, bedrock
Large Woody Debris Count	Count of LWD within wetted width and within bankfull width
Shelter Value	Assigned categorical value: 0 (none), 1 (low), 2 (medium), or 3 (high) according to complexity of the shelter.
Percent Unit Covered	Percent of the unit occupied
Substrate Composition	Composed of dominant and subdominant substrate: silt, sand, gravel, small cobble, large cobble, boulder, bedrock
Percent Exposed Substrate	Percent of substrate above water
Percent Total Canopy	Percent of canopy covering the stream
Percent Hardwood Trees	Percent of canopy composed of hardwood trees
Percent Coniferous Trees	Percent of canopy composed of coniferous trees

Results to be reported include the following:

- Ground-mapped habitat units
  - Total number of habitat units, by type
  - Total length of habitat units, by type
  - Number of habitat units (frequency)
  - Average width of habitat units, by type
  - Number and relative frequency of dominant instream cover types
  - Reach summary data (e.g., average bankfull width and depth, LWD density (within wetted and bankfull))
- Pool holding habitat
  - Total number of pools identified as potential holding habitat (and the criteria of determination)
  - Average and maximum pool depth
  - Percentage of pools with ≥ 5% cover
  - Map showing the suitable holding pools in each 1-mile sampled reach of the upper Tuolumne River
- Tributary mapping data and reconnaissance level mainstem Upper Tuolumne River habitat data collected in 2015

4.3 Task 3. Macroinvertebrate Assessment

If time and logistics allow as the final field schedule is developed, a macroinvertebrate assessment will be conducted following the methods outlined below.

4.3.1 Study Goals

Drifting and benthic macroinvertebrates typically comprise the primary food source for rearing salmonids in fresh water habitats (Allan 1978, Fausch 1984, Harvey and Railsback 2014). Information on macroinvertebrate prey resource availability is a component of an evaluation of the factors affecting production and viability of an existing or introduced salmonid population. The density and taxonomic composition of drifting macroinvertebrates can provide a relative measure of food availability for drift-

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feeding salmonids. To provide a relative measure of food availability for salmonids within the water column, a literature search of similar streams and macroinvertebrate studies in the region (Sierra foothill region) will be conducted. Substrate sampling for benthic macroinvertebrates will provide data that can be used in a standardized bioassessment approach to evaluate the potential for physical habitat impairment. The objectives of the macroinvertebrate assessment are to:

- collect and analyze macroinvertebrate drift samples to determine whether the taxonomic composition and density of drift is consistent with other regional systems currently supporting healthy salmonid populations; and
- collect and analyze benthic macroinvertebrate samples from the substrate to develop metrics for bioassessment and comparison with similar streams and data sets.

4.3.2 Study Methods

4.3.2.1 Sampling Site Selection

The study area for macroinvertebrate sampling within the upper mainstem of the Tuolumne River is from RM 81 to Early Intake (RM 105). The location and number of sampling sites and sampling frequency will represent the seasonal variability of macroinvertebrate populations and related seasonal variability of food resources for stream-dwelling salmonids during the primary salmonid rearing and growth period (spring-fall), as well as the variability of physical habitat characteristics in each study reach.

<u>Number of sites</u>
Depending on opportunities encountered during stream habitat mapping, drift and benthic macroinvertebrate samples will be collected at seven sites, equating to approximately one site per 3.5 river miles.

<u>Locations</u>
Drift sampling will occur at seven sites, based on length of river rafted daily (two sites from Early Intake to Lumsden and five sites from Lumsden to Wards Ferry) at sites selected near overnight camping locations during each rafting trip. Drift samples will be collected in riffle or run habitats and be selected based on suitable depth, velocity, substrate, and accessibility/safety considerations, with two sites per location and two replicates (net placements) per site.

Benthic macroinvertebrate sampling will occur at suitable riffles initially identified in the office using aerial photographs and verified in the field. One composite sample will be collected daily from a suitable riffle or combination of suitable fast-water habitat types during the seven-day raft-based sampling.

<u>Sample timing and frequency</u>
Macroinvertebrate sampling will be conducted daily during the raft-based habitat mapping effort. Drift sampling in early summer (June) will characterize food resources available to rearing juvenile anadromous salmonids. In many temperate streams, aquatic macroinvertebrate diversity and abundance peak during spring and summer and are reduced in late summer and fall. Peak feeding and growth by rearing salmonids occur when prey availability and water temperatures are relatively high, maximizing net energy gain (Rundio and Lindley 2008, Stillwater Sciences 2007, Wurtsbaugh and Davis 1977). Exact sampling dates for this study may be adjusted within the general seasonal period to coincide with other sampling efforts in order to maximize efficiency and accommodate river flow levels. However, macroinvertebrate sampling should not occur during periods of very high flows or when river discharge is changing rapidly due to safety and access concerns and the potential effects of flow fluctuations on invertebrate drift (Brittain and Eikland 1988).

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Drift sampling will begin each afternoon by 1700 hours and proceed until approximately 2000 hours. This sample timing is intended to collect drifting macroinvertebrates during the daily period when feeding activity is often greatest for juvenile Chinook salmon and trout (Sagar and Glova 1988, Johnson 2008) and to avoid pre-dawn and post-dusk peaks in drifting macroinvertebrates that may not be available to drift-feeding salmonids at low light levels. The timing and duration of drift sampling can be adjusted if needed to accommodate rafting safety concerns or logistical constraints. All drift sampling should occur during the peak afternoon-evening feeding period and have the same start and end time.

The timing of the benthic macroinvertebrate sampling is not seasonally dependent, but will be coincident with the drift sampling effort to maximize efficiency and reduce the amount of field sampling time required for the study. Benthic macroinvertebrate samples will be collected once per day during the raft-based sampling effort, typically during mid-day or as determined by the location of suitable sampling riffles and logistics of the habitat mapping study.

4.3.2.2 Sampling Protocols

Invertebrate drift sampling

Drift samples will be collected using stationary nets with rigid rectangular openings and tapered, nylon mesh bags with a collection jar fitted at the downstream end – similar to drift nets used by other researchers (Brittain and Eikeland 1988), including the 1987–1988 drift studies in the lower Tuolumne River (Stillwater Sciences 2010). All drift nets will be identical, with a mesh size small enough to capture small invertebrates such as immature chironomids that may be important salmonid prey, while also large enough to minimize clogging (e.g., 250–500 μ). There is no standard mesh size for drift nets, with mesh size instead chosen according to study objectives, and to represent a compromise between filtration efficiency and clogging (Svendsen et al. 2004).

At each sampling location two transects will be selected perpendicular to the river and two drift nets will be placed at each transect: one near shore and one in the thalweg or as close to the thalweg as water depth and velocity will safely allow. Each drift net will be anchored in the water column using steel (e.g., rebar stakes or fence posts) driven into the stream bed, with the bottom of the net at least 10 cm above the river bottom and the top of the net at least 4–5 cm above the water surface. This vertical net placement ensures capture of terrestrial-origin organisms originating from outside the stream (Leung et al. 2009), which may be an important diet component for anadromous salmonids (Tiffan et al. 2014, Leung et al. 2009, Rundio and Lindley 2008) while avoiding capture of organisms crawling on the substrate. Because drift composition is not uniform across the channel (Waters 1969), placement of near-shore and mid-channel drift nets allows sampling of each portion of the channel to represent potential differences in taxonomic composition, origin (aquatic vs. terrestrial), density, or other factors. The safety of approaching rafts will be considered during the selection of transect locations, and each drift net will be clearly marked with a buoy. During sampling, the drift nets will be attended by one or more field crew members to monitor for approaching rafts or other safety hazards. If needed, field personnel will verbally warn rafters of the potential hazard and assist rafts in avoiding the nets.

Drift nets will be deployed for three hours each day (1700–2000 hours). The width and depth of the submerged portion of each net will be measured upon installation to calculate the effective net area (i.e., the area being sampled). Water velocity will be measured at the midpoint of each net mouth immediately after net installation, at the midpoint of sampling (after 1.5 hours), and immediately before retrieving the net. The three velocity values will be used to calculate the average water velocity at the mouth of each net during sampling, and the average velocity will be multiplied by the sampled area to determine the total volume of water passing through each net during the sampling event. Because net clogging during

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sampling can gradually reduce the velocity of water passing through the net, an average of several water velocities measured over the course of sampling provides a more accurate measure of volume than a single velocity measure.

After removing each drift net from the water, the contents will be carefully washed to the end of the net and into the collection bottle using river water. The bottle will then be removed and all contents will be transferred to a sample container, labeled, and preserved with 95% ethanol for later processing.

Benthic sampling

Benthic sampling will be conducted using a modified version of the targeted riffle composite (TRC) method described in the California State Water Resources Control Board Surface Water Ambient Monitoring Program (SWAMP) Bioassessment Standard Operating Procedure (Ode 2007). The TRC has been widely used in California by state and federal water resource agencies, is consistent with the methods of EPA's Environmental Monitoring and Assessment Program (EMAP) (Peck et al. 2006), and has been adopted as the standard riffle protocol for bioassessment in California (Ode 2007). A similar methodology, the former California Stream Bioassessment Protocol (CSBP) and later the California Monitoring and Assessment Program (CMAP), produced comparable results and was used for the Districts' benthic macroinvertebrate sampling program in the lower Tuolumne River from 2001–2005 and from 2007–2009 (Stillwater Sciences 2010). The SWAMP TRC method was recently used to collect benthic macroinvertebrate samples in the upper Merced River as part of the Merced River Alliance Biological Monitoring and Assessment project (Stillwater Sciences 2008).

Due to site access constraints and non-wadeability in most habitat types, a modified version of the SWAMP protocol will be used to select riffles or other suitable fast-water habitat types for TRC sampling. Whereas the SWAMP protocol specifies that habitats (riffles or other fast-water habitats) for TRC sampling should be selected randomly from a pre-established reach 250 meters in length, riffles sampled for this study will instead be selected randomly from among all potentially wadeable riffles that are accessed during the habitat mapping study and were initially identified in the office by examining high-resolution color aerial photographs of the study reaches. During field sampling, the field crew will carry a set of the aerial photographs with potential sampling riffles identified, to enable identification of alternative sampling riffles if needed. Using the office-based method, a total of seven riffles will be selected for sampling. Riffles selected for sampling will be spaced sufficiently to enable sampling of an average of one riffle per day during the raft-based field effort.

In the field, riffles initially selected for benthic sampling will be evaluated individually as they are encountered during the rafting trip to determine whether substrate, depth, and velocity are suitable for sampling, and if they can be sampled safely. A riffle will be deemed suitable if it has enough gravel or cobble substrate to allow collection of up to eight non-overlapping benthic samples in areas that can be safely accessed on foot by a two-person field crew (i.e., depth and velocity do not prohibit safe access and sampling). If a riffle initially chosen for TRC sampling is unsuitable, the crew will proceed to the next suitable riffle. Ideally, a total of five riffles or other fast-water habitats will be sampled in the study reach using the TRC method. At each riffle selected for TRC sampling, physical habitat and water chemistry data will be collected following the SWAMP protocol for the "basic" level of effort (Ode 2007). These data include GPS coordinates and photographs of the site, water temperature, pH, dissolved oxygen, specific conductance, channel width, riparian canopy cover, bank stability, and channel gradient.

The TRC approach specifies collection of benthic samples at eight riffles within each 250 meter sampling reach (Ode 2007). However, preliminary examination of aerial photographs indicates that the riffles in the upper Tuolumne River are relatively infrequent and widely spaced, thus selection of a 250 meter sampling reach containing multiple riffles will likely be infeasible. A modified approach will therefore be used, which will entail collection of eight benthic samples per riffle. If additional suitable riffles or other suitable fast-water habitat types (e.g., run or pool tail) are located in close proximity to a riffle that has been selected for TRC sampling and can be safely accessed on foot, the required eight samples will be collected at locations distributed randomly among the suitable habitats. Sampling locations in each riffle or combination of fast-water habitat types at each site will be selected randomly using a digital stopwatch or random number chart, as described in Ode (2007). Samples will be collected using a standard D-frame kick net with 500-µ mesh. At each sampling location, a 0.09 m^2 (1 ft^2) area of bottom substrate will be sampled immediately upstream of the net following methods described in Ode (2007). All eight samples collected at each site (riffle or combination of fast-water habitats) will be combined into a single composite sample for the site, preserved in 95% ethanol, and labeled for laboratory processing.

4.3.2.3 Analysis and Reporting

All macroinvertebrate samples will be processed in the laboratory following standardized methods and the data will be entered into a database. Processing will enumerate and identify organisms to the taxonomic level necessary to calculate commonly reported biological metrics (numerical attributes of biotic assemblages) for each sample site from the benthic samples (i.e., TRC samples) and identify the diversity and abundance of primary salmonid prey items in the drift. Benthic macroinvertebrate metrics may include those calculated for benthic macroinvertebrate samples collected in the lower Tuolumne River from 2000–2005 and 2007–2009 (Stillwater Sciences 2010). Laboratory analysis of drift samples will also include length measurement of individual organisms, to allow calculation of biomass at a later date, if desired, to provide a relative measure of energy content and available fish food resources. Results will be included in a technical report that evaluates the adequacy of the macroinvertebrate prey resources to support healthy populations of juvenile anadromous salmonids, as indicated by comparison of the taxonomic composition and relative abundance (drift density) of the upper Tuolumne River macroinvertebrate drift samples with drift samples from other salmonid streams.

5.0 STUDY SCHEDULE

The study will be completed during the summer and fall of 2016; a detailed field schedule will be developed in conjunction with other field studies.

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REVISED DRAFT STUDY PLAN

TURLOCK IRRIGATION DISTRICT
AND
MODESTO IRRIGATION DISTRICT

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

Hatchery and Stocking Practices Review

May 2016

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1.0 BACKGROUND

As part of the La Grange Hydroelectric Project licensing proceeding, the Districts are undertaking the Fish Passage Facilities Alternatives Assessment (Fish Passage Assessment), the goal of which is to identify and develop concept-level alternatives for upstream and downstream passage of Chinook salmon and steelhead at the La Grange and Don Pedro dams. In September 2015, the Districts provided to licensing participants Technical Memorandum No. 1, which identified a number of information gaps critical to informing the biological and associated engineering basis of conceptual design for the Fish Passage Assessment. In November 2015, licensing participants adopted a plan to implement the Upper Tuolumne River Reintroduction Assessment Framework (Framework) intended to develop the information needed to undertake and complete the Fish Passage Assessment and to assess the overall feasibility of reintroducing anadromous salmonids into the upper Tuolumne River (TID/MID 2016). As part of implementing the Framework, a number of environmental studies are planned.

The Hatchery and Stocking Practices Review is one of several studies to be implemented in 2016 in support of the Framework. Information collected during this study will be used to inform an evaluation of the potential for hatchery stocking practices to affect Chinook salmon and steelhead that may be introduced into the upper Tuolumne River above the Don Pedro Project.

2.0 STUDY AREA

The study area for this desktop literature review will encompass the Tuolumne River basin, including Don Pedro Reservoir and the mainstem Tuolumne River, and associated tributaries (North Fork Tuolumne River, Clavey River, Cherry Creek, etc.), to the extent that information is available regarding historical or current hatchery and stocking practices.

3.0 STUDY GOALS

The overall goal of this study is to assess historical and current hatchery stocking practices in the Tuolumne River basin and identify potential interaction of stocking activities with the reintroduction of anadromous salmonids to the reach of the Tuolumne River between the upstream end of the Don Pedro Project and the City and County of San Francisco's Early Intake. Specific objectives of this study are listed below:

- identify the species, source hatcheries and their stocking practices in the area, and time periods of fish that were historically stocked in the Tuolumne River, tributaries to the Tuolumne River, and in Don Pedro Reservoir;
- identify stocking location and seasonal timing of stocking for species currently stocked (and that may be stocked in the future) in the Tuolumne River, tributaries to the Tuolumne River, and in Don Pedro Reservoir;
- identify and describe self-sustaining potamodromous populations (species of fish that migrate [upstream or downstream] exclusively in freshwater) originating from previously stocked species, their life history characteristics, and population characteristics, as available;
- identify available information on documented incidents of disease in hatchery stocks and in the Tuolumne River basin;
- describe life histories of stocked species, as well as their spatial and temporal migrations and distributions to identify the potential to interact with reintroduced anadromous salmonids;
- describe potential spatial and temporal overlap of stocked species and lifestages with potentially-reintroduced species and lifestages (i.e., steelhead and spring-run Chinook salmon) in the Tuolumne River; and
- identify potential effects of historical and existing/future hatchery and stocking practices on efforts to reintroduce anadromous salmonids to the Tuolumne River.

4.0 STUDY METHODS

A desktop literature review will be conducted and is expected to include review of agency technical memoranda, fish stocking data, fish health information, journal articles, and websites to identify and describe historical, current and future fish hatchery and stocking practices in the Tuolumne River Basin. Agencies and organizations involved with fish hatchery and stocking activities will be contacted to gather additional information on historical and existing fish stocking activities in the study area, including the Don Pedro Recreation Agency and California Department of Fish and Wildlife.

Based on the information collected regarding historical and current/future stocking practices, existing hatchery operations, life histories of stocked fish species, and literature on interactions between stocked fish species and anadromous salmonids, potential effects of hatchery and stocking practices to an anadromous salmonid reintroduction effort will be described and evaluated. Potential risks associated with hatchery and stocking practices to an anadromous salmonid reintroduction program will be identified and described.

5.0 STUDY SCHEDULE

The anticipated schedule is to conduct the desktop literature review and contact agency staff from May to July 2016. A draft report will be provided to the Technical Committee in November and a final report will be included in the February 2017 Updated Study Report.

6.0 REFERENCES

Turlock Irrigation District and Modesto Irrigation District (TID/MID). 2016. Fish Passage Facilities Alternatives Assessment Progress Report. Prepared by HDR, Inc. Appendix to La Grange Hydroelectric Project Initial Study Report. February 2016.

REVISED DRAFT STUDY PLAN

TURLOCK IRRIGATION DISTRICT
AND
MODESTO IRRIGATION DISTRICT

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

Upper Tuolumne River Instream Flow Study

May 2016

DRAFT

1.0 BACKGROUND

As part of the La Grange Hydroelectric Project licensing proceeding, the Districts are undertaking the Fish Passage Facilities Alternatives Assessment (Fish Passage Assessment), the goal of which is to identify and develop concept-level alternatives for upstream and downstream passage of Chinook salmon and steelhead at the La Grange and Don Pedro dams. In September 2015, the Districts provided to licensing participants Technical Memorandum No. 1, which identified a number of information gaps critical to informing the biological and associated engineering basis of conceptual design for the Fish Passage Assessment. In November 2015, licensing participants adopted a plan to implement the Upper Tuolumne River Reintroduction Assessment Framework (Framework) intended to develop the information needed to undertake and complete the Fish Passage Assessment and to assess the overall feasibility of reintroducing anadromous salmonids into the upper Tuolumne River (TID/MID 2016). As part of implementing the Framework, a number of environmental studies are planned.

The Upper Tuolumne River Instream Flow Study is one of several studies to be implemented in 2016 in support of the Framework. Information collected during this study will be used to evaluate existing aquatic habitat and provide quantifiable metrics of aquatic habitat suitability in the upper Tuolumne River.

2.0 STUDY AREA

The study area for the Instream Flow Study is the main stem of the Tuolumne River extending from the upstream end of the Don Pedro Project (RM 81 +/-) to Early Intake (RM 105).

3.0 STUDY GOALS

The goals of this study are (1) to model existing aquatic habitat for spring-run and fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (O. *mykiss*); (2) to evaluate the existing aquatic habitat over a representative range of observed water years and operations of the City and County of San Francisco's Holm powerhouse; and (3) to provide quantifiable metrics of aquatic habitat suitability in the context of potential reintroduction of Chinook salmon and steelhead.

4.0 STUDY METHODS

The following instream flow study methods are consistent with normal and customary 2-dimensional (2D) instream flow methodologies, and will provide data that are comparable to data collected and used at other salmonid-bearing streams and rivers in California and elsewhere.

The study will be performed in five steps: (1) reach and site selection; (2) field data collection; (3) hydraulic modeling; (4) aquatic habitat modeling; and (5) report preparation. Each of these steps is described below.

Step 1 – Reach and Site Selection

The establishment of study reaches and the location of a study site within each reach will be based on five primary sources of information: (1) upper Tuolumne River geomorphology; (2) watershed hydrology; (3) habitat mapping study results; (4) spawning gravel mapping study results; and (5) existing aerial imagery. Based on current information, it is expected that two or three study sites will be selected throughout the study area.

Reach segmentation in the study area will be based on geomorphic characteristics (e.g., gradient, channel width, substrate composition) and hydrologic contributions (e.g., accretion, percent contribution to overall streamflow from tributaries, effects of hydropower peaking). Based on these characteristics and results from detailed mesohabitat mapping and gravel surveys, one or more study sites will be selected in each reach. Lastly, study site selection will focus on selecting both low gradient mesohabitats (pool, run and low gradient riffle) and likely short high gradient transition mesohabitats (e.g., high gradient riffle, cascade).

Study sites will be selected of a sufficient size and habitat composition to adequately characterize, and be indicative of, the range of habitat attributes (e.g., spawning, rearing and holding) documented through previous and concurrent field data gathering efforts conducted as part of the Framework. The final length of each site will be dependent on the geomorphic characteristics and lengths of mesohabitats contained within the selected study location. The number and types of mesohabitats selected will also depend on the length and variability of mapped units in the vicinity.

While study sites will initially be developed using field and aerial imagery data sources, final site selection may also be influenced by (1) proximity to camping locations, an important logistical consideration in this remote river canyon, and (2) safety considerations, which are influenced by gradient, channel configuration, hydraulic conditions, and availability of downstream recovery/safety zones.

Step 2 – Field Data Collection

Given the remoteness and limited access to the upper Tuolumne River, field data collection at each site will be completed in one continuous five to seven day period. It is anticipated that most of the out-of-water topography will be developed using airborne Light Detection and Ranging (LiDAR) data collected by NMFS in 2015 along the upper Tuolumne River. Before use, the LiDAR data will be evaluated by a remote sensing expert for quality and study utility.

Additional topographic data will be collected using a variety of methods depending on site conditions. Initially, LiDAR coverage will be evaluated and used to describe the majority of each study site not submerged at the time of the data collection. The remaining in-water and out-of-water topographic data collection will be completed utilizing a number of survey techniques. Given the steep nature of the

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canyon, standard Real Time Kinematic (RTK) Global Positioning System (GPS) survey will likely not be practical. Therefore, the primary survey instruments used will be Robotic Total Stations (RTS), surveyed into a RTK GPS network. The RTS units will be used for topographic surveys conducted on foot and for single beam bathymetric surveys conducted to collect unwadable in-channel topography. Depending on river conditions and safety considerations during each survey, a variety of manned and unmanned craft may be used for bathymetric data collection. Field staff will record all relevant survey information into predefined survey log sheets throughout each survey day.

After each data collection period, the RTK static GPS data files collected by the base station will be submitted to the National Oceanic and Atmospheric Administration's (NOAA) Online Positioning User Service (OPUS). OPUS returns a position corrected and mapped into the high accuracy National Spatial Reference System (NSRS). Using Trimble Business Center software, the OPUS-corrected position will then used to correct the network of RTS collected points from each survey instrument.

Habitat modeling for certain lifestages will require that substrate classification be consistent with habitat suitability criteria (HSC). Once final HSC are defined for this study, substrate classification tables and codes will be developed for use in the field. Similarly, and if applicable, cover types will correspond to cover codes defined in HSC selected for each species.

Prior to field work, detailed substrate information from the *Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study* will be reviewed and, as appropriate, used for field reference. Additionally, if aerial photos are of suitable resolution, preliminary substrate polygons will be digitized throughout each model domain. In the field, crews will use an iPad loaded with aerial photos and GIS mapping software to either validate and refine the desktop delineation or develop substrate polygons and cover features throughout each study site.

Water surface elevations (WSE), discharges, and calibration depths and velocities will be collected throughout each study site at two calibration flows. The final measured flows will ultimately depend on the hydropower peaking operations and the duration of stable flows observed at each study site. Flow stability for data collection and modeling purposes is defined as a 'steady' discharge that results in minimal fluctuation in stage (e.g., no more than +/- 0.05 ft) for a long enough duration to measure discharge, WSEs, depths and velocities throughout the study site. It is anticipated that target flows will range from approximately 200 cfs to 1,200 cfs but will be dictated by upstream hydropeaking operations during each survey period. Based on these targets, hydraulic-habitat relationships modeled in each study site will extend from approximately 50 cfs to 2,000 cfs. The final range will be determined by the overall quality of site specific rating curves and model performance.

WSE's will be surveyed using a RTS in approximately 50 locations throughout the wetted channel for each calibration flow. In addition, spatially referenced depth and velocity validation data will be collected in at approximately 50 locations by an acoustic Doppler current profiler (ADCP) or manual velocity meter depending on location and hydraulic condition. Spot velocities depths and WSE measurements will span the entire longitudinal profile of model site.

Study site discharge measurements will be made using a combination of manual velocity meters and an ADCP mounted on an OceanSciences™ trimaran or similar vessel. ADCP measurements will follow standard USGS procedures (Mueller and Wagner 2009) for measuring discharge.

On-site rating curves will be developed using a combination of stage and discharge measurements and stage recording pressure transducers. At a minimum, three stage and discharge measurements will be made at each site. To supplement these data, stage recorders, which also record temperature, will be deployed at the top and bottom of the each study site to passively record stage over the data collection period. Stage recorders may also be deployed at various locations throughout the site to monitor the rate of stage change at specific mesohabitats. To relate WSE to discharge, the WSE will be measured directly above each installed logger at the time of deployment and again when the units are retrieved. A barometric pressure transducer will also be installed at the site to compensate for changes in atmospheric pressure. For validation purposes, WSEs will be measured during calibration flow surveys in the vicinity of each recorder. In addition to providing stage data for rating curve development, stage and temperature data from the recorders will be used to inform habitat and peaking analyses, discussed in Step 5 below.

Study site photographs will be collected to document site conditions during each survey. A representative collection of site photos, arranged by calibration survey flow will provided in a report attachment.

Step 3 – Hydraulic Modeling

Surface and Mesh Development

Hydraulic modeling for the study site will use River2D (Steffler and Blackburn 2002). The River2D model uses the finite element method to solve the basic equations of vertically averaged 2D flow incorporating mass and momentum conservation in the two horizontal dimensions (Steffler and Blackburn 2002).

The main input parameters for the River2D model include channel surface topography, bed roughness (in the form of an effective roughness height), and upstream and downstream hydraulic boundary conditions (i.e., water levels and discharge). Accurate topography is the primary variable that allows for the development of a well calibrated model.

Topographic surfaces will be constructed by combining the total station survey data, RTS and RTK GPS standard survey data, bathymetric data, and the LiDAR ground return data. In order to increase the definition in areas of topographic gradient and variability, breaklines will be defined within the topographic surface. Breaklines enforce the topographic surface to 'snap' to the entire length of the line and are used to define features with large vertical gradient changes, such as cascades, toe of slopes, and boulders.

Before entering the data into the River2D model, topographic data from the site will be reviewed for errors in ArcMap and ArcScene. Triangulated Irregular Networks (TINs) will be developed to visualize the data in two and three dimensions

Mesh development will follow procedures outlined in the R2D_Mesh User's Manual (Waddle and Steffler 2002). When building a computational mesh, it is important to optimize for computational performance without sacrificing mesh quality. Using the topographic surface nodes to define the mesh is not recommended as the computational requirements for such a model exceed the limits of the software and currently available computer hardware. Instead, a low density uniform mesh is developed and then refined using a variety of techniques.

As recommended by the R2D_Mesh User's Manual, a balance between mesh density and computational burden will be addressed in part by applying a procedure called 'wet refinement' which places nodes at the centroid of each mesh element. This process ensures the appropriate mesh density in wetted areas only, while limiting mesh density in dry areas.

Another method used to refine the mesh is to review mesh-generated elevation contours as compared to bed elevation contours at an interval of 0.82-foot with a goal of close contour approximation. Since the topographic points and mesh nodes are not in the same location, the contours will not be exactly the same. Therefore, to increase contour agreement, additional nodes may be added in topographically complex areas. To achieve the appropriate mesh density over all simulation flows, the mesh will be iteratively refined in the context of the full range of possible wetted areas.

A third method used to refine the mesh will be to identify large elevation differences between topographic data points and the interpolated elevation of each mesh triangle. Most often, large elevation differences exist in areas of high gradient (e.g., cascade) or significant localized topographic relief (e.g., cliff or vertical bank). Mesh triangles that exceed a 0.82-ft difference threshold are highlighted yellow in the mesh development software and further refined until the difference is no longer detected.

QI is a mesh quality index where a value of 1.0 represents a mesh comprised of perfect equilateral triangles. The goal minimum triangle quality index (QI) for each computational mesh is 0.15. Low QI values (i.e., <0.10) do not necessarily compromise model quality, but will increase computational run times. Tools in the mesh development software are used to improve geometry to achieve the minimum goal QI value.

One initial base mesh used for model calibration will be used for all simulation runs. However, it will be necessary to make small changes if model run time errors (i.e., eddy shedding velocity oscillation, extremely high velocity, or Froude number) occur.

Model Calibration

Model parameters such as bed roughness (Ks, in the form of an effective roughness height), substrate transmissivity (tr) and eddy viscosity can be adjusted during model calibration to reflect field conditions. A stage-wise approach with target criteria for model performance will be used to guide calibration. The specific stages and criteria are discussed below.

For the initial hydraulic model, hydraulic calibration tests will be conducted using the target calibration flows of 200 cfs and 1,200 cfs. Bed roughness (Ks) and transmissivity (tr) will be varied as necessary to match observed WSEs and wetted area. As part of normal calibration, Ks and tr values are incrementally adjusted through an integrative sensitivity analysis until modeled WSEs calibrate well to observed WSEs. In addition to the WSE comparisons, velocity and depth predictions will be compared to field measured data to evaluate changes made to Ks.

The term “Ks” is scientific notation for bed roughness factor (in meters) and the term refers to gradation of material in the river. Compared to traditional one-dimensional models, where many two-dimensional effects are abstracted into the resistance factor, the 2D resistance term accounts only for the direct bed shear (Steffler and Blackburn 2002). Ks is iteratively varied as necessary to match observed water surface elevations using the default transmissivity of tr = 0.1. In general, the initial Ks value entered is 1-3 times the grain size documented during field data collection. Multiple regional Ks values (i.e., heterogeneous substrate material and/or large elevation changes) may be selected for each study site based on model performance.

Groundwater transmissivity (tr) is a user-defined variable which corresponds to groundwater flow and the relationship to surface flow. The default value is 0.1 which ensures that groundwater discharge is negligible. Because subsurface flow through gravel or cobble may be present at the study site, it may be

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necessary to modify the default value of tr to aid in the wetting and drying function throughout the model domain.

The target criterion for mean error in WSE between simulated versus observed data is, to a large extent, based on the accuracy of the survey equipment used to measure WSE. It is also important to recognize the influence of highly heterogeneous or high gradient topography (e.g., cascades and high gradient riffles) habitats on differences between field data and model data. Given the expected range of site characteristics in the upper Tuolumne River an average of 0.10 ft difference between simulated and observed WSE will be targeted.

Similarly, no specific target calibration criteria exist for velocity or depth parameters as these variables are greatly influenced by the differences in topographic detail between the field conditions, initial bed file detail, and the final bed detail resulting from the interpolated mesh. Using professional judgment and standard industry practice, velocity and depth variables are reviewed for reasonableness and significant errors in depth (i.e., > 0.33 ft mean error) and velocity (i.e., > 0.5 fps mean error) are evaluated. For all sets of model calibration variables, the correlation coefficient (r) and the coefficient of determination (r2) (i.e., percent of variance in an indicator variable explained by a factor and the measure of the proportion of variance of model results, respectively) will be calculated. In general, coefficients greater than 0.7 are expected while coefficient of determination values for velocity magnitude are expected to be within a range of 0.4 and 0.8 (Pasternack 2011).

Flow field velocity vectors (i.e., the direction and magnitude) are used to evaluate velocity prediction reasonableness during the calibration process but are otherwise not incorporated into the statistical review process.

Model convergence for a given hydraulic simulation is achieved and accepted when the inflow (Qin) equals outflow (Qout) and the solution change is nominal. Solution change is the relative change in the solution variable over the last time step. Specific criteria thresholds do not exist for these parameters and are largely based on the magnitude of the simulation discharge and the professional judgment of the modeler. The target solution change goal will be 0.0001. This target value is consistent with recommendations made in the River2D User's Manual (Steffler and Blackburn 2002).

Step 4 – Aquatic Habitat Modeling

Habitat Suitability Criteria

HSC define the range of microhabitat variables that are suitable for a particular species and lifestage of interest. HSC provide the biological criteria input to the River2D model which combines the physical habitat data and the habitat suitability criteria into a site-wide habitat suitability index (i.e., Weighted Usable Area or WUA) over a range of simulation flows. Variables typically defined with HSC include depth, velocity, instream cover and bottom substrate. HSC values range from 0.0 to 1.0, indicating habitat conditions that are unsuitable to optimal, respectively. WUA is defined as the sum of stream surface area within a nodal area model domain or stream reach, weighted by multiplying area by habitat suitability variables, most often velocity, depth, and substrate or cover, which range from 0.0 to 1.0 each.

Spring-run Chinook salmon HSC information compiled for the McCloud River, a tributary of the Sacramento River, will be used for habitat modeling. The HSC were recently developed for use in a PHABSIM study assessing potential habitat availability related to the reintroduction of Chinook salmon upstream of Shasta Lake (PG&E 2011). The PHABSIM study was conducted for PG&E's McCloud Pit Hydroelectric Project (FERC No. 2106) (PG&E 2012). Using the best available HSC information and

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professional judgment, composite curves were developed for spawning, fry and juvenile lifestages. Holding HSC were not developed in the process. Holding habitat will be evaluated in the *Upper Tuolumne River Habitat Mapping and Macroinvertebrate Assessment.* Model results from this study may, however, inform the suitability of holding habitat. Spring-run periodicity information will rely upon information provided in Technical Memorandum No. 1 (TID/MID 2015).

Steelhead and fall-run Chinook salmon HSC information developed for the lower Tuolumne River instream flow study (Stillwater Sciences 2013) will be used to model habitat suitability in this study. Spawning and juvenile lifestages will be modeled. The Districts note that the lower Tuolumne River HSC may require some modification to appropriately be used in the upper Tuolumne River channel. Modifications to HSC will be made by a regional HSC expert familiar with the proposed curves and any changes will be thoroughly documented in the final report. Periodicity information for these species will rely upon information provided in Technical Memorandum No. 1 (TID/MID 2015).

Model Simulation

Approximately 18 discharges will be simulated for each study site resulting in an expected flow range of 50 cfs to 2,000 cfs. Habitat suitability and WUA for all fish species and lifestages will be calculated for each simulation flow. In order to calculate habitat suitability, four data inputs are required: a fish preference file (i.e., HSC), a channel index, depth, and velocity. A fish preference file is loaded into River2D as a text file. Depth and velocity values are provided from the model once a simulation has converged and is at a steady state. Channel index files are a River2D model file equivalent to a substrate and/or cover map of the entire study site. Substrate may only be applicable to the spawning lifestages and possibly fry/juvenile lifestages (as a cover component) but will depend on the HSC used.

For this study, the habitat suitability calculation will use the standard triple product function which multiplies depth, velocity, and channel index suitability together at each model node. Channel index interpolation will be defined using discrete node selection (i.e., nearest node rather than a continuous linear interpolation of the channel index values from surrounding nodes). Discrete node selection is typically applied to substrate classifications such that the original substrate code value is maintained. If cover codes are defined for the proposed HSC, continuous interpolation will be applied to cover indices where a gradient of cover may be best described by the interpolation function.

Hydropeaking Analysis – Habitat Persistence

It is of particular importance to evaluate and understand the potential effect of hydropeaking operations on the habitat utilized by various lifestages of aquatic organisms. For example, an area with suitable depth, velocity and substrate for spawning adults at one flow may become unsuitable as flows rise or recede over a large range of hydropeaking operations. At some point, if redds were developed at a high flow, they may become dewatered at lower flows. Similarly, it is important to understand the spatial and temporal distribution of habitat for fry and juvenile salmonids. Suitable rearing habitat at one flow may quickly become unsuitable and shift in location when flows rapidly increase or decrease. These analyses are often termed habitat effectiveness, or habitat persistence. These terms relate to the temporal and spatial change in habitat suitability and distribution under changing flow conditions.

Within each model domain, regions of special interest (e.g., spawning gravel patches) will be identified. The areas of interest (AOI) will be areas that could provide suitable spawning and rearing habitat under a range of flow conditions. Polygons representing the AOI regions will be digitized in ArcGIS in order to extract data from model nodes in the computational mesh.

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Relying on information generated from each of the model simulation runs, model parameters such as suitability, WSE, velocity and depth will be extracted at each model node such that changes in each parameter, per unit discharge, can be calculated and evaluated. These analyses will be conducted using Geographic Information System (GIS) and spreadsheet tools.

Effects on aquatic habitat from daily changes in power plant operation will be modeled for time periods specified by species and lifestage periodicity and will be initially conducted at 15-minute to 1-hr time intervals using data collected at each site by stage recorders. Additional longer duration analyses will focus on weekly or monthly time steps and rely on hydrologic time series data from representative water years (e.g., dry, normal and wet). Results for the selected AOI regions in each model domain will be reported in both tabular and spatial form.

Step 5 – Reporting

A detailed technical memorandum will be provided that includes the following sections: (1) Study Goals and Objectives; (2) Methods; (3) Results; (4) Discussion; and (5) Description of Variances from the study plan, if any. A number of report attachments will include, but not be limited to, additional data such as representative site photographs and, habitat suitability maps. Models and interactive spreadsheets will be made available on CD.

5.0 STUDY SCHEDULE

Final study sites will be selected once data from habitat mapping and spawning gravel surveys are completed and data evaluated. Field data collection is anticipated to commence in the fall of 2016. Hydraulic and habitat modeling and associated analyses will be conducted in the fall of 2016 and winter of 2017. A progress report will be included in the February 2017 Updated Study Report.

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REVISED DRAFT STUDY PLAN

TURLOCK IRRIGATION DISTRICT
AND
MODESTO IRRIGATION DISTRICT

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

Regulatory Context for Reintroduction

May 2016

1.0 BACKGROUND

As part of the La Grange Hydroelectric Project licensing proceeding, the Districts are undertaking the Fish Passage Facilities Alternatives Assessment (Fish Passage Assessment), the goal of which is to identify and develop concept-level alternatives for upstream and downstream passage of Chinook salmon and steelhead at the La Grange and Don Pedro dams. In September 2015, the Districts provided to licensing participants Technical Memorandum No. 1, which identified a number of information gaps critical to informing the biological and associated engineering basis of conceptual design for the Fish Passage Assessment. In November 2015, licensing participants adopted a plan to implement the Upper Tuolumne River Reintroduction Assessment Framework (Framework) intended to develop the information needed to undertake and complete the Fish Passage Assessment and to assess the overall feasibility of reintroducing anadromous salmonids into the upper Tuolumne River (TID/MID 2016). As part of implementing the Framework, a number of environmental studies are planned.

The Regulatory Context for Reintroduction review is one of several studies to be implemented in 2016 in support of the Framework. Information collected during this study will be used to evaluate federal, state, and local regulatory issues that may be associated with the reintroduction of Chinook salmon and steelhead into the upper Tuolumne River above the Don Pedro Project.

2.0 STUDY AREA

The study area will encompass the Tuolumne River basin, including Don Pedro Reservoir and the mainstem Tuolumne River, associated tributaries (North Fork Tuolumne River, Clavey River, Cherry Creek, etc.), and surrounding public and private land.

3.0 STUDY GOALS

This regulatory review will evaluate federal, state, and local regulatory issues associated with the potential introduction of fall-run and spring-run Chinook (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) into the upper Tuolumne River. The upper Tuolumne River basin spans the jurisdictions of several federal land management agencies (United States Forest Service [USFS], Bureau of Land Management [BLM], and National Park Service [NPS]), while the lower Tuolumne River basin is primarily state and private land. Current activities related to fisheries management (stocking, setting of fishing areas, seasons, limits, and catch quotas) are the responsibility of the State of California. With the

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potential introduction of protected anadromous salmonids (i.e., spring-run Chinook and steelhead), regulatory requirements related to such laws as the Endangered Species Act, Magnuson-Stevens Fishery Conservation and Management Act, Clean Water Act, National Environmental Protection Act, the Federal Land Policy and Management Act, and California Environmental Quality Act may become relevant to activities occurring in the study area. The goals of this study are to:

- identify applicable existing legal precedent, regulatory guidance and resource management plans in the study area;
- identify additional regulatory guidance and rules that may apply to or affect the reintroduction of Chinook and/or steelhead; and
- identify and define potential federal, state, and local regulatory issues associated with the potential fish passage/reintroduction program.

4.0 STUDY METHODS

The introduction of new species into the upper river may affect current uses and regulatory requirements/restrictions throughout the basin. A comprehensive understanding of the regulatory aspects of introducing federal- and state-listed species to the Tuolumne River watershed is necessary. For purposes of this evaluation, the regulatory context is defined as legal precedent, rules, regulations and guidelines in land and species management that may apply to land and species management in the study area.

State and federal resource management agencies will be contacted to confirm all relevant guidance documents and supporting materials are identified. A summary of regulations and authorities applicable and potentially applicable to activities in the watershed will be completed. This study report will include a matrix of species and land management goals, responsible authorities, and applicable laws and regulations relevant to current and future proposed reintroduction or fish passage activities in the watershed. An initial list of documents to be reviewed is provided below and will be expanded as necessary based on consultation with licensing participants.

- Recovery Plan for Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, and Central Valley steelhead (National Marine Fisheries Service 2014)
- Sierra Nevada Forest and Community Initiative (SNFCI) Action Plan (Sierra Nevada Conservancy 2014)
- The State of the Sierra Nevada's Forests (Sierra Nevada Conservancy 2014)
- Tuolumne Wild and Scenic River Comprehensive Management Plan and supporting documents (NPS 2014)
- Sierra Nevada Forest Plan and Amendments (USFS 2004, 2013)
- Stanislaus National Forest Plan Direction (USFS 2010)
- Sierra Resource Management Plan (BLM 2008)
- Steelhead Restoration and Management Plan for California (California Department of Fish and Game 1996)
- Tuolumne County General Plan (Tuolumne County 1996)
- Tuolumne Wild and Scenic River Management Plan (USFS 1998)
- Red Hills Management Plan (BLM 1985)

5.0 STUDY SCHEDULE

The anticipated schedule is to gather relevant plans and consult licensing participants and agencies from May through July 2016. A draft report will be provided to the Technical Committee in November 2016 with a final report included in the February 2017 Updated Study Report.

6.0 REFERENCES

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REVISED DRAFT STUDY PLAN

TURLOCK IRRIGATION DISTRICT
AND
MODESTO IRRIGATION DISTRICT

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

Socioeconomic Scoping Study

May 2016

1.0 BACKGROUND

As part of the La Grange Hydroelectric Project licensing proceeding, the Districts are undertaking the Fish Passage Facilities Alternatives Assessment (Fish Passage Assessment), the goal of which is to identify and develop concept-level alternatives for upstream and downstream passage of Chinook salmon and steelhead at the La Grange and Don Pedro dams. In September 2015, the Districts provided to licensing participants Technical Memorandum No. 1, which identified a number of information gaps critical to informing the biological and associated engineering basis of conceptual design for the Fish Passage Assessment. In November 2015, licensing participants adopted a plan to implement the Upper Tuolumne River Reintroduction Assessment Framework (Framework) intended to develop the information needed to undertake and complete the Fish Passage Assessment and to assess the overall feasibility of reintroducing anadromous salmonids into the upper Tuolumne River (TID/MID 2016). As part of implementing the Framework, a number of environmental studies are planned.

The Socioeconomic Scoping Study is one of several studies to be implemented in 2016 in support of the Framework. Information collected during this study will be used to evaluate the potential socioeconomic effects of reintroducing Chinook salmon and steelhead into the upper Tuolumne River above the Don Pedro Project.

2.0 STUDY AREA

The study area will encompass the upper and lower Tuolumne River basin, including Don Pedro Reservoir and the mainstem Tuolumne River, associated tributaries (North Fork Tuolumne River, Clavey River, Cherry Creek, etc.), and surrounding public and private land.

3.0 STUDY GOALS

The goal of this study is to develop a comprehensive description of the human environment, activities, and current uses of the resources and facilities in the study area that may be impacted by constructing and/or operating fish passage facilities and the introduction of anadromous fish.

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4.0 STUDY METHODS

Socioeconomic considerations are identified as a key element in assessing whether potential reintroduction methods could be successful (Andersen et al. 2014). Current management of the Don Pedro Reservoir and Tuolumne River supports a wide range of resources, uses, and users. The upper watershed includes the Tuolumne Wild & Scenic River segment managed for several outstanding resource values and is utilized by commercial and private recreational boaters. Other uses in the watershed include the City and County of San Francisco's operation of the Hetch Hetchy Project, private timber practices, water supply, flood control, state recreation areas, private land, and a recreational fishery. Don Pedro Reservoir provides numerous recreational activities, including house boating and a popular recreational fishery. County government and businesses benefit from the economic activities supported by the activities in the watershed.

As part of this study, a comprehensive survey of uses in the Tuolumne River watershed will be conducted and potential issues will be identified for consideration in the reintroduction assessment. A literature survey and review of existing information from the Don Pedro Recreation Agency, county and federal land management agencies, and other sources will be conducted. Surveys and/or focus groups will be used to verify and expand upon available information related to existing uses of the watershed that could be impacted by a fish reintroduction program. The information collected in this study is designed to support and expand upon the socioeconomic considerations identified in the Framework, such as recreation impacts (e.g., river recreation, reservoir recreation, recreational fishing) and impacts on private resources (e.g., timber resources, private landowners, agricultural water supply), and will be considered in any socioeconomic evaluation done once reintroduction and fish passage options are further developed.

5.0 STUDY SCHEDULE

The anticipated schedule is the study team will gather available literature and consult licensing participants and agencies from April to July 2016. The literature review and data gathering will be completed over the summer, with a draft report issued to the Technical Committee by November 2016. The final report will be included in the February 2017 Updated Study Report.

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REVISED DRAFT STUDY PLAN

TURLOCK IRRIGATION DISTRICT
AND
MODESTO IRRIGATION DISTRICT

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study

May 2016

1.0 BACKGROUND

As part of the La Grange Hydroelectric Project licensing proceeding, the Districts are undertaking the Fish Passage Facilities Alternatives Assessment (Fish Passage Assessment), the goal of which is to identify and develop concept-level alternatives for upstream and downstream passage of Chinook salmon and steelhead at the La Grange and Don Pedro dams. In September 2015, the Districts provided to licensing participants Technical Memorandum No. 1, which identified a number of information gaps critical to informing the biological and associated engineering basis of conceptual design for the Fish Passage Assessment. In November 2015, licensing participants adopted a plan to implement the Upper Tuolumne River Reintroduction Assessment Framework (Framework) intended to develop the information needed to undertake and complete the Fish Passage Assessment and to assess the overall feasibility of reintroducing anadromous salmonids into the upper Tuolumne River (TID/MID 2016). As part of implementing the Framework, a number of environmental studies are planned.

The Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study is one of several studies to be implemented in 2016 in support of the Framework. Information collected during this study will be used to characterize the distribution, quantity, and quality of suitable Chinook salmon and steelhead spawning gravel in the upper Tuolumne River.

2.0 STUDY AREA

The study area for mapping Chinook salmon and steelhead spawning gravel in the upper Tuolumne River includes the approximately 24-mile reach from the upstream limit of the Don Pedro Project (approximately RM 81) to Early Intake (approximately RM 105).

3.0 STUDY GOALS

Successful Chinook salmon and steelhead spawning and fry production are dependent on the abundance and quality of suitable spawning gravel. Information on the amount, distribution, and quality of spawning gravel are critical components in estimating habitat carrying capacity and assessing limiting factors. Limited information is available to describe the distribution, quantity, and quality of spawning gravel in the upper Tuolumne River. The goal of this study is to characterize the distribution, quantity, and quality of suitable Chinook salmon and steelhead spawning gravel in the upper Tuolumne River.

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The study objectives are:

- map the distribution of potentially suitable spawning gravel available for Chinook salmon and steelhead in the upper Tuolumne River;
- quantify the amount of suitable spawning gravel in the reach between RM 81 and RM 105; and
- assess the quality of potentially suitable spawning gravel based on gravel size characteristics, sorting, angularity, embeddedness, substrate depth, and permeability measured in a representative sample of gravel patches.

Study results will help inform the feasibility of introducing Chinook salmon and steelhead into the upper Tuolumne River.

4.0 STUDY METHODS

4.1 Spawning Gravel Mapping

Probable locations of gravel patches will initially be delineated in a Geographic Information System (GIS) using recent LIDAR, the best available aerial photography, and other existing information from prior mapping efforts and studies. This desktop mapping step will inform field staff as to the approximate distribution of gravel deposits and the most efficient logistical process for locating and mapping those deposits in the field. Field mapping criteria and protocols will be consistent with studies in the lower Tuolumne River (TID/MID 1992, 2013), and will be refined following this initial desktop analysis, as needed.

Potentially suitable spawning gravel patches will then be delineated in the field on map tiles from high resolution orthorectified aerial imagery (e.g., 8-13-2007 photography and mapbook). A laser range finder will be used to measure the approximate dimensions of each gravel patch, if necessary to support the delineation of patch areas on field tiles. Each patch will be assigned a unique ID. Field delineation of potentially suitable spawning gravel patches will be performed by a two-person crew using whitewater raft support to access the study reach. The crew will stop frequently to locate and investigate preliminary gravel polygons obtained from desktop mapping and any other deposits that appear to meet the mapping criteria. Inflatable kayaks may also be used to navigate unwadable areas requiring investigation. To the extent feasible, mapping will be performed during low or off-peak flow conditions to optimize visibility of potentially suitable spawning gravels. Supplemental access to limited portions of the study reach are available at vehicle road crossings and by foot, depending on terrain and river flow.

4.1.1 Gravel Particle Size Criteria

Species-specific particle size criteria that will be used to delineate potentially suitable spawning gravel for Chinook salmon and steelhead in the upper Tuolumne River study reach are summarized in Table 1.0. Patches with substantially different surface particle size characteristics will be separately delineated. Chinook salmon typically spawn in substrates with a D_{50} of 11–78 mm (0.42–3.0 in) (Platts et al. 1979, as cited in Kondolf and Wolman 1993, Chambers et al. 1954, 1955, as cited in Kondolf and Wolman 1993). Steelhead typically spawn in substrates with a D_{50} of 10–46 mm (0.4–1.8 in.) (Barnhart 1991, Kondolf and Wolman 1993). Wolman (1954) pebble counts will be conducted in selected areas to calibrate visual estimates of grain size parameters using methods developed by Bunte and Abt (2001). These preliminary particle size criteria, based on D_{50} reported in the literature, may be refined in coordination with the Technical Committee prior to the field effort.

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4.1.2 Minimum Gravel Patch Size Criteria

Minimum patch size criteria for mapping potentially suitable spawning gravel will be determined prior to the field effort based on a combination of (1) the minimum area required for a spawning Chinook salmon or steelhead pair and (2) the scale and resolution of available imagery used as a base for field mapping tiles. The minimum spawning area generally identified for Chinook salmon is approximately 12 m^2 (Healy 1991, Bjorn and Reiser 1991, Ward and Kier 1999). Steelhead typically defend a redd only during the period of active spawning, and therefore the area required for a spawning steelhead pair is approximately equal to the disturbed area of the redd. . For mapping purposes, we will initially assume that a minimum patch size of approximately 6 m^2 is required for a steelhead pair to build and defend a redd (Bjornn and Reiser 1991; Orcutt et al. 1968). Preliminary minimum patch size criteria for mapping potentially suitable spawning gravel will be refined prior to field mapping based on review of available spawning patch information from the lower Tuolumne River and other relevant Central Valley river systems.

Table 1.0 Preliminary particle size and minimum patch size criteria for mapping potential spawning gravel for Chinook salmon and steelhead in the upper Tuolumne River.

Species	Gravel D_{50} mm (in.)	Minimum Patch Size Required for Spawning, m^2 (ft^2)	References
Chinook salmon	10–78 (0.4–3)	12 (130)	Platts et al. 1979, Chambers et al. 1954, 1955, all as cited in Kondolf and Wolman 1993; Healy 1991, Bjorn and Reiser 1991, Ward and Kier 1999
Steelhead	10–46 (0.4–2)	6 (65)	Barnhart 1991, Kondolf and Wolman 1993, Bjornn and Reiser 1991, Orcutt et al. 1968

Note: D_{50} – diameter of particle (in millimeters) at which 50 percent of the sample is smaller (*e.g.*, median).

4.2 Spawning Gravel Quality

In addition to the particle size and minimum patch size criteria described above, measurements and observations of the quality of gravel patches will be collected in the field to inform spawning habitat quality. These will include additional gravel particle size parameters (e.g., D_{16}, D_{84}); characterization of particle sorting, angularity, and embeddedness; an estimate of the average substrate depth (where feasible); and measurements of permeability.

4.2.1 Field Observations of Gravel Quality

Sorting describes the homogeneity of surficial particles within a patch. Spawning salmonids prefer substrates that are relatively well sorted. The degree of sorting will be visually estimated using the comparison chart in Compton (1985). Angular grains tend to pack more tightly than rounded particles and are more likely to slow intragravel flow. More loosely packed and rounded particles also increase a fish's ability to dislodge the substrate during redd construction. The degree of particle angularity within a patch will be visually estimated based on the comparison chart in Powers (1989). Substrate embeddedness describes the presence of fine sediment in the gravel interstices. Substrate embeddedness is measured by selecting a random sample of coarse surface particles within the patch and measuring the percent of the particle that is surrounded or buried by fine sediment (fines and sands <2 mm) (Burns and Edwards 1985). Embeddedness measurements will be conducted concurrent with pebble counts and/or during permeability sampling. The substrate depth required for redd construction and egg deposition likely depends on the size of the spawning female and on particle size characteristics, as well as flow

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depth and velocity. Chinook salmon egg pocket depths range from 8 to 51 cm (3 to 20 in), with an average of 22 cm (8.5 in) (Burner 1951). Steelhead egg pocket depths range from 15 to 28 cm (6 to 11 in), with an average of 21 cm (8.4 in) (Briggs 1953). Substrate depth will be estimated from exposure of bedrock and boulder framework and by probing with a Silvey rod.

4.2.2 Gravel Permeability

Gravel permeability will be collected to characterize incubation conditions and estimate predicted survival-to-emergence. The quality of spawning gravel will be assessed by measuring streambed permeability at select patches following the methods of Barnard and McBain (1994). Gravel inflow rate (ml/sec), which is an index of intragravel permeability (cm/hr), will be measured using a steel standpipe adapted from the Terhune Mark VI standpipe design (Terhume 1958; Barnard and McBain 1994). At select gravel patches, the standpipe will be driven into the gravel to an approximate depth of 30 cm (12 inches) using a protective end cap and sledge hammer. A battery powered peristaltic pump (e.g., IP Masterflex brand pump or equivalent) will be used to create a 2.5 cm head differential in the standpipe and the rate at which water is drawn from the pipe will be measured. While maintaining this constant pressure head, water will be drawn through the perforations in the standpipe buried in the gravel, and a stopwatch will be used to measure the time required to collect a volume of water.

Gravel permeability can be highly variable within and between patches in a reach. Therefore, a sampling plan will be developed based on the results of the spawning gravel mapping effort. The sampling plan will outline an approach and provide field protocols for characterizing the permeability of potential spawning patches throughout the study reach. The approach will generally rely on assigning patches to a morphologic unit (e.g., pool tail) and sampling from consistently similar positions within a morphologic unit. Sampling will occur in the morphological unit(s) that best exhibit the effects of fine sediment supply on spawning gravel quality and that have the highest potential value to spawning Chinook and steelhead. Permeability sampling results may be stratified by subreach, as appropriate. Desktop and field-based mapping of potentially suitable spawning gravel patches will inform an appropriate system for delineating morphological units, appropriate permeability sampling locations within those units, and appropriate delineation of any subreaches useful in extrapolating permeability sampling results.

4.2.3 Gravel Quality Ranking

When a gravel patch is identified as potentially suitable based on minimum area and particle size criteria, a qualitative ranking of overall suitability from 1 (poor) to 10 (good) will be assigned to the patch based on an overall assessment of the following physical characteristics (substrate particle size, sorting, angularity, embeddedness, gravel depth, permeability, and patch location and size). A separate ranking will be assigned for spawning gravel patches potentially suitable for Chinook salmon and steelhead. Although reliable rankings rely heavily on the professional judgment and personal experience of the survey participants, this ranking will allow comparison of patch quality. Rankings will be summarized as follows: 1–3= low suitability, 4–7= medium suitability, and 8–10= high suitability.

4.3 Data Processing and Analysis

Potentially suitable spawning gravel patches delineated on field tiles will be digitized using GIS, and area estimates for each patch will be calculated. The quantity and quality of potentially suitable spawning gravel patches will be summarized in tabular format.

Results to be reported include the following:

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- shapefiles with polygons of potentially suitable spawning gravel patches and associated patch attributes;
- a database of attributes for each mapped gravel patch (i.e., measured and/or estimated particle size parameters, sorting, angularity, embeddedness, estimated mean depth [where feasible], associated channel morphological feature, and quality score);
- mean, minimum and maximum gravel inflow rates (ml/sec) as an index of intragravel permeability (cm/hr) for each sample site, presented by river mile location; and
- derived mean permeability (cm/hr) by river mile.

5.0 STUDY SCHEDULE

The anticipated schedule is to conduct the initial office-based analysis in May-June 2016, with subsequent field surveys in August/September 2016 for gravel mapping and gravel quality assessments. Mapping of potentially suitable spawning gravel will occur over two separate five-day field trips. Permeability sampling will occur over one three-day field trip to be conducted after the gravel mapping is completed. A draft report will be provided to the Technical Committee in November 2016 with a final report to be included in the February 2017 Updated Study Report.

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LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

FISH PASSAGE FACILITIES ALTERNATIVES ASSESSMENT
WATER TEMPERATURE SUBCOMMITTEE CONFERENCE CALL

SEPTEMBER 15, 2016

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Water Temperature Criteria Subcommittee Conference Call

Thursday, September 15, 2016
1:00 pm to 3:00 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	Allison Boucher	Tuolumne River Conservancy
2	Steve Boyd	Turlock Irrigation District
3	Paul Bratovich	HDR, consultant to the Districts
4	Jean Castillo	National Marine Fisheries Service
5	Greg Dias	Modesto Irrigation District
6	Jesse Deason	HDR, consultant to the Districts
7	John Devine	HDR, consultant to the Districts
8	Art Godwin	Turlock Irrigation District
9	Andy Gordus	California Department of Fish and Wildlife, Fresno
10	Chuck Hanson	Hanson Environmental, consultant to the Districts
11	Jonathan Knapp	City and County of San Francisco
12	Patrick Koepele	Tuolumne River Trust
13	Bao Le	HDR, consultant to the Districts
14	Ellen Levin	City and County of San Francisco
15	Lonnie Moore	Private citizen
16	Gretchen Murphey	California Department of Fish and Wildlife
17	Bill Paris	Modesto Irrigation District
18	Bill Sears	City and County of San Francisco
19	Chris Shutes	California Sportfishing Protection Alliance
20	Ron Yoshiyama	City and County of San Francisco

On September 15, 2016, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the first Water Temperature Criteria Subcommittee (Temperature Subcommittee) conference call for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework. This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials.

Mr. Bao Le (HDR, consultant to the Districts) welcomed meeting attendees. Mr. Le said meeting materials for this call are available on the La Grange Project licensing website. There are three documents: (1) meeting agenda, (2) Temperature Subcommittee draft process and schedule, and (3) water temperature criteria matrix. Mr. Le said the process and schedule document is meant to provide a draft description of the purpose of the Temperature Subcommittee and what the Temperature Subcommittee will accomplish. Mr. Le said the water temperature criteria matrix is the result of an action item the Districts had from Workshop No. 5, held on May 19, 2016, to develop a document summarizing what water temperature criteria were developed for the Yuba River, as well as what criteria were developed for other potentially relevant programs in the Central Valley.

Mr. Le reviewed the meeting agenda and the meeting objectives. Mr. Le asked if there are any questions. There were none.

Mr. Paul Bratovich (HDR) reviewed the draft process and schedule document. Mr. Bratovich said evaluating thermal habitat suitability is a fundamental component in determining the feasibility of a reintroduction program, especially for anadromous salmonids. Mr. Bratovich added that evaluating water thermal habitat suitability could be considered as an appropriate initial step in evaluating physical habitat suitability or availability because if habitat is not thermally suitable then it will not be suitable from other habitat perspectives. Mr. Bratovich said the process and schedule document briefly discusses why the Temperature Subcommittee was formed and the purpose of the group. The document also describes what work the Temperature Subcommittee will accomplish and provides an implementation schedule. By December 2016, the goal is to have a technical document that evaluates thermal habitat suitability for reintroduction purposes. Mr. Bratovich noted there is a lot to accomplish in a relatively short amount of time.

Mr. Bratovich said the Temperature Subcommittee needs to establish the purpose of the proposed activities. The purpose could be as simple as establishing the technical basis for evaluating temperature regimes in different reaches of the Tuolumne River. Mr. Bratovich said drilling down to specific objectives will help frame exactly what the Temperature Subcommittee will do and how it will be done. To evaluate thermal habitat suitability, the Temperature Subcommittee must first confirm target species being considered for reintroduction, life stage periodicities, what river reaches should be considered, and at what times temperature criteria are applicable.

Mr. Le said some work has already been done to establish an area of consideration and target species and life stage periodicities. Fieldwork for the Upper Tuolumne River Basin Fish Migration Barriers Study is nearing completion and total barriers have been identified in some of the tributaries and could be used to help identify evaluation reaches. Mr. Le said relevant information on proposed species and some life stage periodicity information is also available in the Fish Passage Facilities Assessment Technical Memorandum (TM) No. 1 (available here on the La Grange Project licensing website). Mr. Le noted that although this document was provided to licensing participants for review in fall 2015 and identified additional relevant information needs, the Districts have not received any feedback on TM No. 1.

Mr. Bratovich said he has been involved in several processes similar to this one, and in these other processes it had been very helpful at the beginning of the process to produce a glossary of terms. Mr. Bratovich said terms related to thermal habitat suitability, such as “optimal”, are often interpreted to mean different things by different individuals. A glossary of terms helps ensure all members of the team are speaking the same language. Mr. Le said the Districts will develop a glossary of terms.

Mr. Bratovich said that after the purpose of the Temperature Subcommittee is established, the next step is to undertake a comprehensive literature review. Mr. Bratovich said some comprehensive reviews of information in the Central Valley have already been completed. There is a lot of information available in the Central Valley as well as in the rest of California and the Pacific Northwest. Mr. Bratovich said a literature review completed by the Yuba Salmon Forum (YSF) contains over 100 references and this literature review would be a good basis to start this effort. This group will also want to include site-specific data, if available, for the Tuolumne River as well.

Mr. Bratovich said once the literature review is completed, the next step is to turn the information collected into a suite of water temperature index values that indicate suitability for reintroduction purposes by such variables as species, run, and life stage. Once water temperature index values are created, the Temperature Subcommittee will need to determine what metrics will be used. There are many different types of metrics, such as maximum weekly average temperature (MWAT) and seven day average daily maximum (7DADM). The literature review will produce a number of different options to support further discussion. Once the Temperature Subcommittee decides on a metric, thermal habitat suitability will be evaluated using data produced by the Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study.

Mr. Le asked if anyone would like to share additional thoughts regarding the purpose of the Temperature Subcommittee or the overview document. Mr. Chris Shutes (California Sportfishing Protection Alliance) said a lot of the activities proposed for the Temperature Subcommittee were addressed previously in the YSF process. Mr. Shutes said many individuals on this conference call participated in that process. Mr. Shutes noted that the YSF had a lot of stakeholder buy-in. Mr. Bratovich agreed with this point. Mr. Shutes suggested that the document prepared for the YSF entitled *Water Temperature Considerations for Yuba River Basin Anadromous Salmonid Reintroduction Evaluations* be distributed to the Temperature Subcommittee for review. The Temperature Subcommittee can determine how much can be adapted for this process. We can also walk through how YSF decisions were made and why, and this may help the process for the Tuolumne River move along quicker and be more cost-effective. Mr. Le said that is a good point and part of the rationale for including Mr. Bratovich in this process was his YSF experience. Mr. Le said the Districts see the YSF serving as a foundation for the work to be done here and using the available information from that process seems prudent as a means to avoid "reinventing the wheel".

Mr. Le asked if there are any questions about the overall process or the suite of objectives. There were none.

Mr. Le said the implementation schedule laid out in the overview document is fairly aggressive. The goal is to complete all objectives by the end of 2016. The end product will be a technical document summarizing the findings.

Mr. Le said the Districts had an action item from Workshop No. 5 to summarize water temperature criteria from other processes in the Central Valley. This information is summarized in the water temperature criteria matrix. Mr. Le noted that based on the four or five processes summarized in the matrix, there is quite a bit of variation among watersheds regarding criteria, metrics, and compliance. Mr. Le added that the matrix is not intended to be an endorsement by the Districts of any one process in particular. Dr. Chuck Hanson (Hanson Environmental, consultant to the Districts) added that the purpose of the matrix is to facilitate discussion and provide a central source of information. The matrix summarizes information available in technical reports and various other sources related to water temperature criteria on the American River, Feather River, San Joaquin River, Shasta River, and Yuba River developed for FERC processes, State Board processes, and other processes. The document also summarizes EPA (2003) criteria to provide context for federal river-specific criteria. Dr. Hanson said the matrix is a living document that can serve as a cornerstone to help define temperature criteria from a suitability perspective as well as a sub-optimal perspective.

Mr. Le asked if there are any comments about the matrix and if individuals know of additional rivers or reaches to add to matrix. He also asked if individuals think the matrix is informative. Ms. Jean Castillo (National Marine Fisheries Service [NMFS]) said she thinks the matrix is very informative, especially since she is new to the area. Ms. Castillo said she thinks a glossary of terms is a great idea. She added that a list of acronyms would also be helpful. Mr. Le said the Districts will prepare an acronym list in addition to a glossary of terms.

Mr. Le asked the individuals on the call to review the matrix. He said the Districts welcome any comments, thoughts, or additions to the document. Mr. Le reiterated that the matrix is a living document.

Regarding the literature review, Mr. Le said information collected by previous review efforts will serve as a valuable starting place. It is now time to get feedback on what management agency literature and documents must still be reviewed. Mr. Bratovich added that basin-specific information must also be reviewed.

Mr. Le said the objective of the next Temperature Subcommittee call will be to present and discuss the results from the literature review. Prior to the next call, Mr. Le asked that members of the Temperature Subcommittee provide any information they think is relevant to the literature review, whether or not it may have already been reviewed as part of the YSF literature review. Mr. Le said any information should be sent to Ms. Rose Staples (HDR) at rose.staples@hdrinc.com.

Mr. Le said there is also a need to establish the species of interest. At this time, fall-run Chinook, spring-run Chinook, and steelhead are being considered the target species of interest. However, Mr. Le noted that the Districts are skeptical about whether fall-run Chinook should still be considered a species of interest. At this time, the Districts will keep fall-run Chinook as part of the evaluation but wanted to make this point about their concerns. The Districts welcome feedback on this topic. Ms. Castillo said she will check back with her NMFS colleagues about this. Ms. Gretchen Murphey (California Department of Fish and Wildlife [CDFW]) asked what species are being considered by the Reintroduction Goals Subcommittee. Mr. Le said until further feedback is received, the Reintroduction Goals Subcommittee is considering all three as species of interest. Mr. Lonnie Moore (private citizen) said he recently filed a paper on the FERC docket related to this topic. The paper summarizes historical information and previous studies about the historical presence of fall-run Chinook, spring-run Chinook, and steelhead in the Tuolumne River.

Mr. Le asked if there are any comments or questions about the literature review. There were none.

Ms. Murphey asked if an updated Don Pedro Project Swim Tunnel Study Report has been released. Mr. John Devine (HDR) said an updated study report was recently filed with FERC and should be appearing in the FERC docket soon. He said he would be happy to send a link to Ms. Murphey if she is unable to find it. [*On September 20, 2016, Mr. Devine emailed Ms. Murphey to explain he had been mistaken and an updated Swim Tunnel Study Report had not been filed with FERC. Mr. Devine said on September 6, 2016, the Districts received comments on the January 2015 draft Swim Tunnel Study Report from CDFW. The Districts will file the final report once the Districts respond to and address CDFW's comments.*]

Mr. Le said the Districts would like to have the next Temperature Subcommittee call in mid-October. Between now and the next call, Temperature Subcommittee members will plan to provide information to add to the literature review and the Districts will develop an acronym list and glossary of terms in addition to updating the body of literature relevant to temperature suitability criteria. Mr. Le requested that feedback on the literature review be provided to Ms. Staples by Friday, September 23.

Meeting attendees discussed dates for the next Temperature Subcommittee call. Mr. Le said the Districts will send out a Doodle poll for October 11, 12, 14, 17 and 18. The Districts will also send out notes from today's call.

Ms. Castillo requested that Mr. Le send her a copy of TM. No.1. Mr. Le said he will send this.

Dr. Ron Yoshiyama (City and County of San Francisco) requested that the year be added to future meeting agendas and meeting notes. Mr. Le said the year will be added to future meeting documents.

ACTION ITEMS

1. The Districts will distribute *Water Temperature Considerations for Yuba River Basin Anadromous Salmonid Reintroduction Evaluations* to the Temperature Subcommittee for review.

2. The Districts will prepare a glossary of terms.

3. The Districts will prepare an acronym list.

4. Ms. Castillo said she will check back with her NMFS colleagues about species for consideration.

5. Temperature Subcommittee members will provide feedback on information that should be considered as part of updating the existing YSF literature review by Friday, September 23.

6. The Districts will send out a Doodle poll for the next Temperature Subcommittee call. (complete)

7. The Districts will send out meeting notes. (complete)

8. Mr. Le will send Ms. Castillo a copy of TM No. 1. (complete)

9. The Districts will add the year to future meeting documents.

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Water Temperature Criteria Subcommittee Conference Call

Thursday, September 15, 1:00 pm to 3:00 pm
Conference Line: 1-866-583-7984; Passcode: 814-0607

Meeting Objectives:

1. Review and discuss Water Temperature Criteria Subcommittee Overview.
2. Develop subcommittee “purpose” statement, specific objectives and confirm subcommittee schedule.
3. Review and discuss Water Temperature Criteria Matrix for select Central Valley reintroduction/fish passage programs (Districts’ action item).
4. Discuss available existing information and identify scope for additional water temperature literature review.

TIME	TOPIC
10:00 am – 10:15 am	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
10:15 am – 10:45 am	Water Temperature Criteria Subcommittee (All) a. Why is it important? (Districts) b. Discuss Subcommittee Overview Document (Bao Le/Paul Bratovich)
10:45 am – 11:15 am	Water Temperature Criteria Subcommittee (All) a. Develop Purpose Statement and Objectives (Paul Bratovich) b. Confirm Schedule (Bao Le)
11:15 am – 11:50 am	Temperature Criteria Matrix and Literature Review Discussion (All) a. Temperature Criteria Matrix (Chuck Hanson) b. Existing Information and Additional Need for a Literature Review (Paul Bratovich)
11:50 am – 12:00 pm	Next Steps (All) a. Schedule next call and agenda topics b. Action items from this call

La Grange Hydroelectric Project Licensing (FERC No. 14581)
Upper Tuolumne River Reintroduction Assessment Framework
Water Temperature Subcommittee – Draft Process and Schedule

Overview and Subcommittee Purpose

Water temperature considerations are a primary component of assessing any potential anadromous salmonid reintroduction effort. As such, the Upper Tuolumne River Reintroduction Assessment Framework Plenary Group has established a water temperature subcommittee to begin investigating water temperature considerations pertinent to anadromous salmonid reintroduction opportunities in the accessible reaches of the Tuolumne River upstream of Don Pedro Reservoir (Upper Tuolumne River).

The subcommittee, working in collaboration, is anticipated to address a suite of specific tasks related to the investigation of water temperature considerations, including the following:

- Establish the purpose ("charter") for the water temperature subcommittee.
- Evaluate the need for and if appropriate, conduct a comprehensive literature review of lifestage-specific water temperature relationships for target species of interest (TBD by the subcommittee).
- Identify a suite of water temperature index (WTI) values representing summarization of the literature review.
- Select water temperature criteria for each species-specific lifestage for reintroduction evaluation in the Upper Tuolumne River.
- Identify the water temperature evaluation methodological approach including metrics and application to monitoring and/or modeling data.
- Conduct species and lifestage-specific water temperature evaluations.
- Prepare a technical document reporting the results for all of the above objectives.

Subcommittee Purpose

An initial step in the process will be to establish the purpose for the subcommittee. Once a purpose has been established, detailed subcommittee objectives will also be identified

Comprehensive Literature Review and Water Temperature Index Values

For each species under consideration, an evaluation will be conducted to determine whether a comprehensive review of available literature to identify lifestage-specific water temperature index values is appropriate. For species requiring a literature review, this information may be used in the evaluation of thermally suitable habitat for reintroduction of anadromous salmonids in the Upper Tuolumne River. The thermal requirements of anadromous salmonids, in particular Chinook salmon and steelhead, have been extensively studied in California and elsewhere. The literature review will draw upon regional research, and if available, site specific information to inform the selection of WTI values to be used in the subcommittee's evaluation of the water temperature-related reintroduction potential in the reaches of the Upper Tuolumne River. Other considerations regarding thermal suitability may also be considered such as local adaptation, genetics, and information on potential source populations of target species.

Criteria Selection

In order to support a subsequent evaluation of thermally suitable habitat for selected target species in the Upper Tuolumne River, the subcommittee will collaboratively need to identify, define, and select appropriate water temperature criteria (e.g., WTIs, metric(s), lifestages, temporal distributions, etc.) based upon the available information resulting from the literature review and relevant site-specific information from Tuolumne River studies, if available.

Selecting and Implementing an Evaluation Approach

For the evaluation of thermally suitable habitat for potential reintroduction of anadromous salmonids into the upper Tuolumne River Basin, it is anticipated that water temperature modeling and/or monitoring will be applied for a comparison among selected rivers and reaches in the Basin. Concurrent with subcommittee activities, the Upper Tuolumne River Temperature Monitoring and Modeling Study is being implemented in support of the La Grange Hydroelectric Project licensing. Because this study has been approved by licensing participants, including those participating on the subcommittee, it is proposed that the model being developed as part of this study be used to support the thermally suitable habitat evaluation.

Reporting

As noted above, results of subcommittee activities will be summarized in a technical document. The technical document will undergo subcommittee review and be provided to the Upper Tuolumne River Reintroduction Assessment Framework Plenary Group when complete.

<u>Implementation Schedule</u>

It is envisioned that the aforementioned water temperature considerations will be addressed by the subcommittee through a series of subcommittee meetings corresponding to a schedule for the completion of key steps. At each step of the way (i.e., each meeting) the objective is to obtain agreement/acceptance of the topic addressed. A schedule is as follows:

- September 15, 2016
  - Convene subcommittee and develop "purpose" statement and objectives.
  - Review available, existing information and identify scope for additional literature review of lifestage-specific water temperature relationships.
  - Confirm subcommittee schedule.
- Early October 2016
  - Present/discuss results of literature review.
  - Identify a suite of WTI values representing a summarization of the literature review.
- Mid- to late October 2016
  - Select water temperature criteria for each species-specific lifestage for reintroduction evaluation.
    - Existing water temperature guidelines/standards.
    - Site-specific WTIs.
- November 2016

- Identify the water temperature evaluation methodological approach.
  - Water temperature metrics.
  - Metrics application to water temperature model and/or monitoring data.
- Conduct species and lifestage-specific evaluations.
- Prepare draft technical document reporting the results for all of the above objectives.

- December 2016
  - Prepare a final technical document.

Water Temperature Criteria for Select California Central Valley River Systems

Project	Species	Life Stage	Water Temperature	Timeframe	Location	Metric	Source(s)	Notes
Lower American River	Steelhead	Juvenile (rearing)	65°F or less (at the Watt Avenue Bridge) If analysis during the formulation of the Temperature Plan indicates that meeting a 65ºF water temperature target will prematurely exhaust the available cold water in Folsom Reservoir, the target water temperature in the summer may be increased by 1ºF increments up to 68ºF	May 15 – October 31	Watt Avenue Bridge	Daily average temperature (DAT)	Water Forum 2006 Water Forum 2007 NMFS 2009, as amended 2011, Biological Opinion	
	Fall-run Chinook	Adult (spawning) Egg (incubation)	60°F or less 56°F or less	As early in October as possible As early in November as possible	Hazel Avenue Hazel Avenue			
Lower Feather	Spring-run Chinook and steelhead	Not identified	56°F	January - April	Robinson Riffle	Daily mean	SWRCB 2010	
			56-63°F [1]	May 1-15				
			63°F	May 16 - August				
			63-58°F [2]	September 1-8				
			58°F	September 9-30				
			56°F	October - December				
San Joaquin	Fall-run Chinook and steelhead	Adult	64°F	September	Above Merced	7-day average of the daily maximum water temperature (7DADM)	CALFED 2009	Per modeling report (CALFED 2009): "It should be emphasized that the stakeholders agreed that the Panel criteria should only serve as a means for comparing simulated alternatives and should not be construed as an agreed upon criteria in establishing temperature policy in the basin. "
		Egg (incubation)	55°F	October - December	Above Merced			
		Juvenile (rearing)	61°F	January – April 15	Above Tuolumne Above Stanislaus (first two weeks of April)			
		Smolt	57°F	April 16 - May	Above Stanislaus			
		Juvenile (rearing)	61°F	June - August	Above Stanislaus (first week of June) Mossdale (2nd week of June – third week of July) Vernalis (forth week of July – August)			

[1] Indicates a period of transition from the first temperature to the second temperature.
[2] Indicates a period of transition from the first temperature to the second temperature.

Project	Species	Life Stage	Water Temperature	Timeframe	Location	Metric	Source(s)	Notes
Shasta	Winter-run Chinook	Egg/Alvin	56°F or less	May 15 – September 30	Between Balls Ferry and Bend Bridge	Daily average temperature (DAT)	BOR 2016 NMFS 2016	Scenarios identified to manage water to 55°F or less (7DADM) through the winter run spawning area.
	Spring-run Chinook	Egg/Alvin	56°F or less	October				
Yuba	Steelhead	Adult (migration)	64°F[3] / 68°F[4]	August – March	Smartsville, Daguerre Point Dam, Marysville	Maximum weekly average temperature (MWAT) Average daily water temperature (ADT) and monthly exceedance distributions	River Management Team (RMT) 2013 Bratovich et al. 2012	
		Adult (holding)	61°F / 65°F	August – March	Smartsville, Daguerre Point Dam, Marysville			
		Adult (spawning)	54°F / 57°F	January – April	Smartsville and Daguerre Point Dam			
		Egg (incubation)	54°F / 57°F	January – May	Smartsville and Daguerre Point Dam			
		Juvenile (rearing and downstream movement)	65°F / 68°F	Year-round	Daguerre Point Dam and Marysville			
		Smolt (emigration)	52°F / 55°F	October – April 15	Daguerre Point Dam and Marysville			
	Spring-run Chinook	Adult (immigration)	64°F / 68°F	April – September	Smartsville, Daguerre Point Dam, Marysville			
		Adult (holding)	61°F / 65°F	April – September	Smartsville, Daguerre Point Dam, Marysville			
		Adult (spawning)	56°F / 58°F	September – October 15	Smartsville			
		Egg (incubation)	56°F / 58°F	September – December	Smartsville			
		Juvenile (rearing and downstream movement)	61°F / 65°F	Year-round	Daguerre Point Dam, Marysville			
		Smolt (emigration)	63°F / 68°F	October – May 15	Daguerre Point Dam, Marysville			
	Fall-run Chinook	Adult (immigration and staging)	64°F / 68°F	July – December	Daguerre Point Dam and Marysville			
		Adult (spawning)	56°F / 58°F	October – December	Smartsville and Daguerre Point Dam			
		Egg (incubation)	56°F / 58°F	October – March	Smartsville and Daguerre Point Dam			
		Juvenile (rearing and downstream movement)	61°F / 65°F	December 15 – June	Daguerre Point Dam and Marysville			

[3] Upper optimum water temperature index (WTI).
[4] Upper tolerance WTI.

Project	Species	Life Stage	Water Temperature	Timeframe	Location	Metric	Source(s)	Notes
EPA	Salmon and trout	Adult (migration)	<64°F <68°F generally in lower part of river basins that likely reach temp naturally, if there are cold-water refugia	Unspecified (species specific)	NA	7DADM	EPA 2003	Note: source is EPA Region 10 Guidance for Pacific Northwest state and Tribal Temperature Water Quality Standards.
	Salmon and trout	Adult (spawning) Egg (incubation) Fry (emergence)	<55°F	Unspecified (species specific)	NA			
	Salmon	Juvenile (rearing)	<61°F	"Early year"	Mid- to upper river basin			"Core" juvenile rearing
	Salmon	Smolt	<59°F	Unspecified (species specific)	NA			
	Steelhead	Smolt	<57°F	Unspecified (species specific)	NA			
	Salmon and steelhead	Juvenile (rearing)	<64°F	"Late year"	Lower river basin			"Non-Core" juvenile rearing

Sources:

CALFED. 2009. San Joaquin River Basin, Water Temperature Modeling and Analysis. October 2009.

EPA (U.S. Environmental Protection Agency). 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. April.

NMFS (National Marine Fisheries Service). 2016. Sacramento River Temperature Management Plan concurrence letter. June 28, 2016.

SWRCB (State Water Resources Control Board). 2010. Water Quality Certification for Feather River, FERC Project No. 2100. Order 2010-0016.

SWRCB. 2016. Sacramento River Temperature Management Plan approval letter. July 8, 2016.

Water Forum. 2006. Lower American River Flow Management Standard. July 31, 2006.

Water Forum. 2007. Summary of the Lower American River Flow Management Standard. January 2007.

Yuba Accord River Management Team. 2013. Yuba Accord Monitoring and Evaluation Program. Draft Interim Report. April 2013

Bratovich et al. 2012. Water Temperature Considerations for Yuba River Basin Anadromous Salmonid Reintroduction Evaluations. October 2012.

References:

Boles, G. L., S. M. Turek, C. C. Maxwell, and D. M. McGill. 1988. Water Temperature Effects on Chinook Salmon (*Oncorhynchus Tshawytscha*) With Emphasis on the Sacramento River: A Literature Review. California Department of Water Resources.

EPA. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. April.

Myrick, C.A. and J.J. Cech. 2001. Temperature effects on Chinook salmon and steelhead: A review focusing on California's Central Valley populations. Department of Wildlife, Fish, and Conservation Biology, University of California. Davis.

Myrick, C.A. and J.J. Cech, Jr. 2004. Temperature effects on juvenile anadromous salmonids in California's Central Valley: What don't we know? Reviews in Fish Biology and Fisheries 14: 113-123.

NMFS. 2004. Biological Opinion on the Long-Term Central Valley Project and State Water Project Operations Criteria and Plan.

NMFS. 2009. Biological Opinion for the Coordinated Long-Term Operation of the Central Valley Project (CVP) and State Water Project (SWP).

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

FISH PASSAGE FACILITIES ALTERNATIVES ASSESSMENT
WATER TEMPERATURE SUBCOMMITTEE CONFERENCE CALL

OCTOBER 14, 2016

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Water Temperature Criteria Subcommittee Conference Call

Friday, October 14, 2016
1:00 pm to 3:00 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	Steve Boyd	Turlock Irrigation District
2	Paul Bratovich	HDR Inc., consultant to the Districts
3	Jean Castillo	National Marine Fisheries Service
4	Jesse Deason	HDR Inc., consultant to the Districts
5	John Devine	HDR Inc., consultant to the Districts
6	Greg Dias	Modesto Irrigation District
7	Tim Heyne	California Department of Fish and Wildlife
8	Bao Le	HDR Inc., consultant to the Districts
9	Ellen Levin	City and County of San Francisco
10	Lonnie Moore*	Private citizen
11	Gretchen Murphey	California Department of Fish and Wildlife
12	Bill Paris	Modesto Irrigation District
13	Bill Sears	City and County of San Francisco
14	Chris Shutes	California Sportfishing Protection Alliance
15	John Wooster	National Marine Fisheries Service
16	Ron Yoshiyama	City and County of San Francisco

* Joined call about 15 minutes late.

On October 14, 2016, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the second Water Temperature Criteria Subcommittee (Temperature Subcommittee) conference call for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials.

Mr. Bao Le (HDR, consultant to the Districts) welcomed meeting attendees. Mr. Le said the purpose of the Temperature Subcommittee is to establish a technical basis for evaluating thermal suitability for the purposes of the Framework. As background, Mr. Le said the Upper Tuolumne River Basin Fish Migration Barriers Study Progress Report included several statements about thermal suitability in the upper Tuolumne River. In the agency's comments on the report, the National Marine Fisheries Service (NMFS) stated that such statements were premature. Given that no thermal suitability criteria had yet been decided on by licensing participants, the Districts agreed with NMFS's comments that statements about thermal suitability were premature. Subsequently, the topic of thermal suitability criteria was discussed by the Plenary Group. As part of implementing the Framework, the Plenary Group decided to create the Temperature Subcommittee.

Mr. Le summarized discussions at the September 15 Temperature Subcommittee call. Mr. Le said on the call, licensing participants discussed the temperature criteria matrix prepared by the Districts. Mr. Le said the water temperature criteria matrix was the result of an action item the Districts had from Workshop No. 5 to develop a document summarizing what water temperature values were developed for the Yuba River, as well as what information were developed for other potentially relevant programs in the Central Valley. Mr. Le said at the September 15 conference call, licensing participants decided the best path forward was to first update the literature review completed by the Yuba Salmon Forum (YSF). The literature review would be updated to include results from recent studies as well as site-specific information about the Tuolumne River. Mr. Le said on the first Temperature Subcommittee call, the Districts requested that any feedback on what information or data should be added to update the YSF literature review be provided by September 23. Mr. Le said no feedback was received.

Mr. Bratovich (HDR) said the YSF completed a comprehensive literature review of Central Valley temperature experiments and field observations. Mr. Bratovich said the literature review contains over 100 references and that many of the individuals on this call participated in the YSF. Mr. Bratovich noted that where data needed to be augmented, the review extended to information collected in the Pacific Northwest. Based on the information collected, the YSF developed water temperature index values for each life stage of spring-run Chinook and steelhead. Ultimately, the YSF identified upper optimal and upper tolerable index values for each life stage. Maximum weekly average temperature (MWAT) was used as the metric.

Mr. Le said the Districts have updated the YSF literature review, and this draft was provided to licensing participants yesterday. The foundation of the document is Appendix A of "Water Temperature Considerations for Yuba River Basin Anadromous Salmonid Reintroduction Evaluations" (Bratovich et al. 2012). Additional information has been added, including site-specific information about the Tuolumne River collected as part of the Don Pedro Project relicensing proceeding and data collected for the temperature criteria matrix (provided to Temperature Subcommittee members prior to the September 15 call).

Mr. Bill Sears (City and County of San Francisco) asked what is the difference between "water temperature criteria" and "index values". Mr. Bratovich said there is a lot of phraseology that can influence how data may be interpreted or understood. Some literature references water temperature "guidelines". EPA (2003) refers to both "criteria" and "guidelines". Mr. Bratovich said "index values" is a term used to reference specific water temperature values that are indicative of a specific physiological response. Mr. Bratovich said some of the references collected in the YSF literature review use Celsius while others use Fahrenheit. Some references provided values to a tenth of a degree while others used whole integers. Mr. Bratovich said YSF chose whole-integer "values of consideration" for evaluating thermal suitability.

Ms. Gretchen Murphey (California Department of Fish and Wildlife) requested that the Literature Review Summary provide values in Celsius as well as Fahrenheit. Mr. Le said future iterations of the document will provide values in both Celsius and Fahrenheit.

Mr. Le said the YSF literature review identified life stage specific temperature information by species (i.e., steelhead and Chinook) although fall-run and spring-run Chinook values were grouped together. Mr. Bratovich noted that separate holding values for spring-run Chinook were also established.

Mr. Le asked if anyone on the call has looked at the updated literature review. Ms. Murphey said she reviewed part of the document. Mr. Chris Shutes (California Sportfishing Protection Alliance) said he also reviewed part of the document.

Mr. Shutes noted that the the Swim Tunnel Study Report is included in the updated literature review. Mr. Shutes said he is trying to understand how that study is relevant to thinking about reintroduction. Mr. Shutes asked how the Districts see the study as being relevant for the purposes of evaluating reintroduction in the upper Tuolumne River. Mr. Le said the Don Pedro Project relicensing studies included several studies that seemed natural to include in the updated literature review, including the Swim Tunnel Study and the two fish model studies, W&AR-06 and W&AR-10. Mr. Le said in general, studies were added to the literature review if they provided site-specific data. Once the literature review is complete, the next step would be to discuss what implications these studies may have for reintroduction. Mr. John Devine (HDR) added that site-specific data on the thermal tolerance of juvenile *O. mykiss* seemed appropriate regarding possible relevance to temperature benchmarks on the Tuolumne River.

Mr. Shutes asked if the Districts would like comments on what still should be added to the literature review or comments on the relevance and usefulness of the studies included in the literature review for evaluating reintroduction. Mr. Le stated that although comments were due on September 23 and none were received, comments are still welcome. Mr. Le said at a minimum, individuals should provide any key studies or data or other relevant information that may be missing from the literature review. Comments on how specific studies included in the literature review may or may not be relevant to considering reintroduction would also be valuable.

Meeting attendees discussed when comments on the updated literature review should be provided. Comments are due to Ms. Rose Staples (HDR) at rose.staples@hdrinc.com by November 1, 2016.

Mr. Shutes said the Literature Review Summary is currently in the form of a narrative, with the temperature values sprinkled throughout. In the YSF Planning Document, the numbers were displayed in tables. It may be useful to display the numbers in both a narrative form and in tables. Ms. Jean Castillo (National Marine Fisheries Service [NMFS]) agreed that a table would be helpful. Mr. John Wooster (NMFS) asked what would be the difference between the table prepared for the first Temperature Subcommittee call and this new table. Mr. Le replied that the matrix discussed on the first call summarized temperature values identified in several Central Valley reintroduction or salmon management programs. This new table would display numbers pulled from the literature review, which would also include the numbers from the matrix.

Mr. Le said the narrative provides a lot of helpful background on the nature and context of the studies. However, a table summarizing relevant numbers could be added to the narrative section of each life stage. Meeting attendees agreed with this approach.

Mr. Wooster asked if there is a central location where the references are stored. Mr. Le and Mr. Bratovich confirmed copies of all the references are available. Mr. Wooster asked if copies of all the references, or select references, can be shared with the group. Mr. Le said he can provide any references that may be of interest, if folks first send him a list of the references they would like to review. Mr. Wooster said he would provide a list of the references he would like.

Mr. Le said the next Temperature Subcommittee call will be in early- or mid-November to discuss what water temperature index values should be used and to start establishing a technical basis for evaluating thermal suitability. Meeting attendees discussed the date for the next Temperature Subcommittee call. Mr. Le said he will send out a Doodle poll with possible meeting dates. Mr. Le said prior to the next call, the Districts will provide an updated literature review and responses to any comments received on the updated literature review.

Mr. Le asked if there were any comments on the glossary of terms. Ms. Castillo said the glossary was helpful. Mr. Le asked meeting attendees to review the glossary of terms and provide comments on what additional terms should be added by November 1, 2016.

ACTION ITEMS

1. Future iterations of the literature review summary will provide values in both Celsius and Fahrenheit.

2. Licensing participants will provide comments on the updated literature review and glossary of terms to Ms. Rose Staples at rose.staples@hdrinc.com by November 1, 2016.

3. The Districts will update the literature review narrative to include tables at the end of each life stage section that summarize the relevant temperature values identified in the associated subsection.

4. Mr. Wooster will send Ms. Rose Staples a list of references that he would like to review and Ms. Rose Staples will send him those references.

5. Mr. Le will send out a Doodle poll with possible meeting dates. (complete)

6. Prior to the next Temperature Subcommittee call, the Districts will send out an updated literature review and responses to any comments received on the updated literature review.

7. The Districts will send out meeting notes from this call. (complete)

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Water Temperature Criteria Subcommittee Conference Call

Friday, October 14, 2016, 1:00 pm to 3:00 pm

Conference Line: 1-866-583-7984; Passcode: 8140607

Meeting Objectives:

1. Review and discuss water temperature literature review summary, glossary of terms/acronym list (Districts' action item).
2. Discuss potential water temperature index (WTI) values that may be relevant to the Upper Tuolumne River Reintroduction Assessment Framework.
3. Discuss next steps and schedule for WTI selection.

TIME	TOPIC
1:00 pm – 1:15 pm	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
1:15 pm – 2:45 pm	Water Temperature Literature Review Summary, Glossary of Terms/Acronym List (All) a. Summary of documents (Districts) b. Subcommittee discussion and relevance to selection of WTI values (All)
2:45 pm – 3:00 pm	Next Steps (All) a. Schedule next call and agenda topics b. Action items from this call

UPPER TUOLUMNE RIVER REINTRODUCTION ASSESSMENT FRAMEWORK
WATER TEMPERATURE CRITERIA SUBCOMMITTEE

LIFESTAGE-SPECIFIC WATER TEMPERATURE BIOLOGICAL EFFECTS AND INDEX TEMPERATURE VALUES

Literature Review Summary

INTRODUCTION

The La Grange Hydroelectric Project (La Grange Project), owned and operated by the Turlock Irrigation District and Modesto Irrigation District (TID/MID), is currently undergoing the Federal Energy Regulatory Commission (FERC) Integrated Licensing Process. As part of this process, the Districts are implementing a FERC-approved Fish Passage Facilities Alternatives Assessment which consists of developing general design criteria and design considerations applicable to upstream and downstream fish passage facilities at the La Grange Project. Design criteria and considerations include such items as site-specific physical and operational parameters; applicable regulatory requirements; National Marine Fisheries Service (NMFS),U.S. Fish and Wildlife Service (USFWS), and California Department of Fish and Wildlife (CDFW) biological and engineering design criteria; site-specific biological/habitat information relevant to the sizing and configuration of facilities; and any other information gaps that may affect siting, sizing, general design parameters, capital cost, and operating requirements of potential fish passage facilities.

To make certain that detailed, site-specific information is available to support and adequately inform decisions regarding fish reintroduction and fish passage, TID, MID, and licensing participants came to a consensus on the need for and utility of an Upper Tuolumne River Reintroduction Assessment Framework (Framework). The Framework is intended to provide a comprehensive, collaborative, and transparent approach for evaluating the full range of potential issues associated with the future reintroduction of anadromous fish to the upper Tuolumne River. In addition to considering aspects of the technical feasibility of building and operating fish passage facilities, the Framework considers the interrelated issues of ecological feasibility, biological constraints, economics, regulatory implications, and other considerations of reintroduction. Elements of the Framework are interconnected, with fish passage construction and operational requirements needing to properly reflect biological constraints, ecological considerations, and economic cost:benefit assessments.

Water temperature considerations are a primary component of assessing any potential anadromous salmonid reintroduction effort. In support of the Framework, the Districts and licensing participants established a Water Temperature Criteria Subcommittee to begin investigating water temperature considerations pertinent to anadromous salmonid reintroduction opportunities in the accessible reaches of the Tuolumne River upstream of Don Pedro Reservoir (upper Tuolumne River). On September 15, 2016, the Districts hosted the first conference call for the Water Temperature Criteria Subcommittee (draft meeting notes from this call were distributed on October 3 for a 30-day comment period). On the conference call, attendees discussed the need for a comprehensive literature review of regional and site-specific information to inform the selection of water temperature index values to be used in an evaluation of the water temperature-related reintroduction potential in the reaches of the upper Tuolumne River. Meeting attendees agreed that the literature review performed for the Yuba Salmon Forum (Appendix A; Bratovich et al. 2012) to support the anadromous salmonid reintroduction assessment in this watershed coupled with site-specific temperature studies or data for the Tuolumne River, if available, would be a good basis for this effort. The following represents and updated literature review summary and is provided to the Water Temperature Criteria Subcommittee to support selection of water temperature index values for the Framework.

STEELHEAD LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Adult Immigration and Holding

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. Yuba County Water Agency (YCWA) *et al.* (2007) suggests that few studies have been published examining the effects of water temperature on either steelhead immigration or steelhead holding, and none of the available studies were recent (Bruin and Waldsdorf 1975; McCullough *et al.* 2001). The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid 50°F range, and that immigration will be delayed if water temperatures approach approximately 70°F. Water temperature index values of 52°F, 56°F, 61°F, 65°F and 70°F were chosen because they provide a gradation of potential water temperature effects, and the available literature provided the strongest support for these values.

Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of water temperature index values could not be achieved. We also used some pertinent information related to other salmonids (e.g., Chinook salmon). 52°F was selected as a water temperature index value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (McEwan and Jackson 1996; NMFS 2000; NMFS 2002), and "optimum" (Reclamation 1997a) water temperature for steelhead adult immigration. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value. 56°F was selected as a water temperature index value because 56°F represents a water temperature above which adverse effects to migratory and holding steelhead begin to arise (Bruin and Waldsdorf 1975; Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 50-59°F is referred to as the "preferred" range of water temperatures for California summer steelhead holding (Moyle *et al.* 1995). Whereas, water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter- run steelhead (USFWS 1995a). 65°F was selected as a water temperature index value because steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Additionally, over 93% of steelhead detections occurred in the 65.3-71.6°F range, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006) and/or may modify migration timing due to holding in coldwater refugia (High *et al.* 2006). 70°F was selected as the highest water temperature index value because the literature suggests that water temperatures near and above 70.0°F may result in a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001) and are water temperatures referred to as "stressful" to upstream migrating steelhead in the Columbia River (Lantz 1971 as cited in Beschta et al 1987). Further, Coutant (1972) found that the upper incipient lethal temperature (UILT) for adult steelhead was 69.8°F and temperatures between 73-75°F are described as "lethal" to holding adult steelhead in Moyle (2002).

As part of the Framework, TID and MID, in collaboration with stakeholders developed a table of established water temperature criteria from select salmon and steelhead programs in the Central Valley (Temperature Criteria Matrix; presented at the September 15, 2016 Water Temperature

Subcommittee conference call). The table was developed to support the Framework's Water Temperature Criteria Subcommittee whose purpose is to establish a technical basis to evaluate water temperature regimes for target anadromous salmonid reintroduction into the Tuolumne River upstream of Don Pedro Reservoir. For steelhead adult immigration, the Temperature Criteria Matrix identified 64°F in for the San Joaquin (CALFED 2009) and 64°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). For steelhead adult holding, the Temperature Criteria Matrix identified 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value) for the Yuba Reintroduction Assessment (Bratovich et al. 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 64°F (7DADM) for "salmon and trout" migration.

<u>Spawning and Embryo Incubation</u>

Relatively few studies have been published directly addressing the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979; Rombough 1988). Because anadromous steelhead and non-anadromous rainbow trout are genetically and physiologically similar, studies on non-anadromous rainbow trout also were considered in the development of water temperature index values for steelhead spawning and embryo incubation (Moyle 2002; McEwan 2001). From the available literature, water temperatures in the low 50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high 50°F range and above. Water temperatures in the 45-50°F range have been referred to as the "optimum" for spawning steelhead (FERC 1993).

Water temperature index values of 46°F, 52°F, 54°F, 57°F, and 60°F were selected for two reasons. First, the available literature provided the strongest support for water temperature index values at or near 46°F, 52°F, 54°F, 57°F, and 60°F. Second, the index values reflect a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead spawning and embryo incubation. Some literature suggests water temperatures ≤ 50°F are when steelhead spawn (Orcutt *et al.* 1968) and/or are optimal for steelhead spawning and embryo survival (FERC 1993; Myrick and Cech 2001; Timoshina 1972) and temperatures between 39-52°F are "preferred" by spawning steelhead (IEP Steelhead Project Work Team (no date); McEwan and Jackson 1996), a larger body of literature suggests optimal conditions occur at water temperatures ≤ 52°F (Humpesch 1985; NMFS 2000; NMFS 2001a; NMFS 2002; Reclamation 1997b; SWRCB 2003; USFWS 1995b). Further, water temperatures between 48-52°F were referred to as "optimal" (FERC 1993; McEwan and Jackson 1996; NMFS 2000) and "preferred" (Bell 1986) for steelhead embryo incubation. Therefore, 52°F was selected as the lowest water temperature index value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation life stage may reportedly occur above the 52°F water temperature index value.

54°F was selected as the next index value, because although most of the studies conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions, and conditions that cause negative effects to steelhead spawning and embryo incubation. Further, water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993). 57°F was selected as an index value because embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57.0°F. Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50% hatch under incubation temperatures ranging from 33.8°F to 60.8°F that demonstrated a two-fold increase in mortality for embryos incubated at 57.2°F, compared to embryos incubated at 53.6°F. In a laboratory study using gametes from Big Qualicum River, Vancouver Island, steelhead mortality increased to 15% at a constant temperature of 59.0°F, compared to less than 4% mortality at constant temperatures of 42.8°F, 48.2°F, and 53.6°F (Rombough 1988). Also, alevins hatching at 59.0°F were considerably smaller and appeared less well developed than those incubated at the lower temperature treatments. From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). Myrick and Cech (2001) similarly described water temperatures >59°F as "lethal" to incubating steelhead embryos, although FERC (1993) suggested that water temperatures exceeding 68°F were "stressful" to spawning steelhead and "lethal" when greater than 72°F.

As part of the Don Pedro Hydroelectric Project FERC relicensing process, the TID and MID conducted an *O. mykiss* Population Study (TID/MID 2014) for the Lower Tuolumne River below La Grange Diversion Dam. The goal of the study is to provide a quantitative population model to investigate the relative influences of various factors on the lifestage specific production of *O. mykiss in* the Tuolumne River including water temperature effects on population response for specific in-river lifestages. The study noted that although no literature information could be identified regarding upper temperature limits for spawning initiation, maximum temperature limits for spawning are assumed to be on the order of 15°C (59°F) inferred from egg mortality thresholds for resident *O. mykiss* (Velsen 1987) as well as steelhead (Rombough 1988). Similarly, for egg incubation, the model allowed for a broad range of flow and water temperature conditions using the completed model, an initial acute mortality threshold of 15°C (59°F) was included based upon a literature review by Myrick and Cech (2001).

For steelhead spawning and embryo incubation in the Yuba River, the Framework Temperature Criteria Matrix identified 54°F and 57°F for Upper Optimum and Upper Tolerable values, respectively (Bratovich *et al.* 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 55°F (7DADM) for "salmon and trout" spawning and egg incubation.

<u>Juvenile Rearing & Downstream Movement</u>

Water temperature index values were developed to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages. Some steelhead may rear in freshwater for up to three years before emigrating as yearling+ smolts, whereas other individuals move downstream shortly after emergence as post- emergent fry, or rear in the river for several months and move downstream as juveniles without exhibiting the ontogenetic characteristics of smolts . Presumably, these individuals continue to rear and grow in downstream areas (e.g., lower Feather River, Sacramento River, and Upper Delta) and undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are assessed in this Technical Memorandum using the fry and juvenile rearing water temperature index values.

The growth, survival, and successful smoltification of juvenile steelhead are controlled largely by water temperature. The duration of freshwater residence for juvenile steelhead is long relative to that of Chinook salmon, making the juvenile life stage of steelhead more susceptible to the influences of water temperature, particularly during the over-summer rearing period. Central Valley juvenile steelhead have high growth rates at water temperatures in the mid 60°F range, but reportedly require lower water temperatures to successfully undergo the transformation to the smolt stage.

Water temperature index values of 63°F, 65°F, 68°F, 72°F, and 75°F were selected to represent a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead juvenile rearing. The lowest water temperature index value of 63°F was established because Myrick and Cech (2001) describe 63°F as the "preferred" water temperature for wild juvenile steelhead, whereas "preferred" water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. 65°F was also identified as a water temperature index value because NMFS (2000; 2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the optimum water temperature range for juvenile growth (i.e., 59-66°F) (Myrick and Cech 2001), and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999).

Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F water temperature index value. For example, Kaya *et al.* (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F. Cherry *et al.* (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech and Myrick (1999) and FERC (1993). Empirical adult *O. mykiss* population data from the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon rivers were collected in 2007-2009 were plotted against temperature (Figure 4 of Bratovich et al. 2012). The temperature used was the 8^{th} largest average daily temperature during the summer (i.e., up to seven days had higher daily average temperatures). The data show a population density break at about 68.0°F. Although smaller population densities occurred at higher temperatures, the largest population densities occurred at temperatures near 68.0°F or less. In addition growth for a 200 mm juvenile *O. mykiss* versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%) was evaluated. The average empirically derived percent of maximum consumption in an adjacent watershed (Middle Fork American Fork River) was 50% (Hanson *et al.* 1997). Positive growth only occurs up to approximately 68°F. Because of the literature describing 68.0°F as both an upper preferred and an avoidance limit for juvenile *O. mykiss*, and because of the empirical fish population data and bioenergetics growth data, 68°F was established as a upper tolerable water temperature index value.

A water temperature index value of 72°F was established because symptoms of thermal stress in juvenile steelhead have been reported to arise at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen *et al.* 1994). Also, 72°F was selected as a water temperature index value because 71.6°F has been reported as an upper avoidance water temperature (Kaya *et al.* 1977) and an upper thermal tolerance water temperature (Ebersole *et al.* 2001) for juvenile rainbow trout. The highest water temperature index value of 75°F was established because NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75.0°F (EPA 2002; NMFS 2001b). Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al.* 2000; McCullough 2001).

A swim tunnel study conducted on the Lower Tuolumne River (TID/MID 2016) generated high quality field data on the physiological performance of Tuolumne River *O. mykiss* acutely exposed to a temperature range of 13 to 25°C. The data indicated that wild juvenile *O. mykiss* represents an exception to the expected based on the 7DADM criterion for juvenile rearing set out by EPA (2003b) for Pacific Northwest *O. mykiss*. The study recommended that a conservative upper aerobic performance limit of 71.6°F, instead of 64.4°F (EPA), be considered in re-determining a 7DADM for this population.

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified the upper incipient lethal temperature (UILT) for *O. mykiss* juveniles has been estimated at 22.8–25.9ºC (73–79°F) (Threader and Houston 1983). In the model, an initial mortality threshold of 25°C (77°F) daily average temperature was selected for *O. mykiss* juveniles. Note also that both fry rearing and resident adult rearing lifestages of *O. mykiss* also had UILT values of 77°F to support the model.

For steelhead juvenile rearing, the Temperature Criteria Matrix identified 65°F for the Lower American River (Water Forum 2007); 61°F for the San Joaquin (CALFED 2009); and 65°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba (Bratovich *et al.* 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 64°F (7DADM) for "salmon and steelhead" juvenile rearing.

<u>Yearling + Smolt Emigration</u>

Laboratory data suggest that smoltification, and therefore successful emigration of steelhead smolts, is directly controlled by water temperature (Adams *et al.* 1975). Water temperature index values of 52°F and 55°F were selected to evaluate the steelhead smolt emigration life stage, because most literature on water temperature effects on steelhead smolting suggest that water temperatures less than 52°F (Adams *et al.*1975; Myrick and Cech 2001; Rich 1987a) or less than 55°F (EPA 2003a; McCullough *et al.* 2001; Wedemeyer *et al.* 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur. (Adams *et al.* 1973) tested the effect of water temperature (43.7°F, 50.0°F, 59.0°F or 68.0°F) on the increase of gill microsomal Na^{+}-, K^{+}-stimulated ATPase activity associated with parr-smolt transformation in steelhead and found a two-fold increase in Na^{+}-, K^{+}-ATPase at 43.7 and 50.0°C, but no increase at 59.0°F or 68.0°F . In a subsequent study, the highest water temperature where a parr-smolt transformation occurred was at 52.3°F (Adams *et al.* 1975). The results of Adams *et al.* (1975) were reviewed in Myrick and Cech (2001) and Rich (1987b), which both recommended that water temperatures below 52.3°F are required to successfully complete the parr-smolt transformation. Further, Myrick and Cech (2001) suggest that water temperatures between 43-50°F are the "physiologically optimal" temperatures required during the parr-smolt transformation and necessary to maximize saltwater survival. The 52°F water temperature index value established for the steelhead smolt emigration life stage is the index value generally reported in the literature as the upper limit of the water temperature range that provides successful smolt transformation thermal conditions. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value.

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead. They found ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by the EPA to provide temperature water quality standards for the protection of Northwest native salmon and trout, water temperatures less than or equal to 54.5°F were recommended for emigrating juvenile steelhead (EPA 2003b). Water temperatures are considered "unsuitable" for steelhead smolts at >59°F (Myrick and Cech 2001) and "lethal" at 77°F (FERC 1993).

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified an initial UILT mortality threshold of 77°F daily average temperature for *O. mykiss* smolts on the basis of literature reviews by Myrick and Cech (2001).

For steelhead smolt emigration, the Temperature Criteria Matrix identified 57°F for the San Joaquin (CALFED 2009) and 52°F (Upper Optimum Value) and 55°F (Upper Tolerable Value) for the Yuba (Bratovich *et al.* 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 57°F (7DADM) for steelhead smolt.

CHINOOK SALMON LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

It has been suggested that separate water temperatures standards should be developed for each run-type of Chinook salmon. For example, McCullough (1999) states that spring-run Chinook salmon immigrate in spring and spawn in 3rd to 5th order streams and, therefore, face different migration and adult holding temperature regimes than do summer- or fall-run Chinook salmon, which spawn in streams of 5th order or greater . However, to meet the objectives of the current literature review, run-types are not separated because: (1) there is a paucity of literature specific to each life stage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the water temperature index (WTI) values derived from all the literature pertaining to Chinook salmon for a particular life stage will be sufficiently protective of that life stage for each run-type; and (4) all run- types overlap in timing of adult immigration and holding and in some cases are not easily distinguished (Healey 1991).

Adult Immigration and Holding

The adult immigration and adult holding life stages are evaluated together, because it is difficult to determine the thermal regime that Chinook salmon have been exposed to in the river prior to spawning and in order to be sufficiently protective of pre-spawning fish, water temperatures that provide high adult survival and high egg viability must be available throughout the entire pre-spawning freshwater period. Although studies examining the effects of thermal stress on immigrating Chinook salmon are generally lacking, it has been demonstrated that thermal stress during the upstream spawning migration of sockeye salmon negatively affected the secretion of hormones controlling sexual maturation causing numerous reproductive impairment problems (McCullough *et al.* 2001).

The water temperature index values reflect a gradation of potential water temperature effects that range between those reported as "optimal" to those reported as "lethal" for adult Chinook salmon during upstream spawning migrations and holding. The water temperature index values established for the Chinook salmon adult immigration and holding lifestage are 61°F, 65°F, and 68°F. Although 56°F is referenced in the literature frequently as the upper "optimal" water temperature limit for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, Boles *et al.* (1988), Marine (1992), and NMFS (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for adult Chinook salmon immigration. However, Hinze (1959) is a study examining the effects of water temperature on incubating Chinook salmon eggs in the American River Basin. Further, water temperatures between 38-56°F are considered to represent the "observed range" for upstream migrating spring-run Chinook salmon (Bell 1986).

The lowest water temperature index value established was 61°F, because in the NMFS biological opinion for the proposed operation of the Central Valley Project (CVP) and State Water Project (SWP), 59°F to 60°F is reported as…"*The upper limit of the optimal temperature range for adults holding while eggs are maturing*" (NMFS 2000). Also, NMFS (1997b) states…"*Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F*" …and… "*Acceptable range for adults migrating upstream range from 57°F to 67°F*." Oregon Department of Environmental Quality (ODEQ; 1995) reports that "…*many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F*." Study summaries in EPA (2003a) indicate disease risk is high at 62.6°F. Additionally, Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon. EPA (2003a) chose a holding value of 61°F (7DADM) based on laboratory data various assumptions regarding diel temperature fluctuations. 61°F is also a holding temperature index value for steelhead (see above). The 61°F water temperature index value established for the Chinook salmon adult immigration and holding life stage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this life stage may reportedly occur above the 61°F water temperature index value.

An index value of 65°F was established because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 65°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults that ranged from 63.5°F to 66.2°F. Ward *et al.* (2003; 2004) identified an extended period of average daily temperatures above 67°F during July as measured at the Quartz Bowl that preceded the onset of significant pre-spawn mortalities. During 2002, temperatures exceeded 67°F a total of 16 days with a maximum of 20.8°C on July 12. During 2003, temperatures exceed 67°F a total of 11 days with a maximum of 20.9°C on July 23. However during other years when there were minimal pre-spawn mortalities, maximum daily average water temperature at Quartz Bowl never exceeded 67°F more than an few days (Ward *et al.* 2004; Ward *et al.* 2006; McReynolds *et al*. 2007; McReynolds and Garman 2008). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6 of Bratovich et al. 2012). Tracy McReynolds (Pers. Comm. October 2011) indicated that an upper tolerable holding temperature of 65°F was reasonable based on her experience.

An index value of 68°F was established because the Butte Creek data and the literature suggests that thermal stress at water temperatures greater than 68°F is pronounced, and severe adverse effects to immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1997; NMFS 1997b; Ward *et al.* 2004).

Water temperatures between 70-77°F are reported as the range of maximum temperatures for holding pool conditions used by spring-run Chinook salmon in the Sacramento-San Joaquin system (Moyle *et al*. 1995). Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al*. 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999). The upper limit for spring-run Chinook salmon holding in Deer Creek is reportedly 80.6°F, at which point temperatures exceeding this value become "lethal" (Cramer and Hammack 1952, as cited in Moyle *et al.* 1995). As a result of the potential effects to immigrating and holding adult Chinook salmon that reportedly occur at water temperatures greater than or equal to 68°F, index values higher than 68°F were not established.

For Chinook adult immigration, the Framework Temperature Criteria Matrix identified 64°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba River (Bratovich et al. 2012). For Chinook adult holding, the Framework Temperature Criteria Matrix identified 61°F

(Upper Optimum Value) and 65°F (Upper Tolerable Value) for the Yuba River (Bratovich *et al.* 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 64°F (7DADM) for "salmon and trout" adult migration.

Spawning and Embryo Incubation

The adult spawning and embryo (i.e., eggs and alevins) incubation life stage includes redd construction, egg deposition, and embryo incubation. Potential effects to the adult spawning and embryo incubation life stages are evaluated together using one set of water temperature index values because it is difficult to separate the effects of water temperature between lifestages that are closely linked temporally, especially considering that studies describing how water temperature affects embryonic survival and development have included a pre-spawning or spawning adult component in the reporting of water temperature experiments conducted on fertilized eggs (Marine 1992; McCullough 1999; Seymour 1956).

The water temperature index values selected for the Chinook salmon spawning and embryo incubation life stages are 56°F, 58°F, 60°F, and 62°F. Anomalously, FERC (1993) refers to 50°F as the "optimum" water temperature for spawning and incubating Chinook salmon. Additionally, for the adult spawning lifestage, FERC (1993) reports "stressful" and "lethal" water temperatures occurring at >60°F and >70°F, respectively, whereas for incubating Chinook salmon embryos, water temperatures are considered to be "stressful" at <56°F or "lethal" at >60°F. Much literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. NMFS (1993b) reported that optimum water temperatures for egg development are between 43°F and 56°F. Similarly, Myrick and Cech (2001) reported the highest egg survival rates occur between water temperatures of 39-54°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. Bell (1986) recommends water temperatures ranging between 42-57°F for spawning Chinook salmon, and water temperatures between 41-58°F for incubating embryos. USFWS (1995a) reported a water temperature range of 41.0°F to 56.0°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. The preferred water temperature range for Chinook salmon egg incubation in the Sacramento River was suggested as 42.0°F to 56.0°F (NMFS 1997a). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NMFS (2002a) reported 56.0°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F water temperature index value established for the Chinook salmon spawning and embryo incubation life stage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this life stage may reportedly occur above the 56°F water temperature index value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58.0°F. For example, (Reclamation Unpublished Work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs (1957) concluded constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002a) suggests 53.0°F to 58.0°F is the preferred water temperature range for Chinook salmon eggs and fry. Johnson (1953) found consistently higher Chinook salmon egg losses resulted at water temperatures above 60.0°F than at lower temperatures. In order to protect late incubating Chinook salmon embryos and newly emerged fry NMFS (1993a) has determined a water temperature criterion of less than or equal to 60.0°F be maintained in the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. Seymour (1956) provides evidence that 100% mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60.0°F. For Chinook salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957), however, found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F/month). Geist *et al.* (2006) found high (93.8%) Chinook salmon incubation survival through emergence for naturally declining temperatures (0.36°F/day) starting as high as 61.7°F; however, a significant reduction in survival occurred above this temperature.

The literature largely agrees that 100% mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to 62.0°F (Hinze 1959; Myrick and Cech 2003; Seymour 1956; USFWS 1999). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high mortality of Chinook salmon eggs and fry (79%) when incubation temperatures started at 65.2°F and declined naturally for the Columbia River (about 7°F / month). Geist *et al.* (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F

As part of the Don Pedro Hydroelectric Project FERC relicensing process, the TID and MID developed a Chinook Salmon Population Model Study (TID/MID 2013) for the Lower Tuolumne River below La Grange Diversion Dam. The goal of the study is to provide a quantitative population model to investigate the relative influences of various factors on the lifestage specific production of Chinook salmon in the Tuolumne River including water temperature effects on population response for specific in-river lifestages. The Chinook Salmon Population Model (TID/MID 2013) established an initial estimate of 60.4°F as the upper limit for initiation of spawning (Groves and Chandler 1999); also interpreted as the temperature at which spawning habitat will be considered usable by spawners. To address the egg and alevin lifestages, the model established an initial acute egg/alevin mortality threshold of 58°F (TID/MID 2013).

For Chinook spawning and incubation, the Framework Temperature Criteria Matrix identified 60°F or less (as early in October as possible) and 56°F or less (as early in November as possible) for Lower American River fall-run Chinook (Water Forum 2007); 64°F (spawning) and 55°F (incubation) for San Joaquin fall-run Chinook (CALFED 2009); 56°F for Shasta River winter and spring-run Chinook (SWRCB 2016); and 54°F (Upper Optimum Value) and 57°F (Upper Tolerable Value) in the Yuba (Bratovich et al. 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality

Standards (EPA 2003b) identifies 55°F (7DADM) for "salmon and trout" spawning, egg incubation, and fry emergence.

Juvenile Rearing and Downstream Movement

Water temperature index values were identified for the combined spring-run Chinook salmon rearing (fry and juvenile) and juvenile downstream movement lifestages, for the reasons previously described regarding steelhead. Fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement, and are assessed in this Technical Memorandum using the fry and juvenile rearing water temperature index values.

The water temperature index values of 60°F, 65°F, 68°F, 70°F and 75°F were identified for the spring-run Chinook salmon juvenile rearing and downstream movement lifestage . The lowest index value of 60°F was chosen because regulatory documents as well as several source studies, including ones recently conducted on Central Valley Chinook salmon fry and juveniles report 60°F as an optimal water temperature for growth (Banks *et al.* 1971; Brett *et al.* 1982; Marine 1997; NMFS 1997b; NMFS 2000; NMFS 2001a; NMFS 2002; Rich 1987b). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but were not selected as index values, because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990b; Taylor 1990a). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

The 60°F water temperature index value established for the Chinook salmon juvenile rearing and downstream movement life stage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of spring-run Chinook salmon fry and fingerlings. FERC (1993) referred to 58°F as an "optimum" water temperature for juvenile Chinook salmon in the American River. NMFS (2002a) identified 60°F as the "preferred" water temperature for juvenile spring-run Chinook salmon in the Central Valley. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

The index value of 65°F was selected because it represents an intermediate value between 64.0°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (EPA 2003a; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987a). Conversely, numerous studies report that temperatures between 64.0°F and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett *et al.* 1982; Cech and Myrick 1999; Clarke and Shelbourn 1985; EPA 2003a; Myrick and Cech 2001; NMFS 2002; USFWS 1995b). Maximum growth of juvenile fall-run Chinook salmon has been reported to occur in the American River at water temperatures between 56-59°F (Rich 1987b) and in Nimbus Hatchery spring-run Chinook salmon at 66°F (Cech and Myrick 1999).

Growth for a 100 mm juvenile Chinook salmon versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%) was evaluated. The average percent of maximum consumption in an adjacent watershed (Middle Fork American Fork River) for O. mykiss was 50% (Hanson et al. 1997). Positive growth only occurs up to approximately 64°F for food levels expected in the wild (e.g., 50% maximum consumption).

A water temperature index value of 68°F was selected because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at temperatures close to 70.0°F and has been reported to be completely prohibited at 70.5°F (Brett *et al.* 1982; Marine 1997). 75°F was chosen as the highest water temperature index value because high levels of direct mortality to juvenile Chinook salmon reportedly result at this water temperature (Cech and Myrick 1999; Hanson 1991; Myrick and Cech 2001; Rich 1987b). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was chosen because it was derived from experiments using Central Valley Chinook salmon and it is a more rigorous index value representing a more protective upper lethal water temperature level. Furthermore, the lethal level determined in Rich (1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan *et al.* 2000; McCullough *et al.* 2001; Myrick and Cech 2001).

Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952; Orsi 1971), the Chinook Salmon Population Model (TID/MID 2013) established an initial UILT mortality threshold of 77°F for Chinook salmon juveniles as a daily average water temperature. Note that the model also selected this same value for fry mortality.

For Chinook juvenile rearing, the Framework Temperature Criteria Matrix identified 61°F for the San Joaquin (CALFED 2009) and 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value) for both fall and spring-run Chinook in the Yuba River (Bratovich *et al.* 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 61°F (early year) and 64°F (late year) for salmon juvenile rearing based upon a 7DADM.

<u>Yearling + Smolt Emigration</u>

Juvenile Chinook salmon that exhibit extended rearing in the lower Yuba River are assumed to undergo the smoltification process and volitionally emigrate from the river as yearling+ individuals . Water temperature index values of 63°F, 68°F and 72°F were selected for the spring-run Chinook yearling+ emigration lifestage.

A water temperature index value of 63°F was selected because water temperatures at or below this value allow for successful transformation to the smolt stage, and water temperatures above this value may result in impaired smoltification indices, inhibition of smolt development, and decreased survival and successful smoltification of juvenile spring-run Chinook salmon . Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997; Zedonis and Newcomb 1997). 62.6°F was rounded and used to support an index value of 63°F. Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989). A water temperature index value of 68°F was selected because water temperatures above 68°F prohibit successful smoltification (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Support for an index value of 72°F is provided from a study conducted by (Baker *et al.* 1995) in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests a 95% confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5°F to 75.4°F.

Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952), the Chinook Salmon Population Model (TID/MID 2013) established an initial mortality threshold of 77°F for Chinook salmon smolts as a daily average water temperature.

For Chinook smolt migration, the Framework Temperature Criteria Matrix identified 57°F for the San Joaquin (CALFED 2009) and 63°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for both fall and spring-run Chinook in the Yuba River (Bratovich et al. 2012).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 59°F (7DADM) for salmon smolt.

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Upper Tuolumne River Reintroduction Assessment Framework
Water Temperature Criteria Subcommittee
Water Temperature Evaluation
Glossary of Terms

Acute temperature criteria – water temperature identified as being in the **acute temperature zone** for a particular species/lifestage.

Acute temperature exposure – water temperature exposure that is less than 7 days and results in 50% mortality.

Acute temperature zone – zone where acute water temperature exposure occurs with potential for rapid mortality; **zone of resistance**.

Average daily temperature (ADT) – average of temperatures in a 24-hour period.

Chronic temperature criteria – water temperature identified as being in the **chronic temperature zone** for a particular species/lifestage.

Chronic temperature exposure – water temperature exposure that is long-term or $\geq$ 7 days and results in 50% mortality.

Chronic temperature zone – zone where chronic water temperature exposure occurs with no or reduced growth and reproduction and increased mortality; **zone of tolerance**.

Critical thermal maximum – very short duration (minutes) mortality after acute temperature exposure.

Diel temperature – temperature over 24-hour period.

Diurnal temperature – temperature fluctuations between high and low or day and night of the same day.

Lifestage periodicity – season/dates corresponding to a specific lifestage (e.g. spring-run Chinook salmon spawning); identified through study of a particular watershed.

Maximum weekly average temperature (MWAT) – the highest value calculated for all possible 7-day periods over a given time period (e.g. season or lifestage) and generally used to summarize instream water temperature variation occurring on daily or seasonal basis for evaluation of chronic water temperature impacts; found by calculating mathematical mean of multiple, equally spaced, daily water temperatures over a 7-day consecutive period.

Optimum temperature range – zone of temperatures where fish growth, reproduction, and behavior is not appreciably affected by temperature.

Seven (7)-day moving average temperature (7DMA) – "smoothed" average of temperatures over a period of time using moving seven day subsets.

Seven(7)-day moving average daily maximum temperature (7DMADM) – “smoothed” water temperature metric describing the maximum 7-day average of the daily maxima; calculated by adding the daily maximum temperatures recorded at a site on seven consecutive days and dividing by seven, uses moving seven day subsets.

Seven (7)-day average daily maximum temperature (7DADM) – water temperature metric describing the maximum 7-day average of the daily maxima; calculated by adding the daily maximum temperatures recorded at a site on seven consecutive days and dividing by seven.

Upper incipient lethal temperature (UILT) – boundary between lower end of **acute temperature exposure** range and upper end of **chronic temperature exposure** range; where 50% mortality occurs after 7 days (If a shorter duration is used, temperatures will be correspondingly higher).

Upper optimal WTI (UOWTI) – temperatures where physiological processes (growth, disease resistance, normal development of embryos) are not stressed by temperature; **optimal temperature range** identified for specific lifestage.

Upper tolerance WTI (UTWTI) – temperature identified as the boundary between sustained (chronic) tolerance and no tolerance; boundary between **zone of tolerance** and **zone of resistance** identified for a specific lifestage.

Use designation – category applied to a waterbody that determines which **water quality standards (WQS)** will be enforced.

Volitional migration – upstream or downstream migration occurring when anadromous fish are physiologically ready.

Water quality standards (WQS) – specified concentrations/values of various water quality parameters not to be exceeded as established by the U.S. Environmental Protection Agency (EPA) and/or state for beneficial uses such as aquatic life and drinking water.

Water temperature index (WTI) – description of water temperatures that are optimal and/or tolerated by an aquatic species; developed empirically through laboratory and field studies.

Water temperature exceedance curves – used to identify probabilities/duration of time that lifestage-specific **WTI** values would be exceeded over a given time.

Water temperature metrics – provide index of temperature over a period of time (e.g. **MWAT**, **7DADM**).

Water year type – describes amount of precipitation received during water year (e.g. critically dry to wet).

Zone of resistance – water temperature zone between the **UILT** (7 days) and **critical thermal maximum**.

Zone of tolerance – water temperature zone that fish can tolerate that is below the **UILT** and above the **optimal temperature** range, but at higher end temperatures may not thrive and may have modified behavior.

Water Temperature Considerations for Yuba River Basin Anadromous Salmonid Reintroduction Evaluations

Prepared for:

Yuba Salmon Forum Technical Working Group

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1 INTRODUCTION

The Yuba Salmon Forum (YSF) is a multi-stakeholder group addressing the opportunities for reintroducing anadromous salmonids (i.e., spring-run Chinook salmon and steelhead) in the Upper Yuba River Basin upstream of Englebright Dam.

The YSF stakeholder group is comprised of representatives from National Marine Fisheries Service (NMFS), U.S. Forest Service (USFS), California Department of Fish and Game (CDFG), the Yuba County Water Agency (YCWA), Placer County Water Agency (PCWA) and a group of the non-governmental organizations (NGOs) including Trout Unlimited, American Rivers, The Bay Institute, Sierra Club, California Sport Fishing Protection Alliance, and South Yuba River Citizens League. The YSF is comprised of a Plenary Group and a Technical Working Group (TWG). The purpose of the TWG is to address technical issues associated with anadromous salmonid reintroduction. One of the technical issues addressed by the TWG includes water temperature considerations for the reintroduction of anadromous salmonids into the Upper Yuba River Basin.

2 TECHNICAL MEMORANDUM PURPOSE AND OBJECTIVES

The overall purpose of this Technical Memorandum is to establish the technical basis to evaluate water temperature regimes for spring-run Chinook salmon and steelhead reintroduction in the various rivers and reaches of the Upper Yuba River Basin (North Yuba River upstream of New Bullards Bar Reservoir, North Yuba River downstream of New Bullards Bar Dam to the high water mark of Englebright Reservoir, Middle Yuba River, and South Yuba River) **(Figure 1)**.

Specific objectives are to: (1) conduct a comprehensive literature review of lifestage-specific water temperature relationships; (2) identify a suite of water temperature index (WTI) values representing a summarization of the literature review; (3) select water temperature criteria for each species-specific lifestage for reintroduction evaluation; and (4) identify the water temperature evaluation methodological approach (water temperature metrics and metric application to water temperature monitoring and/or modeling data).

NMFS commented (NOAA Memorandum dated January 18, 2012) on the November 2011 version of this technical memorandum, stating that it should demonstrate the need for new criteria in consideration of criteria previously developed by Stillwater Sciences (2006). In summary, this technical memorandum differs from Stillwater Sciences (2006) in some lifestage periodicities (e.g., spring-run Chinook salmon spawning (Sep – mid Nov vs. Sep – Oct), and embryo incubation (Sep – Feb vs. late Sep – Jan). Notably, Stillwater Sciences (2006) assumed that juvenile spring-run Chinook salmon in the Upper Yuba River Basin *"…would not typically over-summer due to excessively high summer water temperatures*." By contrast, this technical memorandum assumes that juvenile rearing in the Upper Yuba River Basin could occur year-round. In addition, this technical memorandum identifies spring-run Chinook salmon smolt emigration potentially occurring from November through mid-May, whereas Stillwater Sciences (2006) did not identify spring-run Chinook salmon smolt emigration as a lifestage to be addressed. Similarly, Stillwater Sciences (2006) did not identify smolt emigration as a steelhead lifestage to be addressed. In addition to lifestage periodicities, this technical memorandum identifies upper optimum and upper tolerance water temperature index values to be used in the evaluation of water temperature suitability for reintroduction of spring-run Chinook salmon and steelhead into the Upper Yuba River Basin, whereas Stillwater Sciences (2006) identified optimal, suboptimal, and chronic-to-acute stress water temperature index values. These categories are not directly comparable, and the actual values also differ between the two reports.

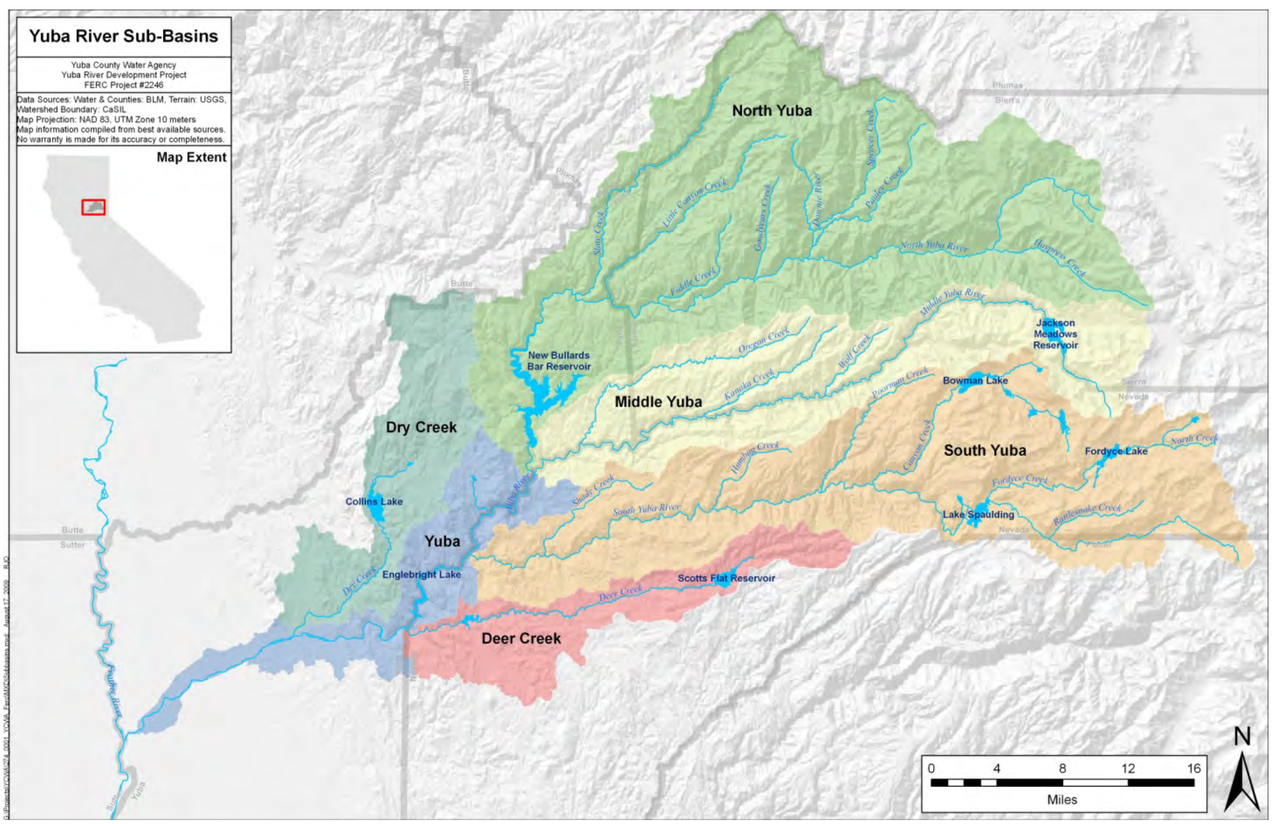


Figure 1. Sub-basins of the Yuba River Basin (source: Yuba County Water Agency 2010).

3 LIFESTAGE PERIODICITIES OF ANADROMOUS SALMONIDS

Lifestage-specific water temperature considerations for spring-run Chinook salmon and steelhead were addressed by the TWG in the evaluation of anadromous reintroduction in the Upper Yuba River Basin. A review of previously conducted studies, as well as recent and currently ongoing data collection activities by the Yuba Accord Monitoring and Evaluation Program (M&E Program) in the lower Yuba River was conducted to identify species- and lifestage-specific temporal periodicities for water temperature considerations. The TWG agreed on the spring-run Chinook salmon and steelhead lifestage periodicities presented in **Table 1** for reintroduction consideration in the Upper Yuba River Basin during a meeting held May 20, 2011. However, it was noted that these periodicities reflect existing conditions in the lower Yuba River, and that lifestage periodicities may change in response to local adaptation over time. It was further noted that although some lifestages may occur concurrently, the periodicities presented in Table 1 reflect specific consideration for water temperature evaluation for reintroduction. For example, spring-run Chinook salmon holding continues to occur during September, even though spawning activity begins during that month.

Table 1. Lifestage-Specific Periodicities for Spring-run Chinook Salmon and Steelhead in the Lower Yuba River.

Lifestage	**Jan**		**Feb**		**Mar**		**Apr**		**May**		**Jun**		**Jul**		**Aug**		**Sep**		**Oct**		**Nov**		**Dec**	
Spring-Run Chinook Salmon																								
Adult Immig. & Holding							■	■	■	■	■	■	■	■	■	■								
Spawning																	■	■	■	■	■			
Embryo Incubation	■	■	■	■													■	■	■	■	■	■	■	■
Juv. Rearing & Outmig.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Yearling+ Smolt Emig.	■	■	■	■	■	■	■	■	■												■	■	■	■
Steelhead																								
Adult Immig. & Holding	■	■	■	■	■	■									■	■	■	■	■	■	■	■	■	■
Spawning	■	■	■	■	■	■	■	■																
Embryo Incubation	■	■	■	■	■	■	■	■	■	■														
Juv. Rearing & Outmig.	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Yearling+ Smolt Emig.	■	■	■	■	■	■	■												■	■	■	■	■	■

4 LITERATURE REVIEW OF WATER TEMPERATURE RELATIONSHIPS FOR STEELHEAD AND CHINOOK SALMON

A comprehensive review and compilation of available literature was conducted to identify the range of acceptable water temperatures for reintroduction evaluation of Chinook salmon and steelhead, by lifestage, in the Upper Yuba River Basin. The thermal requirements of Chinook salmon and steelhead have been extensively studied in California and elsewhere. The literature review informed the selection of a range of WTI values to be used in the TWG's evaluation of the water temperature-related reintroduction potential in the Upper Yuba River Basin. The information presented herein is largely based on information provided in Appendix E2 to the Public Draft EIR/EIS for the Yuba Accord (YCWA *et al.* 2007), Appendix B (Stillwater Sciences 2006) to the Upper Yuba River Studies Program (UYRSP) Technical Report (DWR 2007), and the Yuba Accord River Management Team Water Temperature Objectives Technical Memorandum (RMT 2010).

WTI values were identified from laboratory experiments and field studies that examined how water temperature affects Central Valley Chinook salmon and steelhead. WTI values were also identified from regulatory documents such as biological opinions from NMFS. Results of the literature review are presented in **Appendix A**. Specific temperature index values were then selected by the TWG to evaluate temperature-related reintroduction potential in the Upper Yuba River Basin.

Studies on fish from outside the Central Valley were used to establish WTI values when local studies were unavailable. To avoid unwarranted specificity, only whole integers were selected as WTI values. In some cases, whole integer WTI values were partially derived from literature results that varied from the index value by several tenths of a degree. For example, Combs and Burrows (1957) reported that constant incubation temperatures up to 57.5°F resulted in normal development of Chinook salmon eggs, and their report was referenced as support for a rounded[1] WTI value of 58°F.

The WTI values presented herein represent a gradation of potential biological effects from optimal to lethal water temperatures for each lifestage. Literature on salmonid water temperature requirements generally reports water temperature thresholds using various descriptive terms including "optimal", "preferred", "suitable", "suboptimal", "tolerable", "stressful – chronic and acute", "sublethal", "incipient lethal", and "lethal". Water temperature effects on salmonids are often discussed in terms of "lethal" and "sublethal" effects, and depend on the both the magnitude and the duration of exposure (Sullivan *et al.* 2000), as well as acclimation water temperature. Exposure to adverse water temperatures can result in adverse effects on the biological functions, feeding activity, lifestage timing, growth, reproduction, competitive interactions, susceptibility to disease, growth and development and ultimately probability of survival (McCullough 1999).

[1] Rounding for the purposes of selecting index values is appropriate because the daily variation of experimental treatment temperatures is often high. For example, temperature treatments in Marine (1997) consisted of control (55.4°F to 60.8°F), intermediate (62.6°F to 68.0°F) and extreme (69.8°F to 75.2°F) treatments that varied daily by several degrees.

There are inherent limitations associated with the development and application of WTI values. Some of the limitations are summarized by McEwan (2001). Namely, that WTI values serve as general guidelines, originally developed by researchers on specific streams or under laboratory conditions. Also, research under controlled laboratory conditions does not take into account ecological considerations associated with water temperature regimes, such as predation risk, inter- and intra-specific competition, long-term survival and local adaptation.

5 LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Lifestage-specific WTI summary tables derived from the literature review are provided for steelhead and Chinook salmon: (1) adult immigration and holding; (2) spawning and embryo incubation; (3) juvenile rearing and downstream movement; and (4) yearling + smolt emigration in **Tables 2 - 9** (see below). A written discussion of the literature used to create the summary tables is provided in Appendix A. A short discussion of acute versus chronic temperature tolerance also is provided.

5.1 Steelhead and Chinook Salmon Acute Versus Chronic Temperature Tolerance (Juveniles and Adults)

Lifestage-specific WTI values (Sections 5.2 and 5.3 below) were based on long-term (≥ 7 days) chronic temperature exposure rather than acute temperature exposure (< 7 days). The boundary between the upper end of the chronic exposure range and the lower end of the acute exposure range is typically measured as the upper incipient lethal temperature (UILT) where 50% mortality occurs after 7 days (Elliott 1981)[2].

The UILT for both juvenile steelhead and Chinook salmon is very similar and is between 75-79°F (24-26°C) depending on the study (McCullough 1999; Sullivan et al. 2000; McCullough et al. 2001). The UILT for adult steelhead and Chinook salmon is 70-72°F (21-22°C) (Coutant 1970; Becker 1973; McCullough et al. 2001), which is much lower than that for juveniles and is approximately the same temperature that has been identified as an upstream migration barrier for Chinook salmon (McCullough 1999).

Acute temperature response (< 7 days) is strongly dependent on duration of exposure. **Figure 2** shows some example acute exposure relationships for juvenile salmonids. The hourly (60 minute) acute temperature is 5.4 – 9.0°F (3-5°C) higher than the 7-day (10,000 minute) chronic temperature. Because the acute temperature for juvenile salmonids, approximately 82.4°F (28.4°C) is relatively high, it rarely becomes a factor affecting

[2] Note that some authors have measured the UILT using shorter duration exposure than 7 days (e.g., 1,000 mins or 24 hrs). UILT values based on a shorter duration exposure than 7 days will be higher than the UILT values based on a 7 day exposure.

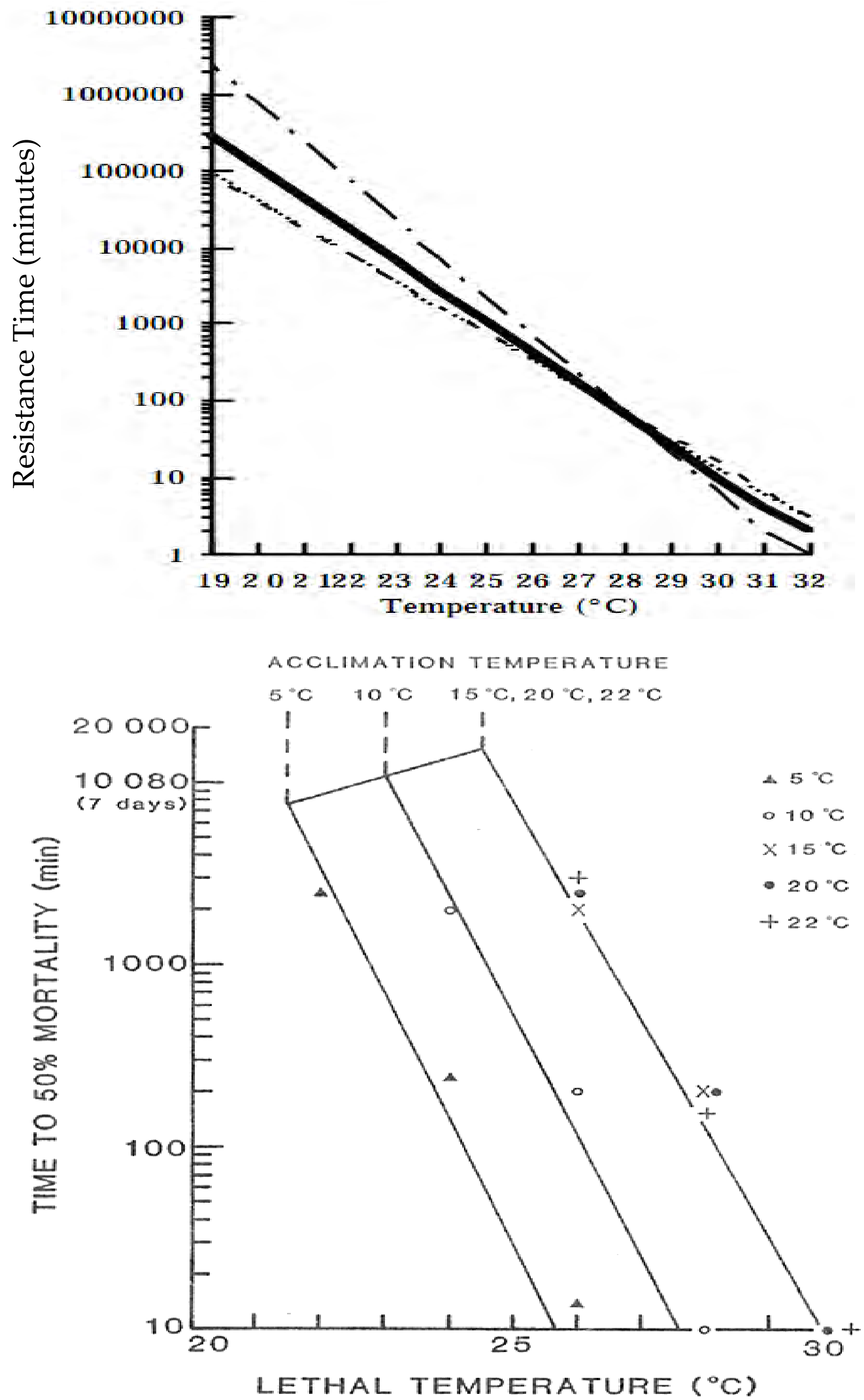


Figure 2. Relationship Between the Time (Minutes) to Mortality and the Lethal Temperature for Rainbow Trout (Top) (Bidgood 1969) and Brown Trout (Bottom) (Elliott 1981). Note the Effect of Acclimation Temperature in the Bottom Figure.

survival in natural streams (Sullivan et al. 2000). However, the acute temperature for adult salmonids is lower – it could become a survival factor particularly for adult spring-run Chinook salmon holding through the summer.

The temperature range between the UILT (7 days) and very short duration mortality (minutes) (e.g., critical thermal maximum) is called the zone of resistance. Below the UILT is a zone of tolerance where fish can tolerate the temperature for an extended period of time (> 7 days). At the higher temperatures in the tolerance zone fish may not feed, grow, or reproduce and they may have modified behavior (e.g., holding in temperature refugia locations). An important point to note is that the effects of water temperature are associated with duration of exposure and, depending upon the actual water temperature value, short duration exposure to relatively high temperatures may not result in sustained adverse effects if temperatures quickly decrease to non-impactive levels.

At lower temperatures in the tolerance zone, denoted "tolerable" in this report, growth and/or reproduction occur, but are reduced from optimal due to temperature effects. The zone of temperature where fish processes (growth, reproduction, behavior) are not affected appreciably by temperature is denoted as the "optimum" temperature range in this report (**Figure 3**).

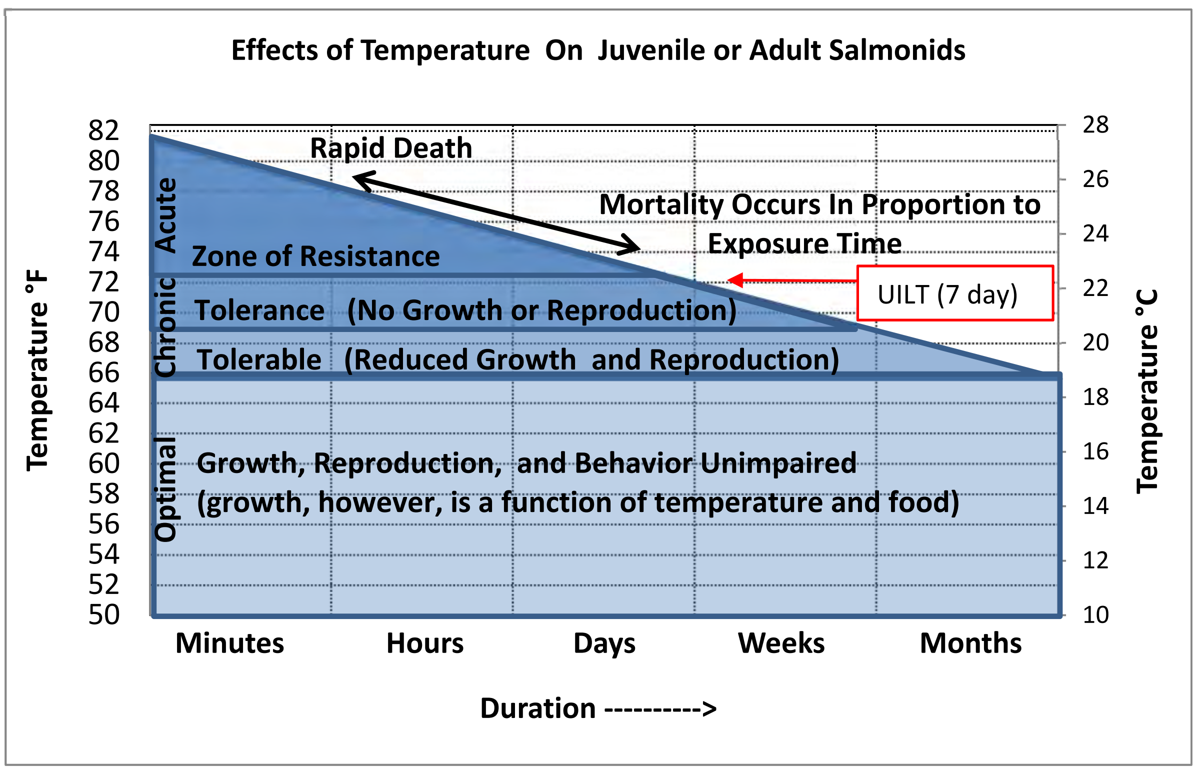


Figure 3. Illustration of Acute, Chronic, and Optimum Temperature Zones.

5.2 Steelhead Lifestage-specific Water Temperature Index Values

5.2.1 Adult Immigration and Holding

Table 2. Steelhead Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F	Preferred range for adult steelhead immigration of 46.0°F to 52.0°F (NMFS 2000; NMFS 2001a; SWRCB 2003). Optimum range for adult steelhead immigration of 46.0°F to 52.1°F (Reclamation 1997a). Recommended adult steelhead immigration temperature range of 46.0°F to 52.0°F (Reclamation 2003).
56°F	To produce rainbow trout eggs of good quality, brood fish must be held at water temperatures not exceeding 56.0°F (Leitritz and Lewis 1980). Rainbow trout brood fish must be held at water temperatures not exceeding 56°F for a period of 2 to 6 months before spawning to produce eggs of good quality (Bruin and Waldsdorf 1975). Holding migratory fish at constant water temperatures above 55.4°F to 60.1°F may impede spawning success (McCullough *et al.* 2001).
61°F	Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS 1995a). Preferred range of water temperature for holding Caliifornia summer steelhead occurs between 50-59°F (Moyle 1995).
64°F	Steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Over 93% of steelhead detections occurred in the 65.3-71.6°F, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006).
70°F	Migration barriers have frequently been reported for pacific salmonids when water temperatures reach 69.8°F to 71.6°F (McCullough *et al.* 2001). Snake River adult steelhead immigration was blocked when water temperatures reached 69.8 (McCullough *et al.* 2001). A water temperature of 68°F was found to drop egg fertility in vivo to 5 percent after 4.5 days (McCullough *et al.* 2001). The UILT for adult steelhead was determined to be 69.8°F (Coutant 1972).

5.2.2 Spawning and Embryo Incubation

Table 3. Steelhead Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
46°F	Orcutt et al. (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F.
52°F	Rainbow trout from Mattighofen (Austria) had highest egg survival at 52.0°F compared to 45.0°F, 59.4°F, and 66.0°F (Humpesch 1985). Water temperatures from 48.0°F to 52.0°F are suitable for steelhead incubation and emergence in the American River and Clear Creek (NMFS 2000; NMFS 2001a; NMFS 2002a). Optimum water temperature range of 46.0°F to 52.0°F for steelhead spawning in the Central Valley (USFWS 1995b). Optimum water temperature range of 46.0°F to 52.1°F for steelhead spawning and 48.0°F to 52.1°F for steelhead egg incubation (Reclamation 1997a). Upper limit of preferred water temperature of 52.0°F for steelhead spawning and egg incubation (SWRCB 2003).
54°F	Big Qualicum River steelhead eggs had 96.6 percent survival to hatch at 53.6°F (Rombough 1988). Highest survival from fertilization to hatch for *Salmo gairdneri* incubated at 53.6°F (Kamler and Kato 1983). Emergent fry were larger when North Santiam River (Oregon) winter steelhead eggs were incubated at 53.6°F than at 60.8°F (Redding and Schreck 1979). The upper optimal water temperature regime based on constant or acclimation water temperatures necessary to achieve full protection of steelhead is 51.8°F to 53.6°F (EPA 2001). From fertilization to hatch, rainbow trout eggs and larvae had 47.3 percent mortality (Timoshina 1972). Survival of rainbow trout eggs declined at water temperatures between 52.0 and 59.4°F (Humpesch 1985). The optimal constant incubation water temperature for steelhead occurs below 53.6°F (McCullough *et al.* 2001).

Index Value	Supporting Literature
57°F	From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). A sharp decrease in survival was observed for rainbow trout embryos incubated above 57.2°F (Kamler and Kato 1983).
60°F	Water temperatures >59°F are described as "lethal" to incubating steelhead embryos (Myrick and Cech 2001), From fertilization to 50 percent hatch, Big Qualicum River steelhead had 93 percent mortality at 60.8°F, 7.7 percent mortality at 57.2°F, and 1 percent mortality at 47.3°F and 39.2°F (Velsen 1987). From fertilization to 50 percent hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56 percent survival when incubated at 59.0°F (Kwain 1975).

5.2.3 Juvenile Rearing and Downstream Movement

Table 4. Steelhead Juvenile Rearing and Downstream Movement Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
63°F	Preferred water temperature for wild juvenile steelhead is reportedly 63°F, whereas preferred water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. Myrick and Cech (2001)
65°F	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). The final preferred water temperature for rainbow fingerlings was between 66.2 and 68°F (Cherry *et al.* 1977). Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971).
68°F	Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry *et al.* 1977). Rainbow trout fingerlings preferred or selected water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya et al. 1977). FERC (1993) referred to 68°F as "stressful" to juvenile steelhead. Empirical fish population and water temperature data in the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon Rivers (**Figure 4**) indicate a sharp reduction in O. *mykiss* population densities when temperatures exceed 68°F for greater than one week. Bioenergetics modeling of growth based on consumption (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above 68°F (**Figure 5**).
72°F	Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen *et al.* 1994). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole *et al.* 2001).
75°F	The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (EPA 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole *et al.* 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan et al. 2000; McCullough 2001).

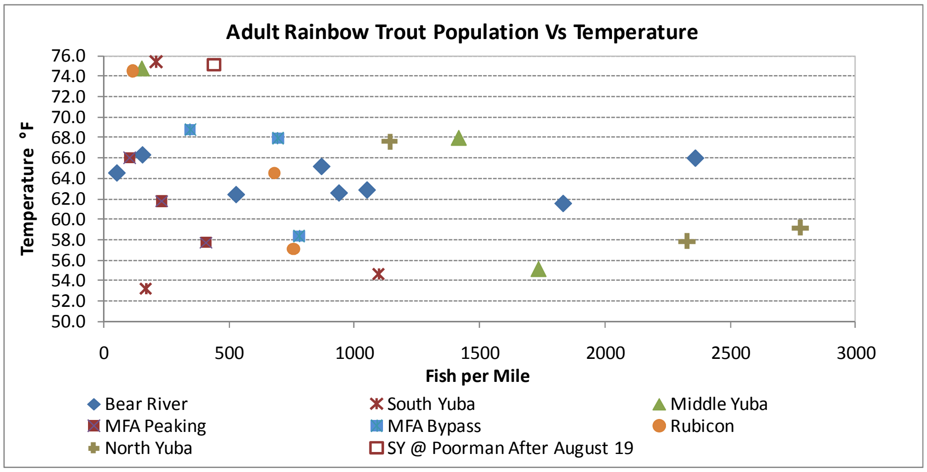
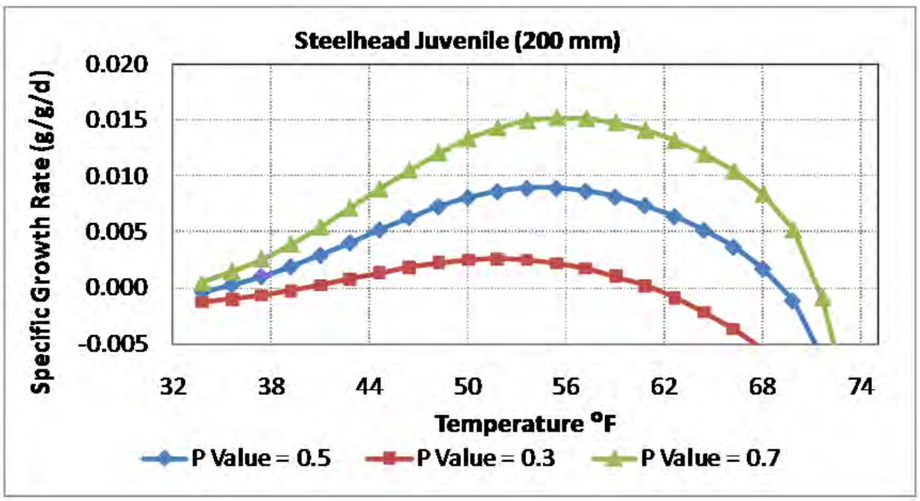


Figure 4. Empirical Adult Fish Population Data in the Middle Fork American and Yuba River Rivers Compared to the Maximum Temperature Exceeded Less Than 7 Days.



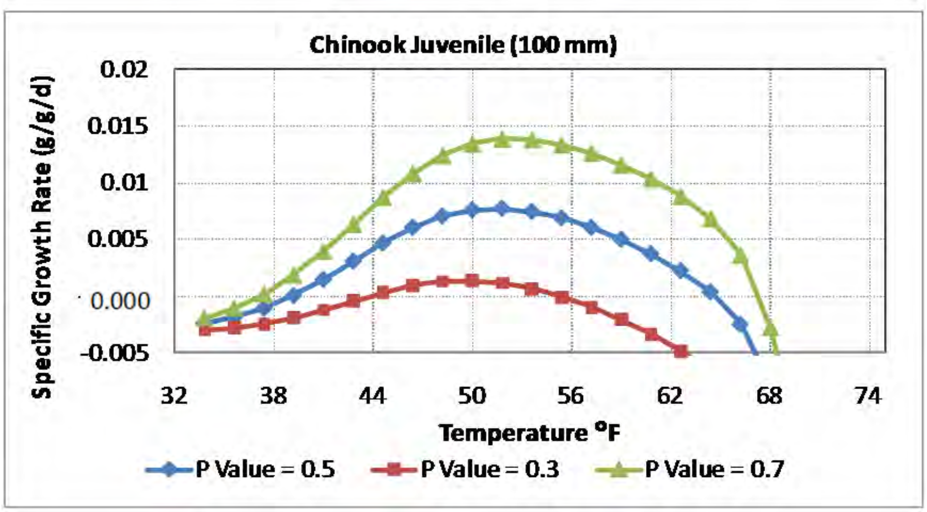


Figure 5. Bioenergetics Growth Rate Modeling For Steelhead and Chinook Salmon Juveniles Over a Range of Temperatures.

5.2.4 Yearling + Smolt Emigration

Table 5. Steelhead Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F	Steelhead successfully smolt at water temperatures in the 43.7°F to 52.3°F range (Myrick and Cech 2001). Steelhead undergo the smolt transformation when reared in water temperatures below 52.3°F, but not at higher water temperatures (Adams *et al.* 1975). Optimum water temperature range for successful smoltification in young steelhead is 44.0°F to 52.3°F (Rich 1987a).
55°F	ATPase activity was decreased and migration reduced for steelhead at water temperatures greater than or equal to 55.4°F (Zaugg and Wagner 1973). Water temperatures should be below 55.4°F at least 60 days prior to release of hatchery steelhead to prevent premature smolting and desmoltification (Wedemeyer *et al.* 1980). In winter steelhead, a temperature of 54.1°F is nearly the upper limit for smolting (McCullough *et al.* 2001; Zaugg and Wagner 1973). Water temperatures less than or equal to 54.5°F are suitable for emigrating juvenile steelhead (EPA 2003b). Water temperatures greater than 55°F prevent increases in ATPase activity in steelhead juveniles (Hoar 1988). Water temperatures greater than 56°F do not permit smoltification in summer steelhead (Zaugg *et al.* 1972)
59°F	Yearling steelhead held at 43.7°F and transferred to 59°F had a substantial reduction in gill ATPase activity, indicating that physiological changes associated with smoltification were reversed (Wedemeyer *et al.* 1980).

5.3 Chinook Salmon Lifestage-Specific Water Temperature Index Values

5.3.1 Adult Immigration and Holding

Table 6. Chinook Salmon Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59°F to 60°F (NMFS 1997b). Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NMFS 2000). Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60°F (ODEQ 1995). Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b). Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon.
65°F	Acceptable range for adults migrating upstream is from 57°F to 67°F (NMFS 1997b). Disease risk becomes high at water temperatures above 64.4°F (EPA 2003b). Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5°F to 66.2°F (Berman 1990). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (**Figure 6**).
68°F	Acceptable range for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992). Spring-run Chinook salmon embryos from adults held at 63.5°F to 66.2°F had greater numbers of pre-hatch mortalities and developmental abnormalities than embryos from adults held at 57.2°F to 59.9°F (Berman 1990). Water temperatures of 68°F resulted in nearly 100 percent mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). In Butte Creek a period of average daily temperatures above 67°F (11-16 days) preceded the onset of significant pre-spawn mortalities. In

	years when 67°F was exceeded only a few days, pre-spawn mortality was minimal (Ward et al. 2004). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea et al. 2006).
70°F	Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al.* 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).

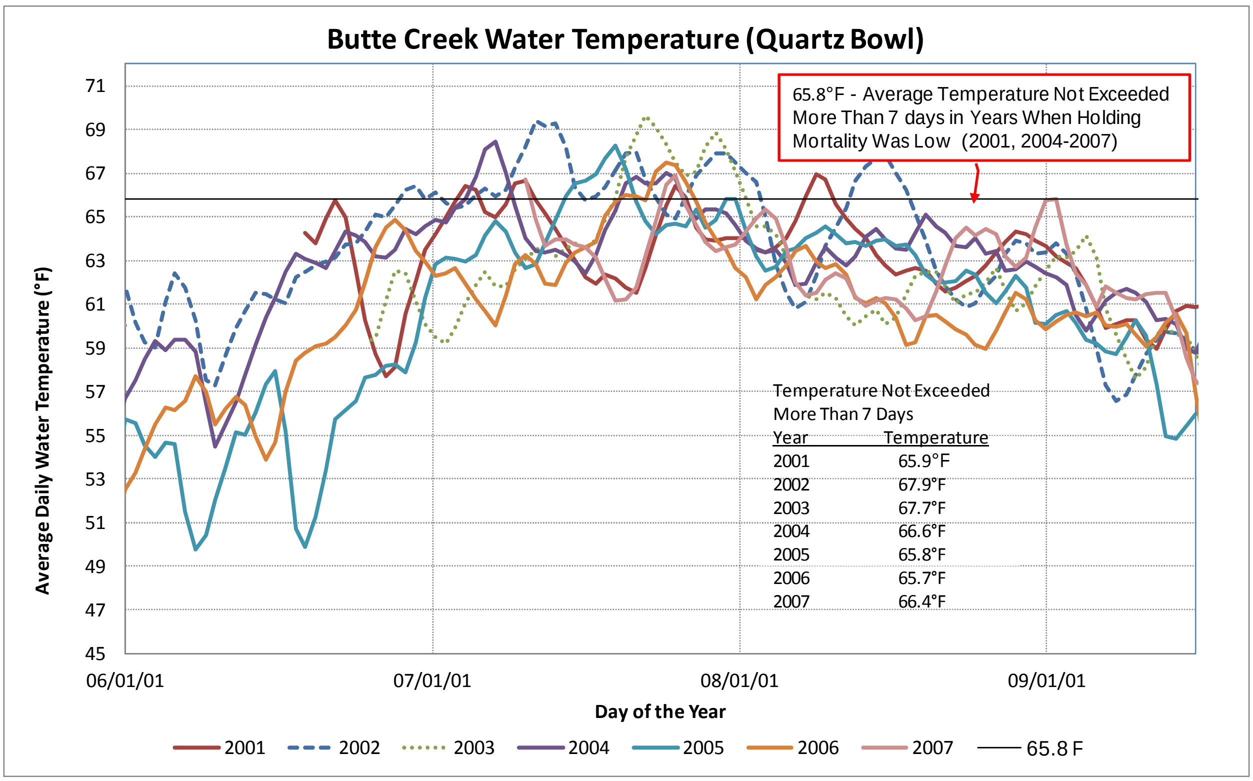


Figure 6. Water Temperature in Butte Creek at Quartz Bowl (2001-2007).

5.3.2 Spawning and Embryo Incubation

Table 7. Chinook Salmon Spawning and Embryo Incubation Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
56°F	Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (Reclamation Unpublished Work). Optimum water temperatures for egg development are between 43°F and 56°F (NMFS 1993b). Upper value of the water temperature range (i.e., 41.0°F to 56.0°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS 1995b). Upper value of the range (i.e., 42.0°F to 56.0°F) given for the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS 1997a). Incubation temperatures above 56°F result in significantly higher alevin mortality (USFWS 1999). 56.0°F is the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River (NMFS 2002a). Water temperatures averaged 56.5°F during the week of fall-run Chinook salmon spawning initiation on the Snake River (Groves and Chandler 1999).
58°F	Upper value of the range given for preferred water temperatures (i.e., 53.0°F to 58.0°F) for eggs and fry (NMFS 2002a). Constant egg incubation temperatures between 42.5°F and 57.5°F resulted in normal development (Combs and Burrows 1957). The natural rate of mortality for alevins occurs at 58°F or less (Reclamation Unpublished Work).
60°F	100 percent mortality can occur to late incubating Chinook salmon embryos (yolk-sac stage) if temperatures are 60°F or greater (Seymour 1956). An October 1 to October 31 water temperature criterion of less than or equal to 60°F in the Sacramento River from Keswick Dam to Bend Bridge has been determined for protection of late incubating larvae and newly emerged fry (NMFS 1993b). Mean weekly water temperature at first observed Chinook salmon spawning in the Columbia River was 59.5°F (Dauble and Watson 1997). Consistently higher egg losses resulted at water temperatures above 60.0°F than at lower temperatures (Johnson and Brice 1953). For Chinook Salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found high (93.8%) Chinook salmon incubation survival through emergence for naturally declining temperatures (0.36°F/day) starting as high as 61.7°F; however, a significant reduction in survival occurred above this temperature.
62°F	100 percent mortality of fertilized Chinook salmon eggs after 12 days at 62°F (Reclamation Unpublished Work). Incubation temperatures of 62ºF to 64°F appear to be the physiological limit for embryo development resulting in 80 to 100 percent mortality prior to emergence (USFWS 1999). 100 percent loss of eggs incubated at water temperatures above 62°F (Hinze 1959). 100 percent mortality occurs during yolk-sac stage when embryos are incubated at 62.5°F (Seymour 1956). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high mortality of Chinook salmon eggs and fry (79%) when incubation temperatures started at 65.2°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

5.3.3 Juvenile Rearing and Downstream Movement

Table 8. Chinook Salmon Juvenile Rearing and Downstream Movement Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F	Optimum water temperature for Chinook salmon fry growth is between 55.0°F and 60°F (Seymour 1956). Water temperature range that produced optimum growth in juvenile Chinook salmon was between 54.0°F and 60.0°F (Rich 1987b). Water temperature criterion of less than or equal to 60.0°F for the protection of Sacramento River winter-run Chinook salmon from Keswick Dam to Bend Bridge (NMFS 1993b). Upper optimal water temperature limit of 61°F for Sacramento River fall-run Chinook salmon juvenile rearing (Marine 1997; Marine and Cech 2004). Upper water temperature limit of 60.0°F preferred for growth and development of spring-run Chinook salmon fry and fingerlings (NMFS 2000; NMFS 2002a). To protect salmon fry and juvenile Chinook salmon in the upper Sacramento River, daily average water temperatures should not exceed 60°F after September 30 (NMFS 1997b). A water temperature of 60°F appeared closest to the optimum for growth of fingerlings (Banks *et al.* 1971). Optimum growth of Nechako River Chinook salmon juveniles would occur at 59°F at a feeding level that is 60 percent of that required to satiate them (Brett *et al.* 1982). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
65°F	Water temperatures between 45°F to 65°F are preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River (NMFS 2002a). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64.0°F are considered not "properly functioning" by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64.0°F (EPA 2001). Disease mortalities diminish at water temperatures below 65.0°F (Ordal and Pacha 1963). Fingerling Chinook salmon reared in water greater than 65.0°F contracted *C. columnaris* and exhibited high mortality (Johnson and Brice 1953). Water temperatures greater than 64.9°F identified as being stressful in the Columbia River Ecosystem (Independent Scientific Group 1996). Juvenile Chinook salmon have an optimum temperature for growth that appears to occur at about 66.2°F (Brett *et al.* 1982). Juvenile Chinook salmon reached a growth maximum at 66.2°F (Cech and Myrick 1999). Optimal range for Chinook salmon survival and growth from 53.0°F to 64.0°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001). Increased incidence of disease, reduced appetite, and reduced growth rates at 66.2±1.4 °F (Rich 1987b). Bioenergetics modeling of growth based on consumption of rainbow trout (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above about 65°F (Figure 5)
68°F	Sacramento River juvenile Chinook salmon reared at water temperatures greater than or equal to 68.0°F suffer reductions in appetite and growth (Marine 1997; Marine and Cech 2004). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).
70°F	No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ±1.8 °F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

75°F	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2°F was determined to be 100 percent lethal due to hyperactivity and disease (Rich 1987b; Zedonis and Newcomb 1997). Lethal temperature threshold for fall-run juvenile Chinook salmon between 74.3 and 76.1°F (McCullough 1999). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan et al. 2000; McCullough et al. 2001; Myrick and Cech 2001)

5.3.4 Yearling + Smolt Emigration

Table 9. Chinook Salmon Yearling + Smolt Emigration Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
63°F	Acceleration and inhibition of Sacramento River Chinook salmon smolt development reportedly may occur at water temperatures above 63°F (Marine 1997; Marine and Cech 2004). Laboratory evidence suggest that survival and smoltification become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997). Juvenile Chinook salmon growth was highest at 62.6°F (Clarke and Shelbourn 1985).
68°F	Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997).
72°F	In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).

5.4 Upstream Migration Behavioral Effects Due to River Temperature Gradients

If volitional upstream passage was provided past Englebright Reservoir (e.g., ladder, dam removal), the potential exists for upstream migrating adult salmonids to have to volitionally pass through significant water temperature differentials from the Lower Yuba River into the South or Middle Yuba rivers (Upper Yuba River) due to cold water releases from New Bullards Bar Reservoir into the Yuba River (via Colgate Powerhouse). **Figure 7** shows an example of water temperature in the Yuba River below Colgate Powerhouse and the South and Middle Fork Yuba rivers near their confluence with the Yuba River. It is possible to modify the temperature differentials by selective withdrawal of water from New Bullards Bar Reservoir (Colgate Powerhouse temperature) or by modifying flows in the South or Middle Yuba rivers; nevertheless, the temperature differentials could be large. For example, during the May-June migration period for spring-run Chinook salmon or the late summer/fall migration period for steelhead, Middle and South Yuba river temperatures are much warmer than the downstream Yuba River temperatures (e.g., > 7°F or > 4°C).

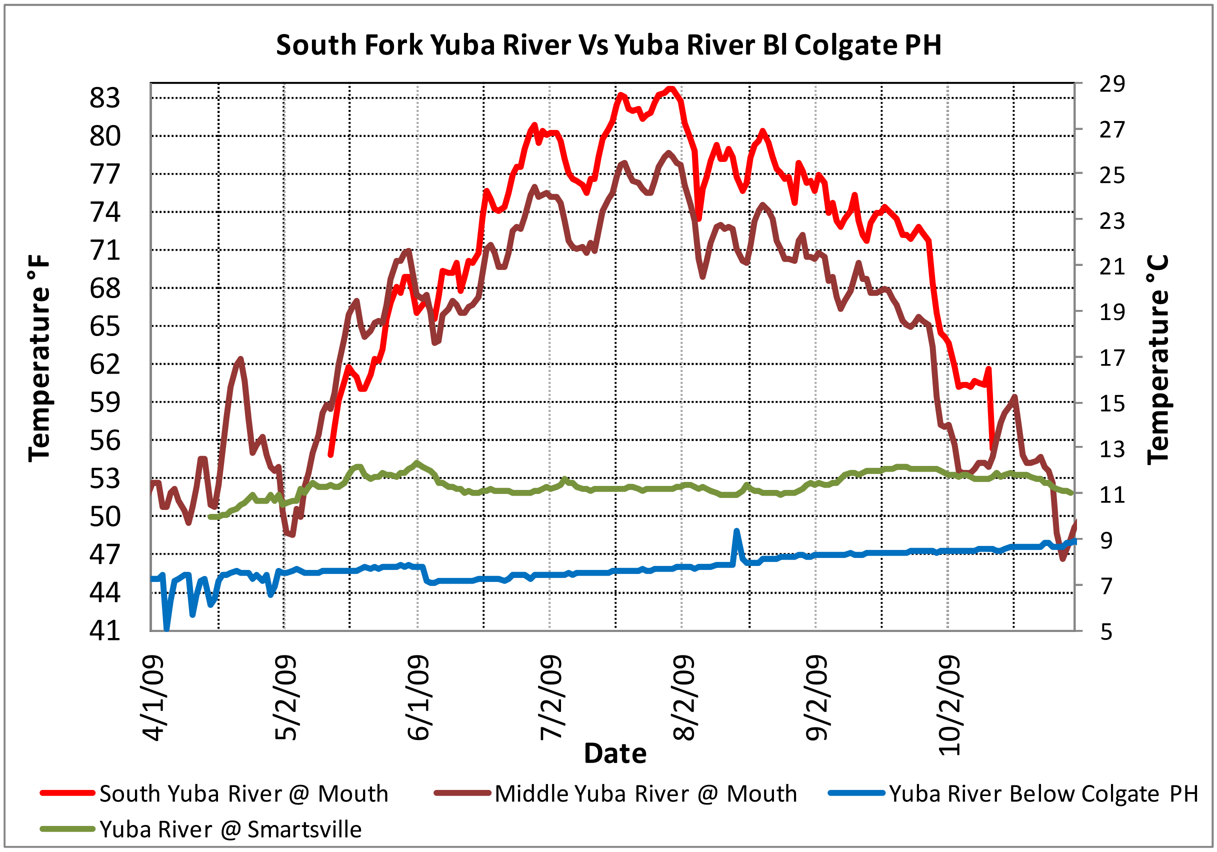


Figure 7. Water Temperature Differentials Between the South and Middle Yuba Rivers, and the Yuba River Below Colgate and at Smartsville.

To date, we have only identified limited information in the literature regarding the effect of temperature differentials on volitional upstream migration of Chinook salmon or steelhead. Typically, as fish migrate upstream in rivers the water temperature becomes cooler. Migrating fish may move from cooler ocean/estuary temperatures (Strange 2010) into warmer river temperatures, but as fish move upstream in rivers, the temperature typically gets cooler. In the case of migration from the Yuba River to the South and Middle Yuba rivers, fish could be faced with moving in a reverse temperature gradient from cooler downstream water, into warmer upstream water.

In the Columbia River both migrating Chinook salmon and steelhead use coolwater tributaries as thermal refugia during warm summer conditions. Staging in coolwater tributaries significantly slows and affects the migratory behavior of the fish (High et al.

2006; Goniea et al. 2006). Also temperature differentials at Columbia River ladders (e.g., colder water at the entrance to the ladder versus warmer water in the ladder), even relatively small temperature differentials, can slow migration rates through the ladders. Caudill et al. (2005) found that few fish passed the ladders when temperature differentials were > 7°F (> 4°C) and that passage times increased with increased temperature differential (e.g., > 2°F).

In the Snake River/Clearwater River system a somewhat analogous temperature situation exists compared to that which may occur in the Yuba River system. During the summer (July-August) cold water is released from Dworshak Reservoir on the North Fork Clearwater River into the Clearwater River. As a result, the Clearwater River becomes colder than the Snake River where they meet near Lewiston, Idaho. Spring-run Chinook salmon are generally not affected because by July, most spring-run Chinook salmon moving up the Clearwater River are already past the mouth of the North Fork Clearwater River, and are up close to or in their higher elevation natal streams getting ready to spawn. It does appear, however, that some later returning spring-run Chinook salmon do hold longer than they would have normally, near or in the North Fork Clearwater River, because of the colder water coming out of Dworshak Reservoir. As a result, there is spawning activity that occurs in the lower North Fork Clearwater River (it is possible that some of these fish may be hatchery fish shunted off from entering Dworshak Hatchery).

The cooling effect of Dworshak Reservoir releases to the Clearwater River does modify the behavior of returning steelhead and fall-run Chinook salmon at the confluence with the Snake River. The cooler water in the Clearwater River draws fish destined for the Snake River into the Clearwater River and they hold in the mouth of the Clearwater River until the Snake River cools down (Personal Communication, Bill Arnsberg, Nez Perce Tribal Biologist).

Our recommendation is that additional literature and data should be obtained and summarized regarding the effect of water temperature differentials on volitional migration (if such information exists). In addition, based on the limited information available, a temperature differential of 7°F (4°C) should precautionarily be viewed as a potential thermal barrier to adult upstream migration. It is possible that even lower temperature differentials (< 7°F) could result in migrating fish holding downstream and not migrating, or significantly delaying migration.

6 TEMPORAL TEMPERATURE PATTERNS RELATED TO WATER TEMPERATURE INDEX VALUES AND METRICS

Typical water temperature patterns in the Yuba River system exhibit a week or two of high temperatures and a much broader range of temperatures that are lower. For example, **Figure 8** shows historical water temperature in the section of the Middle Yuba River near Wolf Creek in 2008. This site is used below to briefly discuss temporal temperature patterns and their relationship to critical WTI values and some typical water temperature metrics used in the literature to summarize water temperature.

Historical daily average water temperatures at the Middle Yuba River site were near the temperature that has been observed to cause mortality to Chinook Salmon in Butte Creek (e.g., 67°F or greater) (Ward et al. 2004). Most of the summer, daily average water temperatures at the Middle Yuba River site were at or below 67°F, but there were a couple of weeks that the average daily water temperature exceeded 67°F (similar to conditions that caused mortality in Butte Creek). Maximum daily water temperatures at the site during much of the summer were near the 7-day UILT[3] for Chinook salmon adults of 69.8-71.6°F (McCullough 1999). However, the duration of time within a day that the water temperature was near the 7-day UILT was short and is not available from the plot nor from typical maximum temperature metrics (see below).

Some typical temperature metrics are shown on Figure 8. The 7-day moving average temperature (7DMA) also exceeded 67°F for the same two time periods that the average daily temperature exceeded 67°F. The maximum weekly average temperature (MWAT) (average of the daily mean temperature of the 7 warmest days) occurred in mid-July and was 67.9°F. The maximum daily temperatures, 7-day moving average daily maximum (7DMADM), were about 4°F greater than the mean daily temperature during the warmest months, and the 7-day average daily maximum temperature (7DADM) occurred at the same time as the MWAT (67.9 °F versus 71.7°F).

Historically in Butte Creek, when average daily water temperature was 67°F for more than about a week (11 and 16 days in 2002 and 2003, respectively) significant adult Chinook salmon mortality occurred. However, if water temperature exceeded 67°F for a relatively short number of days (e.g., < 7 days), significant mortality did not occur (Ward et al. 2004).

An analogous approach for analyzing the Yuba River water temperatures could be used. This could be done by using WTI values, where exceeding the WTI temperature criteria for less than 7 days would not be expected to affect each lifestage, but exceeding the WTI for more than 7 days would be detrimental.

[3] Note, however, the UILT is 7 continuous days exposure and is not comparable to a daily maximum temperature.

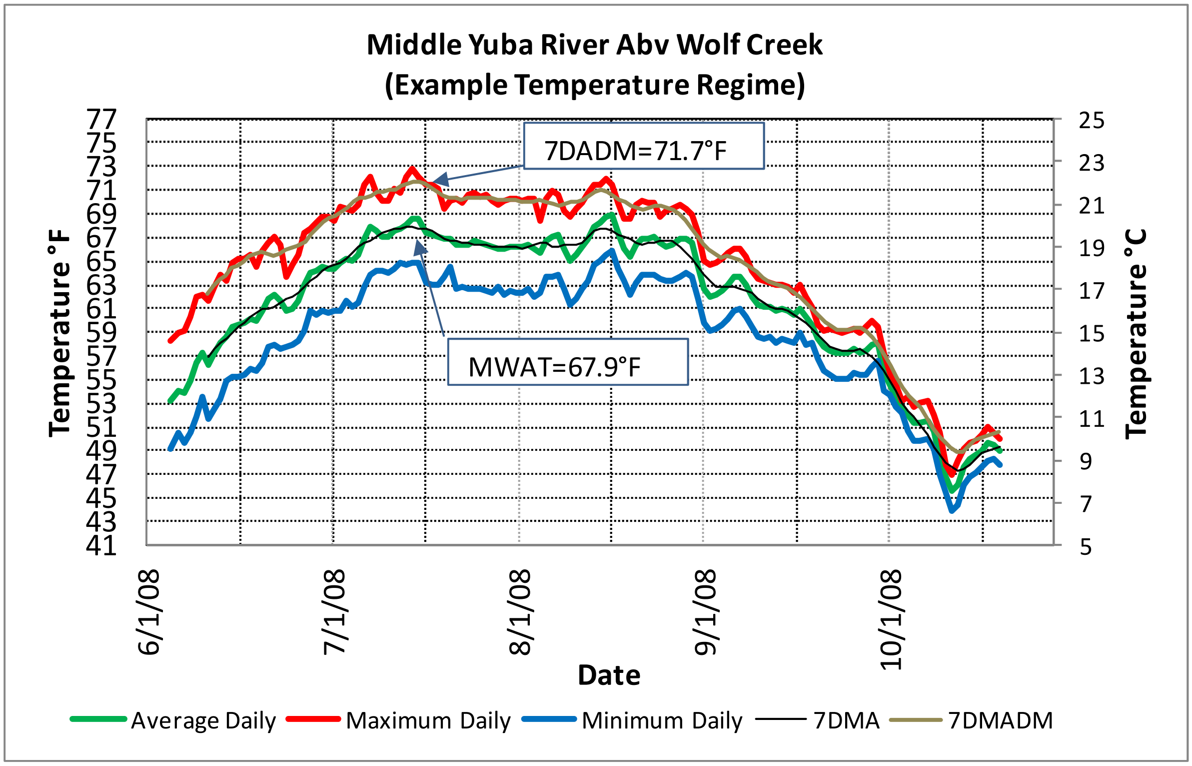


Figure 8. Middle Fork Yuba River Water Temperature Including 7 Day Moving Averages of the Average Daily Temperature and the Maximum Daily Temperature. Also Included Are the Maximum Weekly Average Temperature (MWAT) and the 7 Day Average Daily Maximum Temperature (7DADM).

Quantifying the number of average daily water temperature values that exceed a WTI threshold would be a direct approach to quantifying habitat suitability. The MWAT and/or the moving average (7DMA) identify a maximum average weekly water temperature value, but do not indicate the duration of time that this occurred. Similarly, if acute temperature was a concern, the individual water temperature measurements (e.g., hourly) could be used to identify the number of hours (duration) that a maximum WTI value was exceeded (e.g., tally the number of days and hours). Conversely, the 7DADM and/or the moving average (7DMADM) identify a maximum average weekly maximum temperature value, but do not indicate the duration of time that it occurred.

7 SPECIES- AND LIFESTAGE-SPECIFIC WATER TEMPERATURE RANGE ACCEPTABLE FOR REINTRODUCTION EVALUATION

The goal of the temperature analysis is twofold: (1) to identify the high temperature WTI value(s) that clearly demarcate the spatial/temperature boundary between where steelhead and Chinook salmon lifestages can and cannot exist (even though temperature is a stressor) (upper tolerable WTI); and (2) to determine within the "can exist" boundary, if there is a core area where they can thrive without temperature as a stressor (upper optimal WTI). The upper tolerable temperature represents the upper boundary of the range of acceptable water temperatures for reintroduction evaluation. It represents a water temperature at which fish can survive indefinitely, without experiencing substantial detrimental effects to physiological and biological functions such that survival occurs, but growth and reproduction success are reduced below optimal. The upper optimal temperature represents the upper boundary of the optimum range and represents a temperature below which growth, reproduction, and/or behavior are not affected by temperature. Below, we discuss: (1) existing regulatory water temperature standards or guidelines that could be used as index values; and (2) specific water temperature index values that have been derived based on the literature review in this report.

7.1 Existing Water Temperature Standards/Guidelines

Several different water temperature standards are used currently by states for salmonids (e.g., California, Oregon, and Washington water temperature standards). California's Basin Plan is largely based on not altering the temperature of intrastate waters unless alterations can be shown to not have an effect on beneficial uses for cold freshwater habitat, migration, and/or spawning (**Table 10**). The beneficial uses of the Yuba River are listed in **Table 11**. Specific temperature criteria for species/lifestages are not identified in the Basin Plan nor are there specific temperature objectives for the Yuba River system. However, for the Sacramento River, seasonal temperature criteria have been developed (Table 10). These temperature objectives, while not directly applicable to the Yuba River, give an indication of temperature objectives that have been set for anadromous fish in the basin.

Table 10. Basin Plan Temperature Standards Including Specific Standards for the Sacramento River.

Temperature

The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses.

Temperature objectives for COLD interstate waters, WARM interstate waters, and Enclosed Bays and Estuaries are as specified in the *Water Quality Control Plan for Control of Temperature in the Coastal and Interstate Waters and Enclosed Bays of California* including any revisions. There are also temperature objectives for the Delta in the State Water Board's May 1991 *Water Quality Control Plan for Salinity*.

At no time or place shall the temperature of COLD or WARM intrastate waters be increased more than 5°F above natural receiving water temperature. Temperature changes due to controllable factors shall be limited for the water bodies specified as described in Table III-4. To the extent of any conflict with the above, the more stringent objective applies.

In determining compliance with the water quality objectives for temperature, appropriate averaging periods may be applied provided that beneficial uses will be fully protected.

TABLE III-4
SPECIFIC TEMPERATURE OBJECTIVES

DATES	APPLICABLE WATER BODY
From 1 December to 15 March, the maximum temperature shall be 55°F. From 16 March to 15 April, the maximum temperature shall be 60°F. From 16 April to 15 May, the maximum temperature shall be 65°F. From 16 May to 15 October, the maximum temperature shall be 70°F. From 16 October to 15 November, the maximum temperature shall be 65°F. From 16 November to 30 November, the maximum temperature shall be 60°F.	Sacramento River from its source to Box Canyon Reservoir (9); Sacramento River from Box Canyon Dam to Shasta Lake (11)
The temperature in the epilimnion shall be less than or equal to 75°F or mean daily ambient air temperature, whichever is greater.	Lake Siskiyou (10)
The temperature shall not be elevated above 56°F in the reach from Keswick Dam to Hamilton City nor above 68°F in the reach from Hamilton City to the I Street Bridge during periods when temperature increases will be detrimental to the fishery.	Sacramento River from Shasta Dam to I Street Bridge (13, 30)

Table 11. Basin Plan Beneficial Uses for the Yuba River.

TABLE II-1

SURFACE WATER BODIES AND BENEFICIAL USES

	SURFACE WATER BODIES (1)	HYDRO UNIT NUMBER	MUN: MUNICIPAL AND DOMESTIC SUPPLY	AGRI-CULTURE AGR: IRRIGATION	AGRI-CULTURE AGR: STOCK WATERING	INDUSTRY PROC: PROCESS	INDUSTRY IND: SERVICE SUPPLY	INDUSTRY POW: POWER	RECREATION REC-1: CONTACT	RECREATION REC-1: CANOEING AND RAFTING (1)	RECREATION REC-2: OTHER NONCONTACT	FRESHWATER HABITAT (2) WARM: WARM	FRESHWATER HABITAT (2) COLD: COLD	MIGRATION MIGR: WARM (3)	MIGRATION MIGR: COLD (4)	SPAWNING SPWN: WARM (3)	SPAWNING SPWN: COLD (4)	WILD: WILDLIFE HABITAT	NAV: NAVIGATION
	YUBA RIVER																		
41	SOURCES TO ENGLEBRIGHT RESERVOIR	517.	E	E	E			E	E	E	E		E				E	E	
42	ENGLEBRIGHT DAM TO FEATHER RIVER	515.3		E	E			E	E	E	E	E	E	E	E	E	E	E	

LEGEND
E = EXISTING BENEFICIAL USES
P = POTENTIAL BENEFICIAL USES
L = EXISTING LIMITED BENEFICIAL USE

The EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) provides water temperature recommendations regarding coldwater salmonid uses and numeric criteria to protect those uses for the following:

Salmonid Uses	Criteria
Salmon/trout core juvenile rearing	61°F (16°C) 7DADM
Salmon/trout migration plus non-core juvenile rearing	64°F (18°C) 7DADM
Salmon/trout migration	68°F (20°C) 7DADM
Salmon/trout spawning, egg incubation, and fry emergence	55°F (13°C) 7DADM
Steelhead smoltification	57°F (14°C) 7DADM

These temperature criteria are developed for summer water temperatures, except for the spawning and smolting lifestages which occur earlier in the year. The criteria are intended to represent the upper end of the optimal temperature range for each lifestage. It is important to note that the criteria are based on 7DADM (daily maximum temperatures), while the data used to generate the criteria were primarily based on daily average or continuous temperature field/laboratory data sets (**Table 12**). Several general assumptions were applied by EPA (2003b) to the data to make a connection between 7DADM temperature and the field/laboratory data (Section 8.1).

Table 12. EPA (2003b) Laboratory and Field Data Summary for Generating Water Temperature Criteria.

Life Stage	Temperature Consideration	Temperature & Unit	Reference
Spawning and Egg Incubation	*Temp. Range at which Spawning is Most Frequently Observed in the Field	4 - 14°C (daily avg)	Issue Paper 1; pp 17-18 Issue Paper 5; p 81
	* Egg Incubation Studies - Results in Good Survival -Optimal Range	4 - 12°C (constant) 6 - 10°C (constant)	Issue Paper 5; p 16
	*Reduced Viability of Gametes in Holding Adults	> 13°C (constant)	Issue Paper 5; pp 16 and 75
Juvenile Rearing	*Lethal Temp. (1 Week Exposure)	23 - 26°C (constant)	Issue Paper 5; pp 12, 14 (Table 4), 17, and 83-84
	*Optimal Growth - unlimited food - limited food	13 - 20°C (constant) 10 - 16°C (constant)	Issue Paper 5; pp 3-6 (Table 1), and 38-56
	*Rearing Preference Temp. in Lab and Field Studies	10 - 17°C (constant) < 18°C (7DADM)	Issue Paper 1; p 4 (Table 2). Welsh et al. 2001.
	*Impairment to Smoltification	12 - 15°C (constant)	Issue Paper 5; pp 7 and 57-65
	*Impairment to Steelhead Smoltification	> 12°C (constant)	Issue Paper 5; pp 7 and 57-65
	*Disease Risk (lab studies) -High - Elevated - Minimized	> 18 - 20°C (constant) 14 - 17°C (constant) 12 - 13°C (constant)	Issue Paper 4, pp 12 - 23
Adult Migration	*Lethal Temp. (1 Week Exposure)	21- 22°C (constant)	Issue Paper 5; pp 17, 83 - 87
	*Migration Blockage and Migration Delay	21 - 22°C (average)	Issue Paper 5; pp 9, 10, 72-74. Issue Paper 1; pp 15 - 16
	*Disease Risk (lab studies) - High - Elevated - Minimized	> 18 - 20°C (constant) 14 - 17°C (constant) 12- 13°C (constant)	Issue Paper 4; pp 12 - 23
	*Adult Swimming Performance - Reduced - Optimal	> 20°C (constant) 15 - 19°C (constant)	Issue Paper 5; pp 8, 9, 13, 65 - 71
	* Overall Reduction in Migration Fitness due to Cumulative Stresses	> 17-18°C (prolonged exposures)	Issue Paper 5; p 74

In addition to the numeric temperature criteria, there are a number of other factors (e.g., site specific issues, background temperatures) that EPA (2003b) considered in recommending coldwater salmonid uses and water quality standards (WQS) to protect those uses. These factors and the EPA's recommended approach for establishing WQS are described in EPA (2003b).

EPA (2003b) recognized that salmonids will use waters that are warmer than their optimal thermal range and further recognizes that some portions of rivers and streams naturally (i.e., absent human impacts) were warmer than the salmonid optimal range. They also recognized that some streams have unique diurnal temperature patterns, which may necessitate modified WQS. To account for these issues, the EPA identified three alternate salmonid temperature standard approaches. These include identifying the natural background temperature of the water body, creating site-specific temperature criteria, and/or identifying that a criterion is "unattainable" and altering the use designation to a use designation that has a criterion that is obtainable.

The EPA's water temperature recommendations are intended to assist States and Tribes to adopt temperature WQS that the EPA can approve consistent with its obligations under the Clean Water Act and the Endangered Species Act. States and Tribes that adopt temperature WQS consistent with these recommendations can expect an expedited review by EPA and the Services, subject to new data and information that might be available to during that review (EPA 2003b). In some cases, the criteria seem to be conservative and may exclude habitat that is currently used and/or demonstrably usable by salmonid lifestages. Section 8.1 has a brief discussion of issues related to the EPA (2003b) numerical criteria based on 7DADM temperatures and the needs of the Yuba Salmon Forum.

7.2 Site Specific Water Temperature Index Values

In addition to the EPA (2003b) numeric temperature criteria (Section 7.1) it also seems appropriate to develop Yuba Salmon Forum water temperature index values that are specific to the purposes of the Yuba Salmon Forum and the Yuba River. Below, for each species/lifestage, we provide: (1) an upper tolerance WTI (UTWTI) that identifies the sustained (chronic) tolerance/no tolerance boundary; and (2) the upper optimal WTI (UOWTI) where physiological processes (growth, disease resistance, normal development of embryos) are not stressed by temperature.

The lifestage-specific WTI values are not intended to represent significance thresholds, but instead provide criteria to evaluate reintroduction of anadromous salmonids. Moreover, as suggested by DWR (2007), the use of temperature "boundaries" has inherent drawbacks associated with the often indistinguishable effects at the upper and lower ends of an identified range and attributing undue specificity to values slightly exceeding an identified range. Nonetheless, WTI values, as defined, are used for evaluation of water temperature considerations regarding the reintroduction of steelhead (**Table 13**) and spring-run Chinook salmon (**Table 14**) in the Upper Yuba River Basin.

7.2.1 Steelhead

Table 13. Lifestage-Specific Upper Optimal Water Temperature Index (UOWTI) Values and Upper Tolerance Water Temperature Index (UTWTI) Values Identified as Defining the Range of Acceptable Water Temperatures for Evaluation of the Reintroduction of Steelhead in the Upper Yuba River Basin.

Lifestage	Upper Optimum WTI[1]	Upper Tolerance WTI[1]	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Adult Migration	64°F	68°F	■■	■■	■■					■■	■■	■■	■■	■■
Adult Holding	61°F	65°F	■■	■■	■■					■■	■■	■■	■■	■■
Spawning	54°F	57°F	■■	■■	■■	■■								
Embryo Incubation	54°F	57°F	■■	■■	■■	■■	■■							
Juv. Rearing & Downstream Mvmt.	65°F	68°F	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■
Smolt Emigration	52°F	55°F	■■	■■	■■	■□						■■	■■	■■

[1] The WTI values are to be applied to the water temperature metrics recommended in Section 8, below.

7.2.2 Spring-run Chinook Salmon

Table 14. Lifestage-Specific Upper Optimal Water Temperature Index (UOWTI) Values and Upper Tolerance Water Temperature Index (UTWTI) Values Identified as Defining the Upper Acceptable Water Temperatures for Evaluation of the Reintroduction of Spring-Run Chinook Salmon in the Upper Yuba River Basin.

Lifestage	Upper Optimum WTI[1]	Upper Tolerance WTI[1]	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Adult Migration	64°F	68°F				■■	■■	■■	■■	■■				
Adult Holding	61°F	65°F				■■	■■	■■	■■	■■				
Spawning	56°F	58°F									■■	■■	■□	
Embryo Incubation	56°F	58°F	■■	■■							■■	■■	■■	■■
Juv. Rearing & Downstream Mvmt.	61°F	65°F	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■	■■
Smolt Emigration	63°F	68°F	■■	■■	■■	■■	■□					■■	■■	■■

[1] The WTI values are to be applied to the water temperature metrics recommended in Section 8, below.

8 WATER TEMPERATURE METRICS

Water temperature metrics (e.g., MWAT, 7DADM) are typically designed to provide a reproducible index of temperature over a period of time that can be used in combination with temperature standards (numeric criteria values) to determine if a water temperature body is impaired. Water temperature metrics are by definition an index of the complete temperature time series. As such, they do not completely represent the temperature time series nor are they always the most accurate way to represent the biological response of various lifestages. Water temperature metrics for potential application to the Yuba Salmon Forum specific criteria (UOWTI and UTWTI) are described below.

8.1 7DADM

The EPA (2003a) recommends the 7DADM (maximum 7-day average of the daily maxima) as a water temperature metric for all of the numeric criteria that is applied to a specific species and lifestage. The 7DADM is similar to the maximum weekly average temperature metric that was previously used by the EPA for its national temperature criteria recommendations (EPA 1977). However, in 2003, the EPA initiated use of the 7DADM metric "because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day."

A 7DADM value is calculated by adding the daily maximum temperatures recorded at a site on seven consecutive days and dividing by seven. Thus, it reflects an average of daily maximum temperatures that fish are exposed to over a week-long period. EPA (2003b) states that because this metric "is oriented to daily maximum temperatures, it can be used to protect against acute effects, such as lethality and migration blockage conditions." This statement illustrates two shortcomings of the EPA (2003a) use of the 7DADM metric. The 7DADM: (1) includes no duration information, which is critical to understanding acute (zone of resistance) temperature analysis – rather, it is an index of maximum temperature that occurs for a short time each day and, most importantly; (2) the numeric criteria that are identified by EPA (2003b) are not acute criteria nor derived from acute criteria data, but are chronic temperature criteria.

The EPA (2003b) numeric criteria were derived from chronic field or laboratory studies (e.g., > 7 day continuous or average daily temperatures), including the migratory blockage data (see Section 5.1; Table 12). A couple of simple examples illustrate this concept. The EPA (2003b) juvenile core rearing criteria is 61°F 7DADM and is the same temperature value as the upper optimal growth temperature under limited food (Table 12, 16°C), but the optimal growth temperature was derived from constant temperature laboratory studies. This temperature is much lower than the temperature where acute temperature affects occur. The UILT (7 day) from literature studies is 72 - 79°F (e.g., Table 12) and for shorter duration exposure is even much higher 80 - 88°F (e.g., see Table TT2 in Myrick and Cech 2001). Another example is the migration criteria. The migration blockage source data is based on observations in natural rivers, and is based on daily average or weekly field temperatures (70 – 72°F) (Table 12; McCullough 1999).

A daily maximum temperature equivalent of this temperature (70°F) is approximately 75°F [4], but the EPA (2003b) 7DADM numeric criterion for migration was set at 68°F.

EPA (2003b) states that the 7DADM metric can also can be used to protect against sub-lethal or chronic effects (e.g., temperature effects on growth, disease, smoltification, and competition), but the resultant cumulative thermal exposure fish experience over the course of a week or more needs to be considered when selecting a 7DADM value to protect against these effects. The EPA's general conclusion from studies on fluctuating water temperature regimes (which is what fish generally experience in rivers) is that fluctuating temperatures increase juvenile growth rates when mean temperatures are colder than the optimal growth temperature derived from constant temperature studies, but will reduce growth when the mean temperature exceeds the optimal growth temperature (see Issues Paper 5, pages 51-56). When the mean temperature is above the optimal growth temperature, the “mid-point” temperature between the mean and the maximum is the “equivalent” constant temperature. This “equivalent” constant temperature then can be directly compared to laboratory studies done at constant temperatures. For example, a river with a 7DADM value of 64°F and a 58°F weekly mean temperature (i.e., diurnal variation of ± 5.4°F) will be roughly equivalent to a constant laboratory study temperature of 61.7°F (mid-point between 58°F and 65°F). Thus, both maximum and mean temperatures are important when determining a 7DADM value that is protective against sub-lethal/chronic temperature effects.

To account for using the 7DADM metric based on constant temperature laboratory data, EPA (2003a) assumed an average diel temperature difference between the mean and daily maximum temperature of 5.4°F, although the EPA appears to have decreased the temperature in the laboratory data down by 2.7°F (equivalently added 2.7°F to the criteria). It is completely unclear, however, if or how EPA then also accounted for the fact that 7DADM temperature is on average also 5.4°F greater than the average daily temperature (i.e., was this accounted for or not).

It also is unclear if the “midpoint of the maximum and average temperature” correction was applied for all lifestages. If so, this would be inappropriate based on the data available. The “midpoint” correction literature is only applicable to juvenile growth. There is no evidence presented that it is applicable to other lifestages. Also, the juvenile growth “midpoint” temperature correction is somewhat mis-represented in EPA (2003b). The main study relied on by EPA (2003b) is Hokanson et al. (1977), and that study states that the difference in growth between constant and diel fluctuating temperatures was 39% (1.5°C in a ±3.8C fluctuating range) of the difference between the

[4] Maximum daily temperatures are typically 5.4°F higher than average daily temperature (EPA 2003b).

average and maximum temperature (not 50% or the midpoint) and, perhaps more importantly, most of the studies reviewed by EPA indicate that growth in constant temperature was essentially equivalent to growth in fluctuating temperatures. Elliott (1975), for example, found that a growth model developed from constant temperature experimental data predicted brown trout growth in daily fluctuating temperature environments accurately when the mean daily value of the fluctuating temperature was used as input to the growth model.

For the evaluation of potential water temperature-related impacts associated with the reintroduction of anadromous salmonids into the Upper Yuba River Basin, 7DADM values could be calculated for species-specific lifestage periods on an annual basis over the simulation or empirical data period, and the occurrences when that 7DADM values exceed the EPA (2003b) numeric values could be compared among rivers/reaches in the Upper Yuba River Basin.

8.2 ADT

The average daily temperature (ADT) should be considered for application to the Yuba Salmon Forum specific criteria (WTI values) because nearly all of the data in the literature review were either based on ADT or on continuous temperature (also see Table 12). For juvenile growth, the data from Hokanson et al. (1977) can be directly applied to the constant temperature data to provide a correction, if deemed appropriate. The average daily temperature also can be used to determine the number of days (duration) that a WTI is exceeded, and duration of exceedance can be compared among specific geographic areas.

8.3 MWAT

The Maximum Weekly Average Temperature (MWAT) is a metric used by the California RWQCB that is commonly applied to water temperature numeric objectives. Generally, the MWAT serves as a summary measurement of instream water temperature variation that may occur on a daily or seasonal basis, and is used to evaluate chronic (sub-lethal) water temperature impacts (SWRCB website).

The MWAT is found by calculating the mathematical mean of multiple, equally spaced, daily water temperatures over a 7-day consecutive period. The MWAT is defined as the highest value calculated for all possible 7-day periods over a given time period, which usually extends over the summer or is commensurate to the duration of a salmonid lifestage. In order to determine whether the maximum weekly temperature standard is attained, the mathematical mean of multiple, equally spaced, daily temperatures over a seven-day consecutive period is compared to the criterion.

For the evaluation of acceptable water temperature-related reintroduction potential associated with spring-run Chinook salmon and steelhead in the Upper Yuba River Basin, MWAT values should be calculated for species-specific lifestage periods, on an annual basis over the monitoring or simulation period, and the probability that MWAT values exceed specified water temperature index values will be compared among rivers/reaches in the Upper Yuba River Basin.

The use of a single temperature measurement such as MWAT is convenient from a monitoring and regulatory standpoint, but oversimplifies the complex interactions between water temperature regimes and fish health which are affected by the duration of peak and daily average temperatures. Therefore, for the evaluation of acceptable water temperature-related reintroduction potential associated with spring-run Chinook salmon and steelhead in the Upper Yuba River Basin, it is recommended that both the MWAT, and ADT lifestage-specific exceedance durations, be compared with the UOWTI and UTWTI values.

8.4 7DMAVG

The 7-day moving average of maximum daily temperature (7DMAVG) serves as the basis for instream water temperature standards, including those of the Oregon Department of Environmental Quality (ODEQ). The reason for using the 7DMAVG is to decrease the effect of a single peak temperature on data interpretation. Aquatic organisms are affected more by exposure to high temperature over an extended period than to a single exceedance of the criteria. The ODEQ recognizes that not only summer maximum temperatures are of importance to aquatic biota. The intent is to protect the temperature regime through the year. Built into the ODEQ 7DMAVG standard is the assumption that if stream and riparian conditions are managed such that they meet the summer maximum criteria, those same conditions will protect the temperature regime of the stream through the year.

The 7DMAVG standard is based not on directly lethal temperatures (usually above 70°F), but on sub-lethal effects, which are numerous. Sub-lethal effects can lead to death indirectly, or they may reduce the ability of the fish to successfully reproduce and for their offspring to survive and grow. These sub-lethal effects include an increase in the incidence of disease, an inability to spawn, a reduced survival rate of eggs, a reduced growth and survival rate of juveniles, increased competition for limited habitat and food, reduced ability to compete with other species that are better adapted to higher temperatures (many of these are introduced species) and other adverse effects. Sub-lethal effects of temperature on salmonids occur gradually as stream temperatures increase.

In California, the 7DMAVG has been applied in effectiveness monitoring protocols (e.g. 2006 Green Diamond Resource Company Aquatic Habitat Conservation Plan/Candidate Conservation Agreement and Assurances) and other monitoring efforts (e.g., Upper Yuba River Studies Program 2006 Upper Yuba River Water Temperature Criteria for Chinook salmon and Steelhead). However, for the evaluation of water temperature-related reintroduction potential associated with spring-run Chinook salmon and steelhead in the Upper Yuba River Basin, 7DMAVG is not recommended as a metric.

9 WATER TEMPERATURE EVALUATION CONSIDERATIONS

For the evaluation of water temperatures acceptable for reintroduction of salmonids in the Upper Yuba River Basin, it is anticipated that water temperature modeling and/or monitoring will be applied for a comparison among rivers and reaches in the Upper Yuba River Basin. In addition to the application of the criteria and metrics as described in the preceding sections, it may be appropriate to consider other specific evaluation methodologies.

9.1 Water Year Type

Model output and/or monitoring data could be summarized by water year type. Comparisons of the water temperature-related potential among rivers and reaches in the Upper Yuba River Basin could include water year types. This would help identify reaches/lengths of river that would be suitable in all conditions (e.g., critically dry to wet years) as well as the lengths of river that would be suitable under more favorable conditions (e.g., wet water year types only).

9.2 Water Temperature Exceedance Curves

Model output and/or monitoring data also could be summarized by the calculation of water temperature exceedance curves, by month, occurring over the period of evaluation for each of the rivers and reaches. Exceedance curves are particularly useful for examining the probability of occurrence/duration of water temperatures. The evaluation approach could specifically evaluate the probabilities/duration of time that each of the identified lifestage-specific water temperature index values would be exceeded over the period of evaluation. Comparisons of the water temperature-related potential among rivers and reaches in the Upper Yuba River Basin could be made by presentation of monthly cumulative water temperature exceedance distribution probabilities (using average daily water temperatures) relative to specified water temperature index values corresponding to the appropriate months for each lifestage of spring-run Chinook salmon and steelhead.

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APPENDIX A

LIFESTAGE-SPECIFIC WATER TEMPERATURE BIOLOGICAL EFFECTS AND INDEX TEMPERATURE VALUES

STEELHEAD LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Adult Immigration and Holding

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. YCWA et al. (2007) suggests that few studies have been published examining the effects of water temperature on either steelhead immigration or steelhead holding, and none of the available studies were recent (Bruin and Waldsdorf 1975; McCullough *et al.* 2001). The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid 50°F range, and that immigration will be delayed if water temperatures approach approximately 70°F (**Table 2**). Water temperature index values of 52°F, 56°F, 61°F, 65°F and 70°F were chosen because they provide a gradation of potential water temperature effects, and the available literature provided the strongest support for these values.

Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of water temperature index values could not be achieved. We also used some pertinent information related to other salmonids (e.g., Chinook salmon). 52°F was selected as a water temperature index value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (McEwan and Jackson 1996; NMFS 2000; NMFS 2002a), and "optimum" (Reclamation 1997a) water temperature for steelhead adult immigration. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value. 56°F was selected as a water temperature index value because 56°F represents a water temperature above which adverse effects to migratory and holding steelhead begin to arise (Bruin and Waldsdorf 1975; Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 50-59°F is referred to as the "preferred" range of water temperatures for California summer steelhead holding (Moyle 1995). Whereas, water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS 1995). 65°F was selected as a water temperature index value because steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Additionally, over 93% of steelhead detections occurred in the 65.3-71.6°F range, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006) and/or may modify migration timing due to holding in coldwater refugia (High et al. 2006). 70°F was selected as the highest water temperature index value because the literature suggests that water temperatures near and above 70.0°F may result in a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001) and are water temperatures referred to as "stressful" to upstream migrating steelhead in the Columbia River (Lantz

1971 as cited in Beschta et al 1987). Further, Coutant (1972) found that the UILT for adult steelhead was 69.8°F and temperatures between 73-75°F are described as "lethal" to holding adult steelhead in Moyle (2002).

Spawning and Embryo Incubation

Relatively few studies have been published directly addressing the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979; Rombough 1988). Because anadromous steelhead and non-anadromous rainbow trout are genetically and physiologically similar, studies on non-anadromous rainbow trout also were considered in the development of water temperature index values for steelhead spawning and embryo incubation (Moyle 2002; McEwan 2001). From the available literature, water temperatures in the low 50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high 50°F range and above (**Table 3**). Water temperatures in the 45-50°F range have been referred to as the "optimum" for spawning steelhead (FERC 1993).

Water temperature index values of 46°F , 52°F, 54°F, 57°F, and 60°F were selected for two reasons. First, the available literature provided the strongest support for water temperature index values at or near 46°F, 52°F, 54°F, 57°F, and 60°F. Second, the index values reflect a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead spawning and embryo incubation. Some literature suggests water temperatures ≤ 50°F are when steelhead spawn (Orcutt et al. 1968) and/or are optimal for steelhead spawning and embryo survival (FERC 1993; Myrick and Cech 2001; Timoshina 1972) and temperatures between 39-52°F are "preferred" by spawning steelhead (IEP Steelhead Project Work Team (no date); McEwan and Jackson 1996), a larger body of literature suggests optimal conditions occur at water temperatures ≤ 52°F (Humpesch 1985; NMFS 2000; NMFS 2001a; NMFS 2002a; Reclamation 1997b; SWRCB 2003; USFWS 1995a). Further, water temperatures between 48-52°F were referred to as "optimal" (FERC 1993; McEwan and Jackson 1996; NMFS 2000) and "preferred" (Bell 1986) for steelhead embryo incubation. Therefore, 52°F was selected as the lowest water temperature index value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation life stage may reportedly occur above the 52°F water temperature index value.

54°F was selected as the next index value, because although most of the studies conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions, and conditions that cause negative effects to steelhead spawning and embryo incubation. Further, water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993). 57°F was selected as an index value because embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57.0°F. Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50% hatch under incubation temperatures ranging from 33.8°F to 60.8°F that demonstrated a two-fold increase in mortality for embryos incubated at 57.2°F, compared to embryos incubated at 53.6°F. In a laboratory study using gametes from Big Qualicum River, Vancouver Island, steelhead mortality increased to 15% at a constant temperature of 59.0°F, compared to less than 4% mortality at constant temperatures of 42.8°F, 48.2°F, and 53.6°F (Rombough 1988). Also, alevins hatching at 59.0°F were considerably smaller and appeared less well developed than those incubated at the lower temperature treatments. From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). Myrick and Cech (2001) similarly described water temperatures >59°F as "lethal" to incubating steelhead embryos, although FERC (1993) suggested that water temperatures exceeding 68°F were "stressful" to spawning steelhead and "lethal" when greater than 72°F.

Juvenile Rearing & Downstream Movement

Water temperature index values were developed to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages. Some steelhead may rear in freshwater for up to three years before emigrating as yearling+ smolts, whereas other individuals move downstream shortly after emergence as post-emergent fry, or rear in the river for several months and move downstream as juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals continue to rear and grow in downstream areas (e.g., lower Feather River, Sacramento River, and Upper Delta) and undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are assessed in this Technical Memorandum using the fry and juvenile rearing water temperature index values.

The growth, survival, and successful smoltification of juvenile steelhead are controlled largely by water temperature. The duration of freshwater residence for juvenile steelhead is long relative to that of Chinook salmon, making the juvenile life stage of steelhead more susceptible to the influences of water temperature, particularly during the over-summer rearing period. Central Valley juvenile steelhead have high growth rates at water temperatures in the mid 60°F range, but reportedly require lower water temperatures to successfully undergo the transformation to the smolt stage.

Water temperature index values of 63°F, 65°F, 68°F, 72°F, and 75°F were selected to represent a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead juvenile rearing (Table 4). The lowest water temperature index value of 63°F was established because Myrick and Cech (2001) describe 63°F as the "preferred" water temperature for wild juvenile steelhead, whereas "preferred" water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. 65°F was also identified as a water temperature index value because NMFS (2000; 2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the optimum water temperature range for juvenile growth (i.e., 59-66°F) (Myrick and Cech 2001), and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999).

Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F water temperature index value. For example, Kaya *et al.* (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F. Cherry *et al.* (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech and Myrick (1999) and FERC (1993). Empirical adult *O. mykiss* population data from the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon rivers collected in 2007-2009 are plotted against temperature in Figure 4. The temperature used was the 8th largest average daily temperature during the summer (i.e., up to seven days had higher daily average temperatures). The data show a population density break at about 68.0°F. Although smaller population densities occurred at higher temperatures, the largest population densities occurred at temperatures near 68.0°F or less. In addition Figure 5 shows growth for a 200 mm juvenile O. mykiss versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%). The average empirically derived percent of maximum consumption in an adjacent watershed (Middle Fork American Fork River) was 50% (Hanson et al. 1997). Positive growth only occurs up to approximately 68°F. Because of the literature describing 68.0°F as both an upper preferred and an avoidance limit for juvenile *Oncorhynchus mykiss*, and because of the empirical fish population data and bioenergetics growth data, 68°F was established as a upper tolerable water temperature index value.

A water temperature index value of 72°F was established because symptoms of thermal stress in juvenile steelhead have been reported to arise at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern

California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen *et al.* 1994). Also, 72°F was selected as a water temperature index value because 71.6°F has been reported as an upper avoidance water temperature (Kaya *et al.* 1977) and an upper thermal tolerance water temperature (Ebersole *et al.* 2001) for juvenile rainbow trout. The highest water temperature index value of 75°F was established because NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75.0°F (EPA 2002; NMFS 2001b). Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan et al. 2000; McCullough 2001).

Yearling + Smolt Emigration

Laboratory data suggest that smoltification, and therefore successful emigration of steelhead smolts, is directly controlled by water temperature (Adams *et al.* 1975) (**Table 5**). Water temperature index values of 52°F and 55°F were selected to evaluate the steelhead smolt emigration life stage, because most literature on water temperature effects on steelhead smolting suggest that water temperatures less than 52°F (Adams *et al.* 1975; Myrick and Cech 2001; Rich 1987a) or less than 55°F (EPA 2003a; McCullough *et al.* 2001; Wedemeyer *et al.* 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur. (Adams *et al.* 1973) tested the effect of water temperature (43.7°F, 50.0°F, 59.0°F or 68.0°F) on the increase of gill microsomal Na^+-, K^+-stimulated ATPase activity associated with parr-smolt transformation in steelhead and found a two-fold increase in Na^+-, K^+-ATPase at 43.7 and 50.0°C, but no increase at 59.0°F or 68.0°F. In a subsequent study, the highest water temperature where a parr-smolt transformation occurred was at 52.3°F (Adams *et al.* 1975). The results of Adams *et al.* (1975) were reviewed in Myrick and Cech (2001) and Rich (1987b), which both recommended that water temperatures below 52.3°F are required to successfully complete the parr-smolt transformation. Further, Myrick and Cech (2001) suggest that water temperatures between 43-50°F are the "physiologically optimal" temperatures required during the parr-smolt transformation and necessary to maximize saltwater survival. The 52°F water temperature index value established for the steelhead smolt emigration life stage is the index value generally reported in the literature as the upper limit of the water temperature range that provides successful smolt transformation thermal conditions. Increasing levels of thermal stress to this life stage may reportedly occur above the 52°F water temperature index value.

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead. They found ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by the EPA to provide temperature water quality standards for the protection of Northwest native salmon and trout, water temperatures less than or equal to 54.5°F were recommended for emigrating juvenile steelhead (EPA 2003b). Water temperatures are considered "unsuitable" for steelhead smolts at >59°F (Myrick and Cech 2001) and "lethal" at 77°F (FERC 1993).

CHINOOK SALMON LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

It has been suggested that separate water temperatures standards should be developed for each run-type of Chinook salmon. For example, McCullough (1999) states that spring-run Chinook salmon immigrate in spring and spawn in 3rd to 5th order streams and, therefore, face different migration and adult holding temperature regimes than do summer- or fall-run Chinook salmon, which spawn in streams of 5th order or greater. However, to meet the objectives of the current literature review, run-types are not separated because: (1) there is a paucity of literature specific to each life stage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the WTI values derived from all the literature pertaining to Chinook salmon for a particular life stage will be sufficiently protective of that life stage for each run-type; and (4) all run-types overlap in timing of adult immigration and holding and in some cases are not easily distinguished (Healey 1991). Nonetheless, water temperature relationships for each lifestage of spring-run Chinook salmon available in the literature are emphasized in the consideration and identification of WTI values for evaluation of reintroduction of spring-run Chinook salmon in the Upper Yuba River Basin.

Adult Immigration and Holding

The adult immigration and adult holding life stages are evaluated together, because it is difficult to determine the thermal regime that Chinook salmon have been exposed to in the river prior to spawning and in order to be sufficiently protective of pre-spawning fish, water temperatures that provide high adult survival and high egg viability must be available throughout the entire pre-spawning freshwater period. Although studies examining the effects of thermal stress on immigrating Chinook salmon are generally lacking, it has been demonstrated that thermal stress during the upstream spawning migration of sockeye salmon negatively affected the secretion of hormones controlling sexual maturation causing numerous reproductive impairment problems (McCullough *et al.* 2001).

The water temperature index values reflect a gradation of potential water temperature effects that range between those reported as "optimal" to those reported as "lethal" for adult Chinook salmon during upstream spawning migrations and holding. The water temperature index values established for the Chinook salmon adult immigration and holding lifestage are 61°F, 65°F, and 68°F (**Table 6)**. Although 56°F is referenced in the literature frequently as the upper "optimal" water temperature limit for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, Boles *et al.* (1988), Marine (1992), and NMFS (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for adult Chinook salmon immigration. However, Hinze (1959) is a study examining the effects of water temperature on incubating Chinook salmon eggs in the American River Basin. Further, water temperatures between 38-56°F are considered to represent the "observed range" for upstream migrating spring-run Chinook salmon (Bell 1986).

The lowest water temperature index value established was 61°F, because in the NMFS biological opinion for the proposed operation of the Central Valley Project (CVP) and State Water Project (SWP), 59°F to 60°F is reported as…"*The upper limit of the optimal temperature range for adults holding while eggs are maturing*" (NMFS 2000). Also, NMFS (1997b) states…"*Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F*" …and… "*Acceptable range for adults migrating upstream range from 57°F to 67°F*." ODEQ (1995) reports that "…*many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F*." Study summaries in EPA (2003) indicate disease risk is high at 62.6°F. Additionally, Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon. EPA (2003) chose a holding value of 61°F (7DADM) based on laboratory data various assumptions regarding diel temperature fluctuations. 61°F is also a holding temperature index value for steelhead (see above). The 61°F water temperature index value established for the Chinook salmon adult immigration and holding life stage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this life stage may reportedly occur above the 61°F water temperature index value.

An index value of 65°F was established because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 65°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults that ranged from 63.5°F to 66.2°F. Ward et al. (2003; 2004) identified an extended period of average daily temperatures above 67°F during July as measured at the Quartz Bowl that preceded the onset of significant pre-spawn mortalities. During 2002, temperatures exceeded 67°F a total of 16 days with a maximum of 20.8°C on July 12. During 2003, temperatures exceed 67°F a total of 11 days with a maximum of 20.9°C on July 23. However during other years when there were minimal pre-spawn mortalities, maximum daily average water temperature at Quartz Bowl never exceeded 67°F more than an few days (Ward et al. 2004; Ward et al. 2006; Ward et al. 2007; McReynolds and Garman 2008; McReynolds and Garman 2010). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6). Tracy McReynolds (Pers. Comm. October 2011) indicated that an upper tolerable holding temperature of 65°F was reasonable based on her experience.

An index value of 68°F was established because the Butte Creek data and the literature suggests that thermal stress at water temperatures greater than 68°F is pronounced, and severe adverse effects to immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1997; NMFS 1997b; Ward et al. 2004).

Water temperatures between 70-77°F are reported as the range of maximum temperatures for holding pool conditions used by spring-run Chinook salmon in the Sacramento-San Joaquin system (Moyle et al. 1995). Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough et al. 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999). The upper limit for spring-run Chinook salmon holding in Deer Creek is reportedly 80.6°F, at which point temperatures exceeding this value become "lethal" (Cramer and Hammack (1952), as cited in Moyle et al. (1995). As a result of the potential effects to immigrating and holding adult Chinook salmon that reportedly occur at water temperatures greater than or equal to 68°F, index values higher than 68°F were not established.

Spawning and Embryo Incubation

The adult spawning and embryo (i.e., eggs and alevins) incubation life stage includes redd construction, egg deposition, and embryo incubation. Potential effects to the adult spawning and embryo incubation life stages are evaluated together using one set of water temperature index values because it is difficult to separate the effects of water temperature between lifestages that are closely linked temporally, especially considering that studies describing how water temperature affects embryonic survival and development have included a pre-spawning or spawning adult component in the reporting of water temperature experiments conducted on fertilized eggs (Marine 1992; McCullough 1999; Seymour 1956).

The water temperature index values selected for the Chinook salmon spawning and embryo incubation life stages are 56°F, 58°F, 60°F, and 62°F (**Table 7**). Anomalously, FERC (1993) refers to 50°F as the "optimum" water temperature for spawning and incubating Chinook salmon. Additionally, for the adult spawning lifestage, FERC (1993) reports "stressful" and "lethal" water temperatures occuring at >60°F and >70°F, respectively, whereas for incubating Chinook salmon embryos, water temperatures are considered to be "stressful" at <56°F or "lethal" at >60°F. Much literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. NMFS (1993b) reported that optimum water temperatures for egg development are between 43°F and 56°F. Similarly, Myrick and Cech (2001) reported the highest egg survival rates occur between water temperatures of 39-54°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. Bell (1986) recommends water temperatures ranging between 42-57°F for spawning Chinook salmon, and water temperatures between 41-58°F for incubating embryos. USFWS (1995a) reported a water temperature range of 41.0°F to 56.0°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. The preferred water temperature range for Chinook salmon egg incubation in the Sacramento River was suggested as 42.0°F to 56.0°F (NMFS 1997a). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NMFS (2002a) reported 56.0°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F water temperature index value established for the Chinook salmon spawning and embryo incubation life stage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this life stage may reportedly occur above the 56°F water temperature index value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58.0°F. For example, (Reclamation Unpublished Work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs (1957) concluded constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002a) suggests 53.0°F to 58.0°F is the preferred water temperature range for Chinook salmon eggs and fry.

Johnson (1953) found consistently higher Chinook salmon egg losses resulted at water temperatures above 60.0°F than at lower temperatures. In order to protect late incubating Chinook salmon embryos and newly emerged fry NMFS (1993a) has determined a water temperature criterion of less than or equal to 60.0°F be maintained in the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. Seymour (1956) provides evidence that 100% mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60.0°F. For Chinook salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957), however, found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found high (93.8%) Chinook salmon incubation survival through emergence for naturally declining temperatures (0.36°F/day) starting as high as 61.7°F; however, a significant reduction in survival occurred above this temperature.

The literature largely agrees that 100% mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to 62.0°F (Hinze 1959; Myrick and Cech 2003; Seymour 1956; USFWS 1999). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high mortality of Chinook salmon eggs and fry (79%) when incubation temperatures started at 65.2°F and declined naturally for the Columbia River (about 7°F / month). Geist et al. (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F

Juvenile Rearing & Downstream Movement

Water temperature index values were identified for the combined spring-run Chinook salmon rearing (fry and juvenile) and juvenile downstream movement lifestages, for the reasons previously described regarding steelhead. Fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement, and are assessed in this Technical Memorandum using the fry and juvenile rearing water temperature index values.

The water temperature index values of 60°F, 65°F, 68°F, 70°F and 75°F were identified for the spring-run Chinook salmon juvenile rearing and downstream movement lifestage. The lowest index value of 60°F was chosen because regulatory documents as well as several source studies, including ones recently conducted on Central Valley Chinook salmon fry and juveniles report 60°F as an optimal water temperature for growth (Banks *et al.* 1971; Brett *et al.* 1982; Marine 1997; NMFS 1997b; NMFS 2000;

NMFS 2001a; NMFS 2002a; Rich 1987b) (**Table 8**). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but were not selected as index values, because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990b; Taylor 1990a). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

The 60°F water temperature index value established for the Chinook salmon juvenile rearing and downstream movement life stage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of spring-run Chinook salmon fry and fingerlings. FERC (1993) referred to 58°F as an "optimum" water temperature for juvenile Chinook salmon in the American River. NMFS (2002a) identified 60°F as the "preferred" water temperature for juvenile spring-run Chinook salmon in the Central Valley. Increasing levels of thermal stress to this life stage may reportedly occur above the 60°F water temperature index value.

The index value of 65°F was selected because it represents an intermediate value between 64.0°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (EPA 2003a; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987a). Conversely, numerous studies report that temperatures between 64.0°F and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett *et al.* 1982; Cech and Myrick 1999; Clarke and Shelbourn 1985; EPA 2003a; Myrick and Cech 2001; NMFS 2002a; USFWS 1995a). Maximum growth of juvenile fall-run Chinook salmon has been reported to occur in the American River at water temperatures between 56-59°F (Rich 1987) and in Nimbus Hatchery spring-run Chinook salmon at 66°F (Cech and Myrick 1999). Figure 5 shows growth for a 100 mm juvenile Chinook salmon versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%). The average percent of maximum consumption in an adjacent watershed (Middle Fork American Fork River) for O. *mykiss* was 50% (Hanson et al. 1997). Positive growth only occurs up to approximately 64°F for food levels expected in the wild (e.g., 50% maximum consumption).

A water temperature index value of 68°F was selected because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at temperatures close to 70.0°F and has been reported to be completely prohibited at 70.5°F (Brett *et al.* 1982; Marine 1997). 75°F was chosen as the highest water temperature index value because high levels of direct mortality to juvenile Chinook salmon reportedly result at this water temperature (Cech and Myrick 1999; Hanson 1991; Myrick and Cech 2001; Rich 1987b). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was chosen because it was derived from experiments using Central Valley Chinook salmon and it is a more rigorous index value representing a more protective upper lethal water temperature level. Furthermore, the lethal level determined in Rich (1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan et al. 2000; McCullough et al. 2001; Myrick and Cech 2001)

Yearling + Smolt Emigration

Juvenile Chinook salmon that exhibit extended rearing in the lower Yuba River are assumed to undergo the smoltification process and volitionally emigrate from the river as yearling+ individuals. Water temperature index values of 63°F, 68°F and 72°F were selected for the spring-run Chinook yearling+ emigration lifestage (**Table 9)**.

A water temperature index value of 63°F was selected because water temperatures at or below this value allow for successful transformation to the smolt stage, and water temperatures above this value may result in impaired smoltification indices, inhibition of smolt development, and decreased survival and successful smoltification of juvenile spring-run Chinook salmon. Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997; Zedonis and Newcomb 1997). 62.6°F was rounded and used to support an index value of 63°F. Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989). A water temperature index value of 68°F was selected because water temperatures above 68°F prohibit successful smoltification (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Support for an index value of 72°F is provided from a study conducted by (Baker *et al.* 1995) in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests a 95% confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5°F to 75.4°F.

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

FISH PASSAGE FACILITIES ALTERNATIVES ASSESSMENT
REINTRODUCTION GOALS SUBCOMMITTEE CONFERENCE CALL

OCTOBER 20, 2016

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Reintroduction Goals Subcommittee Conference Call

Thursday, October 20, 2016
1:00 pm to 3:00 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	Allison Boucher	Friends of the Tuolumne
2	Steve Boyd	Turlock Irrigation District
3	Jean Castillo	National Marine Fisheries Service
4	Jesse Deason	HDR, consultant to the Districts
5	John Devine	HDR, consultant to the Districts
6	Chuck Hanson	Hanson Environmental, consultant to the Districts
7	Patrick Koepele	Tuolumne River Trust
8	Bao Le	HDR, consultant to the Districts
9	Lonnie Moore	Private citizen
10	Gretchen Murphey	California Department of Fish and Wildlife
11	Bill Paris	Modesto Irrigation District
12	John Wooster	National Marine Fisheries Service
13	Ron Yoshiyama	City and County of San Francisco

On October 20, 2016, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the second Reintroduction Goals Subcommittee (Goals Subcommittee) conference call for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials.

Mr. Bao Le (HDR, consultant to the Districts) welcomed meeting attendees. Mr. Le said the purpose of the Goals Subcommittee is to establish the overall purpose of the reintroduction program. Mr. Le summarized discussions at the first Goals Subcommittee call, held on April 13, 2016, noting that the call included a lot of discussion about developing a narrative goals statement. After the call, HDR staff, with some reluctance, took an action item to develop an initial draft statement that would serve as a starting point for collaboratively identifying the goal of the reintroduction program or how program success would be defined. Mr. Le said having a defined goal is an important part of the Framework. Currently, the National Marine Fisheries Service (NMFS) and the Districts are collecting information on the upper Tuolumne River to help understand such factors as habitat availability, thermal suitability, and migration barriers. Mr. Le said in order to evaluate the feasibility of a reintroduction action, these data must be evaluated against a defined reintroduction goal(s).

Mr. Le reviewed the meeting agenda and asked if there are any questions about the agenda or the purpose of the meeting. Mr. Wooster noted that Mr. Le said the purpose of the Goals Subcommittee is to develop a statement for the reintroduction "program". Mr. Wooster said he considers a reintroduction "program" to be something that is currently being implemented, whereas this group is evaluating the potential for reintroduction and various other issues that spun out of the FERC-approved Fish Passage Facilities Alternatives Assessment. Mr. Wooster said he believes using the word "program" is little confusing and seems premature. Mr. Le said use of the word "program" is not meant to imply anything specific. Mr. Le said NMFS likely has ideas on what they think success would look like regarding reintroducing fish into the upper Tuolumne River. Mr. Le said he thinks the question is basic; if there is a potential action to put fish into the upper Tuolumne River that are not there currently, what is the objective of this action and how will we know if it is successful? Mr. Le said using the word “program” is not meant to imply there is currently a program in place or that it is known exactly what such a program might entail. Mr. Wooster said he agreed with Mr. Le’s description, but he thinks we should look for a different term to use that suggests that we are currently at the evaluation stage. Dr. Ron Yoshiyama (City and County of San Francisco) suggested using the term “reintroduction concept goals”. Mr. Lonnie Moore (private citizen) suggested using the phrase “reintroduction goals” instead of “program goals”. Mr. Le noted that the word “program” is only used in the agenda, and it is not used in the draft goals statement. Mr. Wooster said he is in favor of the phrase “reintroduction goals”. Mr. Le said the term “reintroduction goals” will be used going forward.

Mr. Le said part of today’s meeting will be spent discussing why having a goal is important. Mr. Le said on the first Goals Subcommittee call, the Districts introduced literature from state and federal agencies in the Pacific Northwest about the need for sound planning related to reintroduction. Anderson et al. (2014) focused on ESA-listed salmonids and is particularly pertinent to our discussions here. A key message from Anderson et al. (2014) is that best practices for reintroduction are not well established. Given the significance of an action like introducing a species, whether the species is new to the reach or one that was previously extirpated, a significant amount of planning is necessary and should include consideration of the benefits, risks, and constraints of the action. Mr. Le said Anderson et al. (2014) supports having the types of discussions this group is having, and knowing in advance the biological goals of the program.

Mr. Le said in addition to Anderson et al. (2014), another important document to consider is the Framework prepared by Mr. Paul Bratovich (HDR). The Framework considers such important components as the goals and objectives of the reintroduction, ecological considerations, biological constraints, regulatory and socioeconomic considerations, and engineering constraints.

Mr. Le said the NMFS Recovery Plan is another important guiding document to help develop and inform a reintroduction goal. Mr. Le said it would be helpful to hear from Mr. Wooster (NMFS) and Ms. Castillo (NMFS) on what NMFS would consider the goal to be. Mr. Le said the goal could be quantitative or qualitative.

Mr. Le asked if individuals on the call knew of other relevant documents to consider. Mr. Le asked if there were any comments or questions. There were none.

Mr. Wooster said regarding the Temperature Subcommittee, he was unable to locate the final version of Bratovich et al. (2012), and requested that Mr. Le send him a copy. Mr. Le said he will do that.

Mr. Le said Ms. Rose Staples (HDR) previously emailed out to this group a draft goals statement. HDR developed this statement in response to an action item from the first Goals Subcommittee call. Mr. Le apologized for the delay in sending out the draft goals statement. He noted that developing the statement was much harder than had been anticipated, given that there are many different and complex issues at play and a diverse group of interests. Mr. Le said the statement is not meant to be attributable to any stakeholder and was intended to serve as a starting point for collaborative discussions to further development of a statement.

Mr. Le reviewed the statement and noted that the statement intended to represent the diversity of potential interests that had been discussed previously. For example, the “identify and evaluate” language in the statement is meant to indicate that may be several reintroduction options to choose from and that currently we are in the early stages of planning which requires that all options be evaluated. Mr. Le said though we may not all agree on the results of the evaluation, it is important that the evaluation is based on solid information that everyone agrees to. The language "reasonable efforts which may enhance and assist" is meant to acknowledge that for any approach, cost and cost/benefit is an important consideration. Mr. Le said it is well known that a reintroduction program can be very expensive, and Anderson et al. (2014) identified cost, and more specifically socioeconomics, as a component to consider. Mr. Le said the final part of the statement, "in the recovery of ESA listed salmonids in the Central Valley", relates to the NMFS Recovery Plan for listed species, and tying the goal to recovery and establishing a distinct population. Mr. Le asked for thoughts or comments on the draft goals statement.

Mr. Wooster said the phrase "in the Central Valley" is potentially too broad for what this group is trying to accomplish. Mr. Wooster said the NMFS Recovery Plan breaks up the Central Valley into sub-regions, each of which has separate recovery goals. Mr. Wooster said an example is the South Central Valley region (which includes the Tuolumne River). The NMFS Recovery Plan states the goal for this region is two populations each of steelhead and spring-run Chinook salmon. This goal is at odds with what we would try for on the Tuolumne River, which would be one population of steelhead and one population of spring-run Chinook (i.e., you could not attain more than one population for each listed species). Mr. Wooster said he did not understand why the statement does not focus on the Tuolumne River, since that is what this group is focusing on. Mr. Le said Mr. Wooster brought up a good point about how the NMFS Recovery Plan contains different goals by sub-region. Mr. Le said the rationale behind "in the Central Valley" was to provide geographic relevance. Mr. John Devine (HDR) said that when the statement was being discussed internally, it seemed important to tie the statement more broadly back to the recovery of ESA listed species for the Central Valley. Mr. Le noted that establishing a population of a listed species on the Tuolumne River would not automatically mean meeting the recovery objectives; therefore, it seemed best to frame the statement in the context of the Central Valley, which seemed to be the appropriate geographic scope as it related to ESA recovery. Mr. Wooster said based on this discussion, he better understands the rationale behind using Central Valley in the statement. Mr. Wooster said the actions may be specific to the Tuolumne River, but the goals statement speaks to how the results would apply to the greater region as it relates to recovery. Mr. Le said he agrees with Mr. Wooster's characterization and that the statement is meant to capture the geographic scope of recovery.

Mr. Wooster said the larger group has been discussing actions to benefit fall-run Chinook, which are not ESA listed. Mr. Wooster asked how consideration of fall-run Chinook fits into this goals statement. Mr. Le said that is a good point, and the statement would need to be modified to included fall-run Chinook, given that fall-run Chinook is not ESA listed. Mr. Wooster said he does not have a suggestion of how to modify the statement, but he agrees it should be modified to include fall-run Chinook. Mr. Patrick Koepele suggested naming the three species under consideration directly in the goals statement. For example, "assist in the recovery of Central Valley steelhead, Central Valley spring-run Chinooks salmon, and fall-run Chinook salmon in the southern Central Valley". Mr. Le said the word "recovery" is used specifically in the context of ESA, so it should not be applied to fall-run Chinook. To include fall-run Chinook, we may need to add an additional sentence to the goals statement. Mr. Le said regarding Mr. Wooster's earlier point about the goals in the Recovery Plan, given that fall-run Chinook are not included in the Recovery Plan, it may make sense to have an independent discussion of how to define goals for fall-run Chinook. To determine goals for fall-run Chinook, we may need to look beyond the Recovery Plan. Dr. Yoshiyama suggested revising the statement to use the phrase "at-risk salmonids". This language would work for all three species given that fall-run Chinook is a candidate species. Dr. Yoshiyama said corollary statements could be added that are specific to each species. Mr. Le said it would be helpful to get additional feedback on the statement and Dr. Yoshiyama's suggestion of corollary statements is an option worth considering. Mr. Le stated corollary statements could be quantitative or narrative. Mr. Le also asked the group whether additional information or literature may be helpful to developing these statements.

Mr. Devine said regarding the internal discussions that took place to draft the goals statement, some individuals thought numeric measurements should be part of the goal. However, HDR couldn't decide what those numbers should be. That is the genesis behind the "identify and evaluate" language in the statement. The reasoning behind that language was the term "evaluate" implies a quantitative goal or metric, without having to pinpoint a specific quantitative goal. Mr. Devine noted that identifying quantitative goals seems important.

Dr. Yoshiyama agreed that there needs to be a quantitative component in this discussion. Dr. Yoshiyama said he thinks there is a difference between a quantitative goal and a quantitative metric or benchmark. One does not necessarily need a quantitative goal to have a quantitative metric. We can proceed without a quantitative goal, and just do as much as we can to foster steelhead or spring-run Chinook, and then use a quantitative metric or benchmark to assess our progress. That way, we can avoid painting ourselves into a corner where the goal may be unattainable. Mr. Devine said the Districts believe it would be inappropriate to invest a considerable amount of money into a reintroduction program without knowing how success is defined and when it can be achieved. Mr. Devine said the Districts believe the only way to move forward without a defined goal is to do so by starting small and building incrementally based on certain benchmarks. Dr. Yoshiyama said he agreed with Mr. Devine and it is important to ask that if the goal was a certain number of fish, what would it take to achieve that target. Dr. Yoshiyama said that wouldn't necessarily mean setting a goal, but instead setting a target or strawman, and then determining what it would take to establish that return such as what ocean survival would be needed and how many smolts and spawners would be needed. With this approach, we can figure out what the costs would be, and this would be an extremely important part of that, but without having a final goal set in stone.

Mr. Devine said he thinks that the target does eventually need to tie back to recovery, especially when talking about listed species. Regarding the southern Central Valley targets, Mr. Devine asked what would be a sufficient number of fish to achieve recovery.

Mr. Le said that HDR prepared the draft statement, but the HDR staff are not experts in the NMFS Recovery Plan or the overall management of salmonids of the Central Valley. Mr. Le said it is important that individuals like Mr. Wooster, Ms. Castillo, and Ms. Murphey, as well as other agency staff with jurisdiction, provide guidance and leadership as this group revises and adds to the goals statement. If we decide the goals will be tied to recovery, we might look to the Recovery Plan or other documents to tease out numbers related to viability or distinct populations.

Mr. Wooster said establishing quantitative goals for steelhead is a much different exercise than establishing quantitative goal for spring-run Chinook. Regarding spring-run Chinook, Lindley (2007) is a good place to start to determine what constitutes a viable population. Mr. Wooster said from there, he would turn to additional staff at NMFS for guidance, specifically Mr. Brian Ellrott, who is the NMFS Recovery Coordinator, and Mr. John Ambrose, who is the NMFS Reintroduction Coordinator. Mr. Wooster said there may be some value to having them participate in a call, or the next call, with this group. Mr. Devine said that would be very helpful.

Mr. Devine said Mr. Wooster had mentioned earlier about the Recovery Plan having goals to establish an "independent and viable" population, and Mr. Devine said that perhaps the goals could tie in to what is meant by "independent and viable". Mr. Wooster said Lindley (2007) is often what NMFS uses to quantify what would be an independent and viable population. Mr. Wooster said Lindley (2007) is a starting point. Mr. Wooster said looking at the Tuolumne River scale, there are two questions to consider: (1) what kind of independent population can be made on the Tuolumne River and (2) how would that independent population relate to the distinct population segment (DPS) or evolutionarily significant unit (ESU). Mr. Wooster said when NMFS is completing a jeopardy analysis, the agency looks at what is happening on the river and how that relates to the ESU. Mr. Le asked Mr. Wooster to send him Lindley (2007), and Mr. Wooster said he would do that.

Mr. Le asked Mr. Wooster to elaborate on the differences between defining quantitative objectives for spring-run Chinook and defining quantitative objectives for steelhead. Mr. Wooster said regarding quantitative metrics, one can plan on regular intervals of Chinook. Returns of Chinook may be traced back to a single cohort, and the population trends are on three-year averages. With steelhead, there is no guarantee of when or if an individual will smolt, which makes the species more difficult to measure than Chinook. Mr. Wooster said we may be able to look to the Pacific Northwest for examples of how to quantify goals for steelhead. Or, we may need to instead consider habitat metrics, such as how much suitable habitat exists, perhaps by life stage. Mr. Wooster said Dr. Yoshiyama made some good points about estimating outmigrant survival based on different scenarios.

Regarding how steelhead life history is considered in the NMFS Recovery Plan, Mr. Le asked if NMFS considers numbers of resident fish. Mr. Wooster said resident population numbers are not considered from a recovery standpoint, but they are something that NMFS is aware of. Mr. Wooster said a large increase in the resident population would not trigger any changes to the listing for steelhead. Mr. Le said this appears to be similar to how bull trout are treated in the Pacific Northwest, as the bull trout ESA listing seeks to protect the migratory form of the species and does not consider resident bull trout in listing status. Mr. Wooster said he is not very familiar with bull trout, but it sounds like a similar situation. Mr. Wooster said Mr. Ellrott would be a good person to ask about the finer details of how steelhead life history is considered in the NMFS Recovery Plan, given that he was the primary author.

Mr. Le asked if there are any other initial thoughts or input on the draft statement. Mr. Le said participation by Mr. Ellrott and/or Mr. Ambrose may be helpful, and asked that Mr. Wooster reach out to these two individuals to determine their interest and availability in participating. Mr. Wooster said Mr. Ellrott would be good to include now, but Mr. Ambrose usually gets involved in these types of processes once they are further developed.

Mr. Le asked if there are any other initial thoughts on the statement. There were none.

Mr. Le said it is important that the goals statement be developed in a collaborative way, and that individuals take some time to review the statement and provide feedback. Mr. Le asked that individuals provide modifications or additions to the statement, corollary statements, quantitative goals, and/or potential sources of information that might help in developing the statement further. Feedback might also be a completely new statement, or input that the statement is headed in the wrong direction. Mr. Le asked that feedback be provided by Thursday, November 3. Mr. Le said all feedback received will be compiled, along with the feedback received today. We will discuss all the feedback on the next call.

Meeting attendees discussed dates for the new Goals Subcommittee call. Mr. Le said he will send out a Doodle poll.

Meeting adjourned.

ACTION ITEMS

1. Going forward, the phrase "reintroduction goals" will be used instead of "program goals".

2. Mr. Le will send Mr. Wooster a copy of Bratovich et al. (2012). (complete)

3. Mr. Wooster will send Mr. Le a copy of Lindley (2007). (complete)

4. Mr. Wooster will contact Mr. Ellrott and Mr. Ambrose about participating on the Goals Subcommittee.

5. Meeting attendees will provide feedback on the goals statement, as well as additional documents that may be helpful for drafting the goals statement, by Thursday, November 3, 2016 to Ms. Rose Staples at rose.staples@hdrinc.com.

6. HDR will compile and organize feedback received on the goals statement.

7. Mr. Le will send out a Doodle poll.

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Reintroduction Goals Subcommittee Conference Call

Thursday, October 20, 2016, 1:00 pm to 3:00 pm
Conference Line: 1-866-583-7984; Passcode: 814-0607

Meeting Objectives:

1. Review and confirm the purpose of the Reintroduction Goals Subcommittee.
2. Review and discuss preliminary draft reintroduction goals statement.
3. Identify next steps on Reintroduction Goals Subcommittee.

TIME	TOPIC
1:00 pm – 1:15 pm	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
1:15 pm – 1:45 pm	Reintroduction Assessment Framework – Development of Program Goals. Why Is It Important? What Purpose Does it Serve? Potential sources to further inform goal development (All) a. Planning Pacific Salmon and Steelhead Reintroductions Aimed at Long-Term Viability and Recovery, Andersen et al. b. NMFS Recovery Plan c. Others?
1:45 pm – 2:45 pm	Tuolumne River Reintroduction Goals – preliminary draft narrative statement (All) – "*Identify and evaluate, in collaboration with stakeholders, reasonable efforts which may enhance and assist in the recovery of ESA listed salmonids in the Central Valley*." a. Brief background on draft narrative statement b. Discuss feedback/refinement from subcommittee members c. Need for quantitative metrics?
2:45 pm – 3:00 pm	Next Steps toward (All) a. Schedule next call and agenda topics Action items from this call

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

REINTRODUCTION ASSESSMENT FRAMEWORK
WATER TEMPERATURE SUBCOMMITTEE IN-PERSON MEETING

DECEMBER 1, 2016

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Water Temperature Subcommittee Meeting

Thursday, December 1, 2016
1:00 pm to 2:30 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	Steve Boyd	Turlock Irrigation District
2	Paul Bratovich	HDR, consultant to the Districts
3	Jean Castillo	National Marine Fisheries Service
4	Calvin Curtin	Turlock Irrigation District
5	Jesse Deason	HDR, consultant to the Districts
6	John Devine*	HDR, consultant to the Districts
7	Greg Dias	Modesto Irrigation District
8	Nann Fangue*	U.C. Davis, consultant to the Districts
9	Dana Ferreira	Office of U.S. Congressman Jeff Denham
10	Mark Gard*	U.S. Fish and Wildlife Service
11	Art Godwin	Turlock Irrigation District
12	Andy Gordus	California Department of Fish and Wildlife
13	Chuck Hanson	Hanson Environmental, consultant to the Districts
14	Zac Jackson	U.S. Fish and Wildlife Service
15	Bill Ketscher	Private citizen
16	Patrick Koepele*	Tuolumne River Trust
17	Bao Le	HDR, consultant to the Districts
18	Ellen Levin*	City and County of San Francisco
19	Lonnie Moore	Private citizen
20	Marco Moreno	Latino Community Roundtable
21	Gretchen Murphey	California Department of Fish and Wildlife
22	Bill Paris	Modesto Irrigation District
23	Amanda Ransom	HDR, consultant to the Districts
24	Bill Sears*	City and County of San Francisco
25	Samantha Wookey	Modesto Irrigation District
26	John Wooster*	National Marine Fisheries Service
27	Ron Yoshiyama	City and County of San Francisco

* Attended by phone.

On December 1, 2016, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the third Water Temperature Subcommittee (Temperature Subcommittee) meeting for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials. After this meeting concluded, the Reintroduction Goals Subcommittee meeting began. Notes from the Reintroduction Goals Subcommittee meeting are available as a separate document.

Mr. Bao Le (HDR, consultant to the Districts) welcomed meeting attendees. Mr. Le summarized the discussions that occurred at the previous Temperature Subcommittee meeting held on October 14, 2016. At the last meeting, the Districts introduced the report on the literature review, which was largely based on the literature review completed for the Yuba Salmon Forum (i.e. Bratovich et al. 2012). The Tuolumne literature review also included site-specific information available for the Tuolumne River. Comments on the literature review were received, and the Districts then updated the literature review and glossary. Mr. Le reviewed the rest of the agenda and asked if there were any questions. There were none.

Mr. Le said comments on the literature review and glossary were received from the California Department of Fish and Wildlife (CDFW). The Districts reviewed and responded to those comments and revised the literature review and glossary of terms (glossary) based on the comments. The Districts' responses, the revised literature review, and the glossary were circulated prior to this meeting. Mr. Le said he does not think it would be efficient use of time to review each specific change to the documents in this meeting, but wanted to allow time in the meeting for individuals to provide comments or ask questions about the updated documents and/or response to comments. There were no comments or questions.

Mr. Le said there is quite a bit of terminology to get use to when it comes to evaluating thermal suitability and it is important that the subcommittee be in agreement on the definition of terms. Mr. Le said Mr. Paul Bratovich (HDR) will provide a presentation about thermal suitability terminology.

Mr. Bratovich said thermal suitability is a fundamental consideration in the reintroduction feasibility process. Thermal suitability is an important consideration because if habitat is not thermally suitable, other measurements of suitability (i.e., physical parameters) may not be relevant. At the first Temperature Subcommittee meeting, Mr. Le provided the Water Temperature Subcommittee – Draft Process and Schedule, which proposed the overall intent of and process for the Temperature Subcommittee. Since then, the literature review was completed and distributed. The literature review identified water temperature indices used at various other programs and projects. Mr. Bratovich said water temperature *metrics* are completely different from water temperature *indices*. Water temperature metrics are how the data is presented (e.g., daily average, weekly average, 7 day average daily maximum, etc.). Water temperature evaluation guidelines are a combination of water temperature indices (i.e., numerical value) and metrics for each species/life stage-specific period. Mr. Bratovich presented a conceptual graphic of the effect of temperature on juvenile and adult salmonids over varying lengths of time. Mr. Bratovich said the optimal zone means that water temperature does not impair any metabolic functions or life history mechanisms. In the chronic zone, the temperature could affect metabolic function or life history mechanisms but fish can still live indefinitely. In the acute zone of resistance, mortality may result in a matter of minutes. Dr. Andy Gordus (CDFW) requested that the graphic be added to the literature review. Mr. Le said the graphic will be added. Mr. Bratovich reviewed common terms used to describe thermal suitability and discussed different types of water temperature metrics that may be adopted for this process. Mr. Bratovich reviewed the water temperature indices identified during the literature review, noting that for each life stage, a number of different values are provided in the literature. Finally, Mr. Bratovich reviewed next steps for the Temperature Subcommittee, which include establishing water temperature evaluation guidelines and determining species/run-specific life stage periodicities and evaluation methodology.

Mr. Le asked if there are any questions or comments about the presentation. There were none. Mr. Le noted that the intent of this presentation is to get everyone on the same page about what is meant by thermal suitability and how relevant terms are defined to set up a discussion of what may be appropriate values and metrics to use.

Mr. Le said Mr. John Wooster (National Marine Fisheries Service [NMFS]) had provided some additional references for the literature review as well as a paper by Boughton et al. (2015), which was distributed ahead of this meeting. Mr. Le said Mr. Wooster characterized Boughton et al. (2015) as the approach the NMFS Science Center (Science Center) is likely to adopt when evaluating temperature suitability in the upper Tuolumne River. Mr. Wooster said in general, the Science Center will use an upper temperature range when it comes to suitable habitat, instead of just a single temperature. By modeling a range of temperatures, the Science Center can determine whether an area provides habitat on a given day. When looking at temperatures between 20°C and 25°C, a dynamic situation occurs. Mr. Wooster said when evaluating temperatures in this range, the model considers how much of the day the temperature exceeds 20°C. This is considered a stress index. These results feed into a bioenergetics model, which takes into account such factors as pool stratification and cover. From there, habitat carrying capacity may be calculated. Mr. Wooster said Boughton et al. (2015) notes a range of temperatures are identified in the literature as "stressful", but not necessarily lethal, and the bioenergetics approach takes this into account. Mr. Wooster said the Science Center has used this approach to study steelhead in southern California as described in Boughton et al. (2015) and to study steelhead in the Bay area. A memo about this second study should be out soon. Mr. Wooster said the Science Center will take a similar approach to thermal suitability studies of spring-run Chinook, but with slightly different numbers.

Mr. Le asked Mr. Wooster to explain if the Science Center's approach considers such factors as available food and refugia in calculating carrying capacity. Mr. Wooster said the first step in the approach is to calculate the stress index, which is a function of degrees over 20°C and the duration of the temperature. Mr. Wooster said food availability and refugia are also considered in the analysis. Dr. Chuck Hanson (Hanson Environmental, consultant to the Districts) said Boughton et al. (2015) appeared to focus on the steelhead over-summering and rearing period. Dr. Hanson asked if the Science Center has expanded this approach to other life stages, such as spawning and incubation. Dr. Hanson also asked if the Science Center has applied this analysis to other species such as spring-run Chinook. Mr. Wooster said these questions generally fall outside his knowledge of the Science Center's activities. Mr. Wooster said the other draft paper he mentioned had applications for migration and spawning. The Science Center has applied this approach to spring-run Chinook in the Tuolumne River and Merced River, and is looking at both systems simultaneously. Mr. Wooster said he did not know about applying the approach to winter-run Chinook or other species. Dr. Hanson said he recently spoke to Dr. Hendrix and Dr. Lindley at the Science Center and they describe an approach to life cycle modeling that is similar to what Mr. Wooster just described. Dr. Hanson wondered if these two approaches were actually one and the same. Mr. Wooster speculated that these were likely the same process.

Mr. Le said a goal of the Temperature Subcommittee is to populate the life stage timing and temperature table. Mr. Le asked Mr. Wooster how this table might tie-in to what NMFS is considering for temperature objectives for evaluating reintroduction. Mr. Le asked if NMFS will be providing information on how the agency evaluates temperature. He also asked when additional analysis from the Science Center using this approach will be available to the Temperature Subcommittee. Mr. Wooster said the Science Center's work on all three life stages of *O. mykiss* will be described in the Russian River estuary paper, which is almost final. Mr. Wooster said the Science Center is currently working on the Tuolumne River and Merced River spring-run Chinook analyses, but he does not know a timeline for this work. Mr. Wooster said the Science Center's approach is somewhat different than taking the water temperature index approach, which is more of a binary approach. Mr. Le said it would be helpful to get input from the Science Center as this subcommittee moves forward on selecting an approach, indices, metrics, and determination on suitability.

Regarding Boughton et al. (2015), Mr. John Devine (HDR) asked if the temperatures selected under the thermal indices for temperature suitability are meant only to apply to the Santa Ynez River or will the Science Center apply these temperatures to other rivers too. Mr. Wooster said it is his understanding that the next study using this approach, which deals with the Russian River, used the same numbers as the Santa Ynez River study, but with some refinement. Mr. Wooster said he thinks both studies used data derived from a literature review, which included many of the same sources as the literature review completed by the Temperature Subcommittee. Mr. Bill Sears (City and County of San Francisco [CCSF]) asked if it would be possible to have the Science Center make a presentation to the Temperature Subcommittee about their approach. Mr. Wooster said a presentation is possible, but he had assumed the Temperature Subcommittee would want a presentation focused on study results, and not study approach. Mr. Wooster advised the Temperature Subcommittee should only plan to receive one presentation from the Science Center.

Mr. Le asked for the timeline for when results will become available for the Tuolumne River and Merced River work. Mr. Wooster said he is expecting to have a draft to review in March 2017. He said he will check in with the Science Center and find out if that schedule is still accurate. Mr. Wooster said that if a draft is available for his review in March, another month to six weeks of internal review would be necessary before the report would be finalized. Mr. Wooster said he expects to see a draft of the report for the Tuolumne River Genetics Study before March.

Mr. Devine asked if it is possible to match the temperatures used in Boughton et al. (2015) to the thermal suitability terms defined in Mr. Bratovich's presentation. For example, the Districts could try to determine how temperatures identified in Boughton et al. (2015) correspond to tolerable, optimum, acute, etc. Mr. Devine asked if the Districts made an attempt to match up temperatures to terms in an effort to connect these two concepts, would Mr. Wooster and/or the Science Center be able to review the results and provide feedback. Mr. Wooster said he would provide feedback.

Dr. Hanson asked Mr. Wooster to provide more details on how the Science Center uses the model output related to the stress index to demonstrate habitat suitability or carrying capacity. Mr. Wooster said he did not know much more than he already described. He noted that the technical memo in progress about the Russian River gives a lot more detail about the modeling approach. Mr. Wooster said Dr. Hanson's questions would be good ones to ask the Science Center when they come to present. Dr. Hanson said it would also be helpful to know more about whether the Science Center has had an opportunity to evaluate the model's predictions against actual results on other rivers. Dr. Hanson noted that the Santa Ynez Watershed is a highly stressed system, which may have implications for using the approach on other rivers. Mr. Wooster said these are all good questions for the Science Center.

Mr. Le asked at what scale the Science Center's approach may be applied. Mr. Le asked if the approach would be applied to the entire Tuolumne River as it relates to suitability and recovery. Mr. Wooster said the focus of the approach is to calculate carrying capacity, and not to calculate the amount of river that is optimal, suboptimal, etc. Mr. Wooster said the question is really how many fish can be supported in the upper river.

Ms. Dana Ferreira (U.S. Congressman Jeff Denham's office) asked if NMFS is proposing different temperatures for different reaches of the river. Mr. Wooster said NMFS is not proposing a temperature for the upper river. Mr. Wooster said there are different objectives for, and differences in how flows are regulated in, the lower river as compared to the upper river. Mr. Wooster said he does not have much ability to propose temperatures in the upper Tuolumne River. Mr. Devine said Ms. Ferreira's question may be better directed to CDFW. Mr. Devine said there are obvious differences between temperatures recommended in EPA (2003) and the temperatures used in the Science Center's approach. Mr. Wooster said the goal in the lower river is to design a protective flow regime for the fish that are already there, while in the upper river the goal is first to evaluate how many fish would survive or could be produced in the existing habitat, and what benefit may be gained to the population by putting fish in this reach. Mr. Devine said it seems that EPA (2003) temperatures recommend 18°C as a compliance or temperature benchmark for over-summering *O. mykiss*, and that if this temperature is exceeded, it is presumably harmful to fish.

Mr. Devine said the question here is if exceeding 18°C is very harmful to fish in the lower river, why wouldn't exceeding 18°C in the upper river also be harmful to the same fish. Mr. Wooster said the 20°C to 25°C stress index attempts to quantify how much harm occurs at these temperatures. Mr. Wooster said at one end of the stress index the habitat is totally unusable, while in the middle of the stress index habitat is sometimes usable.

Mr. Devine asked Dr. Gordus that if it is determined that fish do well at temperatures in the upper reach that are warmer than EPA (2003) recommended temperatures for below the dams, would CDFW consider changing the criteria for the reach below the dams to warmer temperatures. Ms. Gretchen Murphey (CDFW) and Dr. Gordus stated they did not have the authority to weigh in on that question.

Mr. Le asked if there were any additional thoughts or input about the temperature indices discussion. Mr. Bratovich said in reviewing Boughton et al. (2015), and understanding that the Science Center's approach looks at thermal suitability as a gradation of effects, it appears that the question then becomes what constitutes thermally suitable habitat. Mr. Bratovich said the Temperature Subcommittee will need to consider at what point in the gradation of effects is reintroduction feasible. Mr. Bratovich said this question gets to the overall goal of the reintroduction program, and how success is defined. Mr. Wooster said NMFS is looking at it from an entire life cycle perspective. For example, if there is negative growth, it is obvious there will not be a viable population. How much habitat is thermally suitable or not depends on the whole life cycle process.

Mr. Le said the temperature and periodicity timing table is broken out by life stage and species. The voluntary studies being completed by the Districts examine water temperature as well as barriers to migration and instream flows. Mr. Le said it seems that NMFS is trying to consider all these factors at once using one analysis, while individuals participating in the Framework process are looking at these factors as discreet pieces to first be considered individually. Mr. Wooster generally agreed with this characterization.

Dr. Hanson said a classic approach to the topic at hand is to first consider life stage. Normally you would first look at the suitability and distribution of spawning gravel, and then from there estimate redd size and the number of redds that can be supported. Then, you would look at temperature suitability to estimate how many would hatch. Thermal conditions for fry and juveniles would be examined. Making assumptions about emergence and growth, you can calculate how many days are needed for growth and then look to bioenergetics. Outmigration success must also be considered. From there, you can figure out how many fish might survive to adulthood. And then in Year 2, a certain percent of the fish return and using a set of assumptions the analysis continues. Mr. Wooster said the Science Center's approach considers all these factors. Mr. Le said thermal suitability is one of many filters to determine overall reintroduction suitability, and he is curious to better understand the Science Center's approach. Ms. Jean Castillo (NMFS) noted the approach described by Dr. Hanson would be fairly repetitive. Dr. Ron Yoshiyama (CCSF) said this is the general approach the Districts took in the population models built for the lower Tuolumne River.

Dr. Yoshiyama said there are two issues at play here. The first is representing the life cycle, which has already been done by the Districts' population models. The second is habitat suitability. Boughton et al. (2015) describes temperature suitability in the Santa Ynez River in conjunction with food availability. Various other factors appear to already be integrated into the approach. The approach for the Santa Ynez River is a simplified approach compared to what will be necessary for the Tuolumne River as the Santa Ynez approach does not include consideration of resident life history. Dr. Yoshiyama summarized other aspects of Boughton et al. (2015). Dr. Yoshiyama said additional details about the mechanisms behind the bioenergetics approach appear to be forthcoming in the upcoming manuscript mentioned by Mr. Wooster.

Mr. Devine asked Dr. Yoshiyama if Boughton et al. (2015) assumes that when a fish reaches a certain size, it will be anadromous. Dr. Yoshiyama said yes, and that a missing part of the story seems to be the consideration of those fish that reach that size but do not become anadromous. Dr. Yoshiyama said this group can look to analysis on other rivers to inform assumptions about residency and anadromy.

Mr. Le asked about the schedule for the Russian River memo. Mr. Wooster said he believes the memo is drafted and under review. He said he will check on the schedule. Mr. Le asked if the report for the Tuolumne River will includes further details about how carrying capacity is calculated. Mr. Wooster said the Science Center's approach to calculating carrying capacity was honed on the Santa Ynez and fine-tuned for the Russian River. The Russian River memo will include most of the details on methodology.

Mr. Devine said it appears one outcome of the Science Center's work is that NMFS will not be adopting EPA (2003) for salmonids in the upper Tuolumne River. Mr. Wooster said NMFS is only trying to determine how many fish can be produced in that stretch of the river.

Referring to Mr. Bratovich's presentation, Ms. Ferreira said his slides seem to indicate that 60°F to 65°F is optimal for all life stages, and that when 70°F is reached, the conditions are stressful. Mr. Bratovich said that is pretty much true except for spawning, which requires temperatures in the mid-50s. Ms. Ferreira asked if 20°C and 21°C is stressful, and the fish are already stressed from swimming upstream and trying to avoid predation, isn't more water needed in the river to cool it off. Mr. Bratovich said that topic is covered in Boughton et al. (2015). Ms. Ferreira said it is confusing trying to determine what "stressful" actually means and she asked if fish would die at 70°F or 71°F. Mr. Bratovich said Boughton et al. (2015) notes fish die at 24°C and 25°C. Mr. Bratovich questioned how to determine how much stress is too much stress and at what point elevated temperatures become so influential that the population over time will no longer be successful.

Ms. Ferreira asked why 70°F is even being discussed if the temperature is so stressful for fish. Mr. Lonnie Moore (public citizen) said at some points of the year, the stress that may result from higher temperatures may be mitigated by other factors, such as greater amounts of food. Therefore, it is important to consider these higher temperatures.

Ms. Ferreira asked if lower temperatures are generally better for fish. Ms. Murphey said in general lower temperatures are better. In the lower Tuolumne River, fish can generally move around to take advantage of different temperatures that exist in different reaches. The water is coolest in the upstream reaches near the dam. Dr. Yoshiyama said that as the water from the dam flows downstream, it becomes warmer and warmer. A certain amount of water must be released in order to keep the river cool enough for the fish to survive. That is why it is important to explore what higher temperatures mean in the upper river. Dr. Yoshiyama said it is the goal of this group to give some direction to a temperature boundary in the upper river. Ms. Ferreira asked if the studies being done will arrive at that temperature. Ms. Murphey said that would not be an outcome of the studies.

Mr. Le said it is concerning that EPA (2003) may be applied in the lower river but in the upper river more lenient criteria is being considered. Mr. Le asked if lenient criteria are used to justify building fish passage, and fish passage is ultimately built, will the lenient criteria be kept going forward or will more conservative criteria then be implemented. Ms. Murphey said the difference between the upper and lower reaches is that there are no mechanisms for changing the flow in the upper river, while mechanisms do exist for changing flow in the lower river. Mr. Le said the question still exists how these temperature considerations inform whether or not to reintroduce fish. Mr. Le said it seems like more conservative parameters should be considered. Mr. Zac Jackson (US Fish and Wildlife Service) said one way to look at it is that there are 1,000 widgets of habitat and we want to see how many widgets can support fish. Maybe just one widget can support fish, but enough fish can be supported by that one widget that it appears the population can be viable. That doesn't necessarily mean that fish should or should not be introduced. Mr. Le said if water temperature indices are used to assess the widgets, and then fish passage is built, will those same water temperature indices be what is required in the future. Mr. Le said it seems as though any analysis should start with the conservative protective criteria. Mr. Jackson said he understands these are two different approaches, and that if more protective temperatures were implemented, that might change the amount of habitat that is available. Mr. Wooster said NMFS' approach does not say whether a temperature is good or bad, only if it is "stressful" and, based on other factors, how stressful it is. Mr. Wooster said it is known that there are stressful temperatures in the upper river, but there are also areas that are not as stressful. Given that there are both stressful and not stressful areas, NMFS is trying to determine how many fish the reach can support. Mr. Wooster said if fish are reintroduced, temperatures in the upper reach would not be managed. Mr. Devine said that would mean managing the same fish under different temperature regimes. Mr. Devine asked why the agencies would ask the Districts to put more water downstream if it had already been determined that the same population is viable under stressful conditions? Mr. Wooster said the potential benefit of reintroducing fish upstream is potential water savings downstream.

The meeting concluded. After a short break, the Reintroduction Goals Subcommittee meeting began.

Action Items

1. The Districts will add the effects of temperature on juvenile or adult salmonids graphic to the water temperature literature review and literature review summary.

2. Given that the NMFS Science Center may only want to give one presentation to the Temperature Subcommittee, the Temperature Subcommittee will consider the timing of when to request a presentation.

3. The Districts will try to match up the temperature numbers presented in Boughton et al. (2015) with the water temperature definitions provided on slide 5 of Mr. Bratovich's presentation. The Districts will provide their findings to the Temperature Subcommittee and NMFS for feedback. NMFS will provide feedback.

4. Mr. Wooster will provide a schedule for when the Russian River memo will be available for review.

5. Mr. Wooster will provide a schedule for when the Tuolumne and Merced Habitat and Carrying Capacity and Genetics study reports will be available for review.

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Water Temperature/Reintroduction Goals Subcommittees – In-person Meeting

Thursday, December 1, 2016, 1:00 pm to 4:00 pm

Modesto Irrigation District, 1231 11th St., Modesto, CA 95354
Conference Line: 1-866-583-7984; Passcode: 814-0607

Meeting Objectives:

1. Review and discuss updated water temperature literature review summary, glossary of terms/acronym list based upon comments received.
2. Presentation and discussion on relevant temperature terms.
3. Discuss water temperature indices (WTI) when considering anadromous fish reintroduction in the Upper Tuolumne River.
4. Discuss next steps and schedule for WTI selection.
5. Review, discuss and modify draft narrative reintroduction goals statement.
6. Discuss next steps and schedule for finalizing a reintroduction goals statement.

TIME	TOPIC
1:00 pm – 1:10 pm	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
1:10 pm – 2:30 pm	Water Temperature Subcommittee Topics (All) a. Updated Literature Review Summary and Acronym List– comments received (Districts) b. Presentation and discussion on relevant temperature terms (Districts) c. Subcommittee discussion of potential WTI values (All) - NMFS Input
2:30 pm – 3:50 pm	Reintroduction Goals Subcommittee Topics (All) a. Additional discussion on current draft narrative reintroduction goals statement (All) b. Subcommittee discussion of further development of draft narrative goal statement (All) - Additional corollary statements? - Quantitative input (Lindley 2007)?
3:50 pm – 4:00 pm	Next Steps (All) a. Schedule next call and agenda topics b. Action items from this call

Upper Tuolumne River Reintroduction Assessment Framework
Water Temperature Subcommittee
Water Temperature Evaluation
Glossary of Terms

Acute temperature – water temperature identified as being in the **zone of resistance** for a particular species/lifestage. The lower boundary of the acute temperature response range is represented by the **upper incipient lethal temperature**.

Acute temperature exposure – water temperature exposure that is less than 7 days and results in 50% mortality.

Acute temperature zone – zone where acute water temperature exposure occurs with potential for rapid mortality; **zone of resistance**.

Average daily temperature (ADT) – average of temperatures in a 24-hour period.

Chronic temperature – water temperature identified as being in the **temperature tolerance zone** for a particular species/lifestage. The lower boundary of the temperature tolerance zone is represented by the upper optimal temperature.

Chronic temperature exposure – water temperature exposure that is long-term (≥ 7 days).

Chronic temperature zone – zone where chronic water temperature exposure occurs with reduced (or no) growth and reproduction, and increased mortality.

Critical thermal maximum – very short duration (minutes) mortality after acute temperature exposure.

Diel temperature – temperature over 24-hour period.

Diurnal temperature – temperature fluctuations between high and low or day and night of the same day.

Lifestage periodicity – season/dates corresponding to a specific lifestage (e.g. spring-run Chinook salmon spawning); identified through study of a particular watershed.

Maximum weekly average temperature (MWAT) – the highest value calculated for all possible 7-day periods over a given time period (e.g. season or lifestage) and generally used to summarize instream water temperature variation occurring on daily or seasonal basis for evaluation of chronic water temperature impacts; found by calculating mathematical mean of multiple, equally spaced, daily water temperatures over a 7-day consecutive period.

Optimal temperature range – zone of temperatures where physiological processes (growth, reproduction, disease resistance) and behavior are not stressed by temperature.

Seven (7)-day moving average temperature (7DMA) – water temperature metric describing the running 7-day average of average daily water temperatures; calculated by adding the daily average temperatures recorded at a site on seven consecutive days and dividing by seven uses consecutive seven day subsets.

Seven (7)-day moving average daily maximum temperature (7DMADM) – water temperature metric describing the running 7-day average of the daily maxima; calculated by adding the daily maximum temperatures recorded at a site on seven consecutive days and dividing by seven, uses consecutive seven day subsets.

Seven (7)-day average daily maximum temperature (7DADM) – water temperature metric describing the maximum 7-day average of the daily maxima; calculated by adding the daily maximum temperatures recorded at a site on seven consecutive days and dividing by seven.

Upper incipient lethal temperature (UILT) – boundary between lower end of **acute temperature exposure** range and upper end of **chronic temperature exposure** range, at which 50% mortality occurs after 7 days.Upper optimal WTI (UOWTI) – the upper boundary of the optimal temperature range where physiological processes (growth, reproduction, disease resistance) and behavior are not stressed by temperature; **optimal temperature range** identified for specific lifestage.Upper tolerance WTI (UTWTI) – the water temperature at which fish can survive indefinitely, without experiencing substantial detrimental effects to physiological and biological functions such that survival occurs, but growth and reproduction success are reduced below optimal.

Use designation – category applied to a waterbody that determines which **water quality standards (WQS)** will be enforced.

Volitional migration – active behavior of upstream or downstream migration occurring when anadromous fish are physiologically ready.

Water quality standards (WQS) – specified concentrations/values of various water quality parameters not to be exceeded as established by the U.S. Environmental Protection Agency (EPA) and/or state for beneficial uses such as aquatic life and drinking water.

Water temperature index (WTI) values – values representing a gradation of potential water temperature effects ranging between optimal to lethal conditions by species and lifestage; developed empirically through laboratory and field studies.

Water temperature exceedance curves – used to identify probabilities/duration of time that lifestage-specific **WTI** values would be exceeded over a given time.

Water temperature metrics – provide index of temperature over a period of time (e.g. **MWAT**, **7DADM**).

Water year type – describes amount of precipitation received during water year (e.g. critically dry to wet).

Zone of resistance – water temperature zone between the **UILT** (7 days) and **critical thermal maximum**.

Zone of tolerance – water temperature zone that fish can tolerate that is below the **UILT** and above the **optimal temperature** range, but at the higher end of the range individuals may not thrive and may exhibit modified behavior.

UPPER TUOLUMNE RIVER REINTRODUCTION ASSESSMENT FRAMEWORK
WATER TEMPERATURE SUBCOMMITTEE

LIFESTAGE-SPECIFIC WATER TEMPERATURE BIOLOGICAL EFFECTS AND INDEX TEMPERATURE VALUES

Literature Review Summary

INTRODUCTION

The La Grange Hydroelectric Project (La Grange Project), owned and operated by the Turlock Irrigation District and Modesto Irrigation District (TID/MID, or the Districts), is currently undergoing the Federal Energy Regulatory Commission (FERC) Integrated Licensing Process. As part of this process, the Districts are implementing a FERC-approved Fish Passage Facilities Alternatives Assessment which consists of developing general design criteria and design considerations applicable to upstream and downstream fish passage facilities at the La Grange Project. Design criteria and considerations include items such as: site-specific physical and operational parameters; applicable regulatory requirements; National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and California Department of Fish and Wildlife (CDFW) biological and engineering design criteria; site-specific biological/habitat information relevant to the sizing and configuration of facilities; and any other information gaps that may affect siting, sizing, general design parameters, capital cost, and operating requirements of potential fish passage facilities.

To make certain that detailed, site-specific information is available to support and adequately inform decisions regarding fish reintroduction and fish passage, TID, MID, and licensing participants came to a consensus on the need for and utility of an Upper Tuolumne River Reintroduction Assessment Framework (Framework). The Framework is intended to provide a comprehensive, collaborative, and transparent approach for evaluating the full range of potential issues associated with the future reintroduction of anadromous salmonids to the upper Tuolumne River. In addition to considering aspects of the technical feasibility of building and operating fish passage facilities, the Framework considers the interrelated issues of ecological feasibility, biological constraints, economics, regulatory implications, and other considerations of reintroduction. Elements of the Framework are interconnected, with fish passage construction and operational requirements needing to properly reflect biological constraints, ecological considerations, and economic cost-benefit assessments.

Water temperature considerations are a primary component of assessing any potential anadromous salmonid reintroduction effort. In support of the Framework, the Districts and licensing participants established a Water Temperature Subcommittee to begin investigating water temperature considerations pertinent to anadromous salmonid reintroduction opportunities in the accessible reaches of the Tuolumne River upstream of Don Pedro Reservoir (upper Tuolumne River). On September 15, 2016, the Districts hosted the first conference call for the Water Temperature Subcommittee (draft meeting notes from this call were distributed on October 3 for a 30-day comment period). On the conference call, attendees discussed the need for a comprehensive literature review of regional and site-specific information to inform the selection of water temperature index (WTI) values to be used in an evaluation of the water temperature-related reintroduction potential in the reaches of the upper Tuolumne River. Meeting attendees agreed that the literature review performed for the Yuba Salmon Forum (Appendix A; Bratovich *et al.* 2012) to support the anadromous salmonid reintroduction assessment in this watershed coupled with site-specific temperature studies or data for the Tuolumne River, if available, would be a good basis for this effort. The following represents and updated literature review summary and is provided to the Water Temperature Subcommittee to support selection of water temperature index values for the Framework.

STEELHEAD LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Adult Immigration and Holding

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. Yuba County Water Agency (YCWA) *et al.* (2007) suggests that few studies have been published examining the effects of water temperature on either steelhead immigration or steelhead holding, and none of the available studies were recent (Bruin and Waldsdorf 1975; McCullough *et al.* 2001). The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid-50°F range, and that immigration will be delayed if water temperatures approach approximately 70°F (Table 1). WTI values of 52°F, 56°F, 61°F, 64°F, 65°F, 68°F and 70°F were identified because they provide a gradation of potential water temperature effects, and the available literature provided the strongest support for these values.

Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of WTI values could not be achieved. 52°F was identified as a WTI value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (McEwan and Jackson 1996; NMFS 2000; NMFS 2002), and "optimum" (Reclamation 1997a) water temperature for steelhead adult immigration. Increasing levels of thermal stress to this lifestage may reportedly occur above the 52°F WTI value. 56°F was identified as a WTI value because 56°F represents a water temperature above which adverse effects to migratory and holding steelhead begin to arise (Bruin and Waldsdorf 1975; Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 50-59°F is referred to as the "preferred" range of water temperatures for California summer steelhead holding (Moyle *et al.* 1995). Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS 1995a). A water temperature of 64°F (7DADM) was identified as the value for steelhead adult lifestage for the San Joaquin River (CALFED 2009) and as the Upper Optimum Value for steelhead adult migration (MWAT) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" migration (EPA 2003b). 65°F was identified as a WTI value because steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Additionally, over 93% of steelhead detections occurred in the 65.3-71.6°F range, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006) and/or may modify migration timing due to holding in coldwater refugia (High *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). A water temperature of 68°F was found to drop egg fertility in vivo to 5% after 4.5 days (McCullough *et al*. 2001). Additionally, empirical adult *O. mykiss* population data from the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon rivers were collected in 2007-2009 were plotted against temperature (Figure 4 of Bratovich *et al*. 2012). The data show a population density break at about 68°F. Although smaller population densities occurred at higher temperatures, the largest population densities occurred at temperatures near 68.0°F or less. 70°F was identified as the highest WTI value because the literature suggests that water temperatures near and above 70.0°F may result in a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001) and are water temperatures referred to as "stressful" to upstream migrating steelhead in the Columbia River (Lantz 1971 as cited in Beschta *et al.* 1987). Further, Coutant (1972) found that the upper incipient lethal temperature (UILT) for adult steelhead was 69.8°F and temperatures between 73-75°F are described as "lethal" to holding adult steelhead in Moyle (2002).

As part of the Framework, TID and MID, in collaboration with stakeholders developed a table of WTI values from select salmon and steelhead programs in the Central Valley (Temperature Criteria Matrix; presented at the September 15, 2016 Water Temperature Subcommittee conference call). The table was developed to support the Framework's Water Temperature Subcommittee whose purpose is to establish a technical basis to evaluate water temperature regimes for target anadromous salmonid reintroduction into the Tuolumne River upstream of Don Pedro Reservoir. For steelhead adult immigration, the Temperature Criteria Matrix identified 64°F for the San Joaquin (CALFED 2009) and 64°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
For steelhead adult holding, the Temperature Criteria Matrix identified 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Table 1. Steelhead Adult Immigration and Holding WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F (11.1°C)	Preferred range for adult steelhead immigration of 46.0°F to 52.0°F (NMFS 2000; NMFS 2001a; SWRCB 2003). Optimum range for adult steelhead immigration of 46.0°F to 52.1°F[1] (Reclamation 1997a). Recommended adult steelhead immigration temperature range of 46.0°F to 52.0°F (Reclamation 2003).
56°F (13.3°C)	To produce rainbow trout eggs of good quality, brood fish must be held at water temperatures not exceeding 56.0°F (Leitritz and Lewis 1980). Rainbow trout brood fish must be held at water temperatures not exceeding 56°F for a period of 2 to 6 months before spawning to produce eggs of good quality (Bruin and Waldsdorf 1975). Holding migratory fish at constant water temperatures above 55.4°F to 60.1°F may impede spawning success (McCullough *et al.* 2001).
61°F (16.1°C)	Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter- run steelhead (USFWS 1995a). Preferred range of water temperature for holding California summer steelhead occurs between 50-59°F (Moyle 1995). A water temperature of 61°F was identified as the Upper Optimum Value for steelhead adult holding, MWAT, for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
64°F (17.8°C)	Steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Over 93% of steelhead detections occurred in the 65.3-71.6°F, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006). A water temperature of 64°F was identified as the value for steelhead adult lifestage, 7DADM, for the San Joaquin River (CALFED 2009) and as the Upper Optimum Value for steelhead adult migration, MWAT, for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" migration (EPA 2003b).
65°F (18.3°C)	A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). A water temperature of 68°F was found to drop egg fertility in vivo to 5% after 4.5 days (McCullough *et al.* 2001).
70°F (21.1°C)	Migration barriers have frequently been reported for pacific salmonids when water temperatures reach 69.8°F to 71.6°F (McCullough *et al.* 2001). Snake River adult steelhead immigration was blocked when water temperatures reached 69.8 (McCullough *et al.* 2001). The UILT for adult steelhead was determined to be 69.8°F (Coutant 1972).

Spawning and Embryo Incubation

Relatively few studies have been published directly addressing the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979; Rombough 1988). Because anadromous steelhead and non-anadromous rainbow trout are genetically and physiologically similar, studies on non-anadromous rainbow trout also were considered in the development of WTI values for steelhead spawning and embryo incubation (Moyle 2002; McEwan 2001). From the available literature, water temperatures in the low

[1] Similar to Bratovich *et al*. 2012, rounded whole integers were identified for index values to avoid unwarranted specificity.

50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high 50°F range and above (Table 2). Water temperatures in the 45-50°F range have been referred to as the "optimum" for spawning steelhead (FERC 1993).

WTI values of 46°F, 52°F, 54°F, 55°F, 57°F, 59°F and 60°F were identified for two reasons. First, the available literature provided the strongest support for WTI values at or near these integers. Second, the index values reflect a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead spawning and embryo incubation. Some literature suggests water temperatures ≤ 50°F are when steelhead spawn (Orcutt *et al.* 1968) and/or are optimal for steelhead spawning and embryo survival (FERC 1993; Myrick and Cech 2001; Timoshina 1972) and temperatures between 39-52°F are "preferred" by spawning steelhead (IEP Steelhead Project Work Team (no date); McEwan and Jackson 1996). Orcutt *et al.* (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F. A larger body of literature suggests optimal conditions occur at water temperatures ≤ 52°F (Humpesch 1985; NMFS 2000; NMFS 2001a; NMFS 2002; Reclamation 1997b; SWRCB 2003; USFWS 1995b). Further, water temperatures between 48-52°F were referred to as "optimal" (FERC 1993; McEwan and Jackson 1996; NMFS 2000) and "preferred" (Bell 1986) for steelhead embryo incubation. Therefore, 52°F was identified as the lowest WTI value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation lifestage may reportedly occur above the 52°F WTI value.

54°F was identified as the next index value, because although most of the studies conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions, and conditions that cause negative effects to steelhead spawning and embryo incubation. Further, water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning and egg incubation (EPA 2003b). For steelhead spawning and embryo incubation in the Yuba River, the Framework Temperature Criteria Matrix identified 54°F and 57°F for Upper Optimum and Upper Tolerable values, respectively (Bratovich *et al.* 2012). 57°F was identified as an index value because embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57°F. Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50% hatch under incubation temperatures ranging from 33.8°F to 60.8°F that demonstrated a two-fold increase in mortality for embryos incubated at 57.2°F, compared to embryos incubated at 53.6°F.

In a laboratory study using gametes from Big Qualicum River, Vancouver Island, steelhead mortality increased to 15% at a constant temperature of 59.0°F, compared to less than 4% mortality at constant temperatures of 42.8°F, 48.2°F, and 53.6°F (Rombough 1988). Also, alevins hatching at 59°F were considerably smaller and appeared less well developed than those incubated at the lower temperature treatments. From fertilization to 50% hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56% survival when incubated at 59.0°F (Kwain 1975).

As part of the Don Pedro Hydroelectric Project FERC relicensing process, the Districts conducted an *O. mykiss* Population Study (TID/MID 2014) for the Lower Tuolumne River below La Grange Diversion Dam. The goal of the study is to provide a quantitative population model to investigate the relative influences of various factors on the lifestage-specific production of *O. mykiss* in the Tuolumne River including water temperature effects on population response for specific in-river lifestages. The study noted that although no literature information could be identified regarding upper temperature limits for spawning initiation, maximum temperature limits for spawning are assumed to be on the order of 15°C (59°F) inferred from egg mortality thresholds for resident *O. mykiss* (Velsen 1987) as well as steelhead (Rombough 1988). Similarly, for egg incubation, the model allowed for a broad range of flow and water temperature conditions using the completed model, an initial acute mortality threshold of 15°C (59°F) was included based upon a literature review by Myrick and Cech (2001).

From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). Myrick and Cech (2001) similarly described water temperatures >59°F as "lethal" to incubating steelhead embryos, although FERC (1993) suggested that water temperatures exceeding 68°F were "stressful" to spawning steelhead and "lethal" when greater than 72°F.

Table 2. Steelhead Spawning and Embryo Incubation WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
46°F (7.8°C)	Orcutt *et al*. (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F.
52°F (11.1°C)	Rainbow trout from Mattighofen (Austria) had highest egg survival at 52.0°F compared to 45.0°F, 59.4°F, and 66.0°F (Humpesch 1985). Water temperatures from 48.0°F to 52.0°F are suitable for steelhead incubation and emergence in the American River and Clear Creek (NMFS 2000; NMFS 2001a; NMFS 2002a). Optimum water temperature range of 46.0°F to 52.0°F for steelhead spawning in the Central Valley (USFWS 1995b). Optimum water temperature range of 46.0°F to 52.1°F for steelhead spawning and 48.0°F to 52.1°F for steelhead egg incubation (Reclamation 1997a). Upper limit of preferred water temperature of 52.0°F for steelhead spawning and egg incubation (SWRCB 2003).
54°F (12.2°C)	Big Qualicum River steelhead eggs had 96.6% survival to hatch at 53.6°F (Rombough 1988). Highest survival from fertilization to hatch for *Salmo gairdneri* incubated at 53.6°F (Kamler and Kato 1983). Emergent fry were larger when North Santiam River (Oregon) winter steelhead eggs were incubated at 53.6°F than at 60.8°F (Redding and Schreck 1979). The upper optimal water temperature regime based on constant or acclimation water temperatures necessary to achieve full protection of steelhead is 51.8°F to 53.6°F (EPA 2001). From fertilization to hatch, rainbow trout eggs and larvae had 47.3% mortality (Timoshina 1972). Survival of rainbow trout eggs declined at water temperatures between 52.0 and 59.4°F (Humpesch 1985). The optimal constant incubation water temperature for steelhead occurs below 53.6°F (McCullough *et al.* 2001). A water temperature of 54°F (MWAT) was identified as the Upper Optimum Value for steelhead spawning and embryo incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
55°F (12.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning and egg incubation (EPA 2003b). Water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993).
57°F (13.9°C)	From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). A sharp decrease in survival was observed for rainbow trout embryos incubated above 57.2°F (Kamler and Kato 1983). A water temperature of 57°F (MWAT) was identified as the Upper Tolerable Value for steelhead spawning and embryo incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
59°F (15°C)	Based on egg mortality thresholds for steelhead, maximum temperature limits for spawning are assumed to be 59°F (Rombaugh 1988 as cited in TID/MID 2014). A water temperature of 59°F was identified as the initial acute mortality threshold for steelhead egg incubation (Myrick and Cech 2001 as cited in TID/MID 2014). From fertilization to 50% hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56% survival when incubated at 59.0°F (Kwain 1975).
60°F (15.6°C)	Water temperatures >59°F are described as "lethal" to incubating steelhead embryos (Myrick and Cech 2001), From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987).

Juvenile Rearing & Downstream Movement

Water temperature index values were developed to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages. Some steelhead may rear in freshwater for up to three years before emigrating as yearling+ smolts, whereas other individuals move downstream shortly after emergence as post- emergent fry, or rear in the river for several months and move downstream as juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals continue to rear and grow in downstream areas and undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are assessed in this Technical Memorandum using the fry and juvenile rearing WTI values.

The growth, survival, and successful smoltification of juvenile steelhead are controlled largely by water temperature. The duration of freshwater residence for juvenile steelhead is long relative to that of Chinook salmon, making the juvenile lifestage of steelhead more susceptible to the influences of water temperature, particularly during the over-summer rearing period. Central Valley juvenile steelhead have high growth rates at water temperatures in the mid-60°F range, but reportedly require lower water temperatures to successfully undergo the transformation to the smolt stage.

WTI values of 61°F, 63°F, 64°F, 65°F, 68°F, 72°F, 75°F, and 77°F were identified to represent a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead juvenile rearing (Table 3). A water temperature of 61°F (7DADM) was identified as the value for steelhead juvenile rearing for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 61°F (7DADM) for "salmon and trout" core juvenile rearing. The WTI value of 63°F was identified because Myrick and Cech (2001) describe 63°F as the "preferred" water temperature for wild juvenile steelhead, whereas "preferred" water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" juvenile rearing (EPA 2003b). 65°F was also identified as a WTI value because NMFS (2000; 2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the optimum water temperature range for juvenile growth (i.e., 59-66°F) (Myrick and Cech 2001), and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999). Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F WTI value.

Kaya *et al.* (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F. Cherry *et al.* (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech and Myrick (1999) and FERC (1993). Growth for 200 mm juvenile *O. mykiss* versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%) was evaluated. The average empirically derived percent of maximum consumption in the Middle Fork American Fork River was 50% (Hanson *et al.* 1997). Positive growth only occurs up to approximately 68°F. Because of the literature describing 68°F as both an upper preferred and an avoidance limit for juvenile *O. mykiss*, and because of the empirical fish population data and bioenergetics growth data, 68°F was identified as an upper tolerable WTI value.

A WTI value of 72°F was identified because symptoms of thermal stress in juvenile steelhead have been reported to arise at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen *et al.* 1994). Also, 72°F was identified as a WTI value because 71.6°F has been reported as an upper avoidance water temperature (Kaya *et al.* 1977) and an upper thermal tolerance water temperature (Ebersole *et al.* 2001) for juvenile rainbow trout. The WTI value of 75°F was identified because NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75°F (EPA 2002; NMFS 2001b). Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al.* 2000; McCullough 2001).

A swim tunnel study conducted on the Lower Tuolumne River (TID/MID 2016) generated high quality field data on the physiological performance of Tuolumne River *O. mykiss* acutely exposed to a temperature range of 13 to 25°C (55.4°F to 77°F). The data indicated that wild juvenile *O. mykiss* represents an exception to the expected based on the 7DADM criterion for juvenile rearing set out by EPA (2003b) for Pacific Northwest *O. mykiss*. The study recommended that a conservative upper aerobic performance limit of 71.6°F, instead of 64.4°F (EPA), be considered in re-determining a 7DADM for this population.

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified the UILT for *O. mykiss* juveniles has been estimated at 22.8–25.9ºC (73–79°F) (Threader and Houston 1983). In the model, an initial mortality threshold of 25°C (77°F) daily average temperature was identified for *O. mykiss* juveniles. Note also that both fry rearing and resident adult rearing lifestages of *O. mykiss* also had UILT values of 77°F to support the model.

For steelhead juvenile rearing, the Temperature Criteria Matrix identified 65°F for the Lower American River (Water Forum 2007); 61°F for the San Joaquin (CALFED 2009); and 65°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al.* 2012).

Table 3. Steelhead Juvenile Rearing WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
61°F (16.1°C)	A water temperature of 61°F (7DADM) was identified as the value for steelhead juvenile rearing for the San Joaquin River (CALFED 2009).
63°F (17.2°C)	Preferred water temperature for wild juvenile steelhead is reportedly 63°F, whereas preferred water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. Myrick and Cech (2001)
64°F (17.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" juvenile rearing (EPA 2003b).
65°F (18.3°C)	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). The final preferred water temperature for rainbow fingerlings was between 66.2 and 68°F (Cherry *et al.* 1977). Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). A water temperature of 65°F (daily average temperature) was identified as the value for steelhead juvenile rearing for the Lower American River (Water Forum 2007). A water temperature of 65°F (MWAT) was identified as the Upper Optimum Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry *et al.* 1977). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al*. 1977). FERC (1993) referred to 68°F as "stressful" to juvenile steelhead. Empirical fish population and water temperature data in the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon Rivers (Figure 4 of Bratovich *et al.* 2012) indicate a sharp reduction in O. *mykiss* population densities when temperatures exceed 68°F for greater than one week. Bioenergetics modeling of growth based on consumption (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above 68°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
72°F (22.2°C)	Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen *et al.* 1994). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole *et al.* 2001). A swim tunnel study conducted on the Lower Tuolumne recommended a conservative upper aerobic performance limit of 71.6°F for steelhead juvenile rearing (TID/MID 2016).
75°F (23.9°C)	The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (EPA 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole *et al.* 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al*. 2000; McCullough 2001).
77°F (25°C)	In the model associated with the Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014), an initial mortality threshold of 77°F daily average temperature was identified for *O. mykiss* juveniles.

Smolt Emigration

Laboratory data suggest that smoltification, and therefore successful emigration of steelhead smolts, is directly controlled by water temperature (Adams *et al.* 1975) (Table 4). WTI values of 52°F and 55°F were identified to evaluate the steelhead smolt emigration lifestage, because most literature on water temperature effects on steelhead smolting suggest that water temperatures less than 52°F (Adams *et al.*1975; Myrick and Cech 2001; Rich 1987a) or less than 55°F (EPA 2003a; McCullough *et al.* 2001; Wedemeyer *et al.* 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur. Adams *et al.* (1973) tested the effect of water temperature (43.7°F, 50.0°F, 59.0°F or 68.0°F) on the increase of gill microsomal Na^+-, K^+-stimulated ATPase activity associated with parr-smolt transformation in steelhead and found a two-fold increase in Na^+-, K^+-ATPase at 43.7 and 50.0°F, but no increase at 59.0°F or 68.0°F. In a subsequent study, the highest water temperature where a parr-smolt transformation occurred was at 52.3°F (Adams *et al.* 1975). The results of Adams *et al.* (1975) were reviewed in Myrick and Cech (2001) and Rich (1987b), which both recommended that water temperatures below 52.3°F are required to successfully complete the parr-smolt transformation. Further, Myrick and Cech (2001) suggest that water temperatures between 43-50°F are the "physiologically optimal" temperatures required during the parr-smolt transformation and necessary to maximize saltwater survival. The 52°F WTI value identified for the steelhead smolt emigration lifestage is the index value generally reported in the literature as the upper limit of the water temperature range that provides successful smolt transformation thermal conditions. Increasing levels of thermal stress to this lifestage may reportedly occur above the 52°F WTI value.

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead. They found ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by the EPA to provide temperature water quality standards for the protection of Northwest native salmon and trout, water temperatures greater than 54.5°F were identified as an impairment to smoltification for juvenile steelhead (EPA 2003b). Water temperatures are considered "unsuitable" for steelhead smolts at >59°F (Myrick and Cech 2001) and "lethal" at 77°F (FERC 1993).

For steelhead smolt emigration, the Temperature Criteria Matrix identified 57°F for the San Joaquin (CALFED 2009) and 52°F (Upper Optimum Value) and 55°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 57°F (7DADM) for steelhead smoltification.

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified an initial UILT mortality threshold of 77°F daily average temperature for *O. mykiss* smolts on the basis of literature reviews by Myrick and Cech (2001).

Table 4. Steelhead Smolt Emigration WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F (11.1°C)	Steelhead successfully smolt at water temperatures in the 43.7°F to 52.3°F range (Myrick and Cech 2001). Steelhead undergo the smolt transformation when reared in water temperatures below 52.3°F, but not at higher water temperatures (Adams *et al.* 1975). Optimum water temperature range for successful smoltification in young steelhead is 44.0°F to 52.3°F (Rich 1987a). A water temperature of 52°F (MWAT) was identified as the Upper Optimum Value for steelhead smolt emigration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
55°F (12.8°C)	ATPase activity was decreased and migration reduced for steelhead at water temperatures greater than or equal to 55.4°F (Zaugg and Wagner 1973). Water temperatures should be below 55.4°F at least 60 days prior to release of hatchery steelhead to prevent premature smolting and desmoltification (Wedemeyer *et al.* 1980). In winter steelhead, a temperature of 54.1°F is nearly the upper limit for smolting (McCullough *et al.* 2001; Zaugg and Wagner 1973). Water temperatures less than or equal to 54.5°F are suitable for emigrating juvenile steelhead (EPA 2003b). Water temperatures greater than 55°F prevent increases in ATPase activity in steelhead juveniles (Hoar 1988). Water temperatures greater than 56°F do not permit smoltification in summer steelhead (Zaugg *et al.* 1972). A water temperature of 55°F (MWAT) was identified as the Upper Tolerable Value for steelhead smolt emigration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
57°F (13.9°C)	A water temperature of 57°F (7DADM) was identified as the value for steelhead smolt emigration for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 57°F (7DADM) for steelhead smoltification (EPA 2003b).
59°F (15°C)	Yearling steelhead held at 43.7°F and transferred to 59°F had a substantial reduction in gill ATPase activity, indicating that physiological changes associated with smoltification were reversed (Wedemeyer *et al.* 1980).
77°F (25°C)	A water temperature of 77°F (daily average temperature) was identified as UILT mortality threshold for *O. mykiss* smolts (Myrick and Cech 2001 as cited in TID/MID 2014).

CHINOOK SALMON LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

It has been suggested that separate water temperatures standards should be developed for each run-type of Chinook salmon. For example, McCullough (1999) states that spring-run Chinook salmon immigrate in spring and spawn in 3rd to 5th order streams and, therefore, face different migration and adult holding temperature regimes than do summer- or fall-run Chinook salmon, which spawn in streams of 5th order or greater . However:(1) there is a general paucity of literature specific to each lifestage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the WTI values derived from all the literature pertaining to Chinook salmon for a particular lifestage will be sufficiently protective of that lifestage for each run-type; and (4) all run- types overlap in timing of adult immigration and holding and in some cases are not easily distinguished (Healey 1991). Information distinctly applicable to spring-run or fall-run Chinook salmon is identified where run-specific information is available.

Adult Immigration and Holding

The adult immigration and staging lifestages for fall-run Chinook salmon are evaluated together, because they are believed to not spend significant amounts of time after immigrating and prior to spawning. The adult immigration and holding lifestages are evaluated separately for spring-run Chinook salmon, because of the potential extended duration of holding after immigrating and prior to spawning.

The WTI values reflect a gradation of potential water temperature effects that range between those reported as "optimal" to those reported as "lethal" for adult Chinook salmon during upstream spawning migrations and holding. The WTI values identified for the Chinook salmon adult immigration and holding lifestage are 60°F, 61°F, 64°F, 65°F, 68°F and 70°F (Table 5). Although 56°F is referenced in the literature frequently as the upper "optimal" water temperature limit for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, Boles *et al.* (1988), Marine (1992), and NMFS (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for adult Chinook salmon immigration. However, Hinze (1959) is a study examining the effects of water temperature on incubating Chinook salmon eggs in the American River Basin. Further, water temperatures between 38-56°F are considered to represent the "observed range" for upstream migrating spring-run Chinook salmon (Bell 1986).

The lowest WTI value identified was 60°F because in a previous NMFS biological opinion for the proposed operation of the Central Valley Project (CVP) and State Water Project (SWP), 59°F to 60°F is reported as…"*The upper limit of the optimal temperature range for adults holding while eggs are maturing*" (NMFS 2000). Also, NMFS (1997b) states…"*Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F*". Oregon Department of Environmental Quality (ODEQ; 1995) reports that "*…many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F.*" Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b).

Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon. EPA (2003a) chose a holding value of 61°F (7DADM) based on laboratory data various assumptions regarding diel temperature fluctuations. The 61°F WTI value identified for the Chinook salmon adult immigration and holding lifestage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this lifestage may reportedly occur above the 61°F WTI value.

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 64°F (7DADM) for "salmon and trout" adult migration. A water temperature of 64°F (MWAT) was identified as the Upper Optimum Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al*. 2012).

An index value of 65°F was identified because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 65°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults that ranged from 63.5°F to 66.2°F. During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6 of Bratovich *et al.* 2012). Tracy McReynolds (pers. comm. October 2011) suggested that an upper tolerable holding temperature of 65°F was reasonable. A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

An index value of 68°F was identified because the Butte Creek data and the literature suggests that thermal stress at water temperatures greater than 68°F is pronounced, and severe adverse effects to immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1997; NMFS 1997b; Ward *et al.* 2004).

Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68°F (Marine 1992). Water temperatures of 68°F resulted in nearly 100% mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Water temperatures between 70-77°F are reported as the range of maximum temperatures for holding pool conditions used by spring-run Chinook salmon in the Sacramento-San Joaquin system (Moyle *et al*. 1995). Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al*. 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).

For spring-run Chinook salmon adult immigration, the Framework Temperature Criteria Matrix identified 64°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al*. 2012). For spring-run Chinook salmon adult holding, the Framework Temperature Criteria Matrix identified 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al.* 2012).

Table 5. Chinook Salmon Adult Immigration and Holding WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F (15.6°C)	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59°F to 60°F (NMFS 1997b). Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NMFS 2000). Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60°F (ODEQ 1995). Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b).
61°F (16.1°C)	A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon.
64°F (17.8°C)	A water temperature of 64°F (MWAT) was identified as the Upper Optimum Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" adult migration (EPA 2003b).
65°F (18.3°C)	Acceptable range for adults migrating upstream is from 57°F to 67°F (NMFS 1997b). Disease risk becomes high at water temperatures above 64.4°F (EPA 2003b). Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5°F to 66.2°F (Berman 1990). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6 of Bratovich *et al.* 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992). Water temperatures of 68°F resulted in nearly 100% mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
70°F (21.1°C)	Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al.* 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).

Spawning and Embryo Incubation

The adult spawning and embryo (i.e., eggs and alevins) incubation lifestages share one set of WTI values because spawning and embryonic survival and development typically are considered concurrently in the literature on the effects of water temperature. Spawning and incubation evaluations are conducted separately due to differences in their temporal distributions.

The WTI values identified for the Chinook salmon spawning and embryo incubation lifestages are 55°F, 56°F, 58°F, 60°F, and 62°F (Table 6). Anomalously, FERC (1993) refers to 50°F as the "optimum" water temperature for spawning and incubating Chinook salmon. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning, egg incubation, and fry emergence (EPA 2003b). A water temperature of 55°F (7DADM) was identified as the value for Chinook incubation for the San Joaquin River fall-run Chinook salmon (CALFED 2009).

Additionally, for the adult spawning lifestage, FERC (1993) reports "stressful" and "lethal" water temperatures occurring at >60°F and >70°F, respectively, whereas for incubating Chinook salmon embryos, water temperatures are considered to be "stressful" at <56°F or "lethal" at >60°F. Much literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. NMFS (1993b) reported that optimum water temperatures for egg development are between 43°F and 56°F. Similarly, Myrick and Cech (2001) reported the highest egg survival rates occur between water temperatures of 39-54°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. Bell (1986) recommends water temperatures ranging between 42-57°F for spawning Chinook salmon, and water temperatures between 41-58°F for incubating embryos. USFWS (1995a) reported a water temperature range of 41°F to 56°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. The preferred water temperature range for Chinook salmon egg incubation in the Sacramento River was suggested as 42°F to 56°F (NMFS 1997a). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NMFS (2002a) reported 56°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F WTI value identified for the Chinook salmon spawning and embryo incubation lifestage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this lifestage may reportedly occur above the 56°F WTI value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58°F. For example, (Reclamation Unpublished Work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs (1957) concluded constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002a) suggests 53°F to 58°F is the preferred water temperature range for Chinook salmon eggs and fry. The model associated with the Chinook Salmon Population Model Study (TID/MID 2013), established an initial acute egg/alevin mortality threshold of 58°F. A water temperature of 58°F (MWAT) was identified as the Upper Tolerable Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Johnson (1953) found consistently higher Chinook salmon egg losses resulted at water temperatures above 60°F than at lower temperatures. In order to protect late incubating Chinook salmon embryos and newly emerged fry NMFS (1993a) determined that a water temperature criterion of less than or equal to 60°F be maintained in the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. Seymour (1956) provides evidence that

100% mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60°F. For Chinook salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957), however, found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F/month). The Chinook Salmon Population Model (TID/MID 2013) established an initial estimate of 60.4°F as the upper limit for initiation of spawning (Groves and Chandler 1999); also interpreted as the temperature at which spawning habitat will be considered usable by spawners.

The literature largely agrees that 100% mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to about 62°F (Hinze 1959; Myrick and Cech 2003; Seymour 1956; USFWS 1999). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Geist *et al.* (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

For Chinook salmon spawning and incubation, the Framework Temperature Criteria Matrix identified 60°F or less (as early in October as possible) and 56°F or less (as early in November as possible) as water temperature targets for lower American River fall-run Chinook salmon (Water Forum 2007); 64°F (spawning) and 55°F (incubation) for San Joaquin fall-run Chinook salmon (CALFED 2009); 56°F for Shasta River winter and spring-run Chinook salmon (SWRCB 2016); and 56°F (Upper Optimum Value) and 58°F (Upper Tolerable Value) in the Yuba River Basin (Bratovich *et al*. 2012).

Table 6. Chinook Salmon Spawning and Embryo Incubation WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
55°F (12.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning, egg incubation, and fry emergence (EPA 2003b). A water temperature of 55°F (7DADM) was identified as the value for Chinook incubation for the San Joaquin River fall-run Chinook salmon (CALFED 2009).
56°F (13.3°C)	Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (Reclamation Unpublished Work). Optimum water temperatures for egg development are between 43°F and 56°F (NMFS 1993b). Upper value of the water temperature range (i.e., 41°F to 56°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS 1995b). Upper value of the range (i.e., 42°F to 56°F) given for the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS 1997a). Incubation temperatures above 56°F result in significantly higher alevin mortality (USFWS 1999). 56°F is the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River (NMFS 2002a). Water temperatures averaged 56.5°F during the week of fall-run Chinook salmon spawning initiation on the Snake River (Groves and Chandler 1999). A water temperature of 56°F or less (daily average temperature), as early in November as possible, was identified as the value for fall-run Chinook salmon spawning and incubation for the lower American River (Water Forum 2007). A water temperature of 56°F (daily average temperature) was identified as the value for Chinook spawning and incubation for the Shasta River winter- and spring-run Chinook (SWRCB 2016). A water temperature of 56°F (MWAT) was identified as the Upper Optimum Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
58°F (14.4°C)	Upper value of the range given for preferred water temperatures (i.e., 53°F to 58°F) for eggs and fry (NMFS 2002a). Constant egg incubation temperatures between 42.5°F and 57.5°F resulted in normal development (Combs and Burrows 1957). The natural rate of mortality for alevins occurs at 58°F or less (Reclamation Unpublished Work). The model associated with the Chinook Salmon Population Model Study, established an initial acute egg/alevin mortality threshold of 58°F (TID/MID 2013). A water temperature of 58°F (MWAT) was identified as the Upper Tolerable Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Index Value	Supporting Literature
60°F (15.6°C)	100% mortality can occur to late incubating Chinook salmon embryos (yolk-sac stage) if temperatures are 60°F or greater (Seymour 1956). An October 1 to October 31 water temperature criterion of less than or equal to 60°F in the Sacramento River from Keswick Dam to Bend Bridge has been determined for protection of late incubating larvae and newly emerged fry (NMFS 1993b). Mean weekly water temperature at first observed Chinook salmon spawning in the Columbia River was 59.5°F (Dauble and Watson 1997). Consistently higher egg losses resulted at water temperatures above 60°F than at lower temperatures (Johnson and Brice 1953). For Chinook Salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F/month). A water temperature of 60°F or less (daily average temperature), as early in October as possible, was identified as a target value for Chinook spawning and incubation for the lower American River fall-run Chinook (Water Forum 2007). The model associated with the Chinook Salmon Population Model Study (TID/MID 2013), established an initial estimate of 60.4°F as the upper limit for initiation of spawning (Groves and Chandler 1999).
62°F (16.7°C)	100% mortality of fertilized Chinook salmon eggs after 12 days at 62°F (Reclamation Unpublished Work). Incubation temperatures of 62°F to 64°F appear to be the physiological limit for embryo development resulting in 80 to 100% mortality prior to emergence (USFWS 1999). 100% loss of eggs incubated at water temperatures above 62°F (Hinze 1959). 100% mortality occurs during yolk-sac stage when embryos are incubated at 62.5°F (Seymour 1956). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Geist *et al*. (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

Juvenile Rearing and Downstream Movement

WTI values were developed to evaluate the Chinook salmon rearing (fry and juvenile) and juvenile downstream movement lifestages. Some Chinook salmon juveniles, both fall-run and spring-run, move downstream shortly after emergence as post- emergent fry, or rear in the river for several months and move downstream as YOY juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are presented in this Technical Memorandum using the fry and juvenile rearing WTI values.

The WTI values of 60°F, 61°F, 64°F, 65°F, 68°F, 70°F,75°F, and 77°F were identified for the Chinook salmon juvenile rearing and downstream movement lifestage. The lowest index value of 60°F was identified because regulatory documents as well as several source studies, including ones conducted on Central Valley Chinook salmon fry and juveniles, report 60°F as an optimal water temperature for growth (Banks *et al.* 1971; Brett *et al.* 1982; Marine 1997; NMFS 1997b; NMFS 2000; NMFS 2001a; NMFS 2002; Rich 1987b) (Table 7). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but were not identified as index values, because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990b; Taylor 1990a). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

The 60°F WTI value identified for the Chinook salmon juvenile rearing and downstream movement lifestage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of spring-run Chinook salmon fry and fingerlings. NMFS (2002a) identified 60°F as the "preferred" water temperature for juvenile spring-run Chinook salmon in the Central Valley. Increasing levels of thermal stress to this lifestage may reportedly occur above the 60°F WTI value.

A water temperature of 61°F (7DADM) was identified as the value for Chinook juvenile rearing for the San Joaquin River (CALFED 2009). A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 61°F (7DADM; early year) for salmon juvenile rearing (EPA 2003b).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM; late year) for salmon juvenile rearing (EPA 2003b). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64°F are considered not ″properly functioning" by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64°F (EPA 2001). Optimal range for Chinook salmon survival and growth from 53°F to 64°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001).

The index value of 65°F was identified because it represents an intermediate value between 64°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (EPA 2003a; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987a). Conversely, numerous studies report that temperatures between 64.0°F and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett *et al.* 1982; Cech and Myrick 1999; Clarke and Shelbourn 1985; EPA 2003a; Myrick and Cech 2001; NMFS 2002; USFWS 1995b). Maximum growth of juvenile fall-run Chinook salmon has been reported to occur in the American River at water temperatures between 56-59°F (Rich 1987b) and in Nimbus Hatchery spring-run Chinook salmon at 66°F (Cech and Myrick 1999). Bioenergetics modeling of growth based on consumption for 100 mm juvenile Chinook salmon in the Middle Fork American River watershed indicates that growth likely does not occur above about 65°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook juvenile rearing for the Yuba Reintroduction

Assessment for both fall- and spring-run Chinook salmon (Bratovich *et al.* 2012).

A WTI value of 68°F was identified because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).

Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at temperatures close to 70.0°F and has been reported to be completely prohibited at 70.5°F (Brett *et al.* 1982; Marine 1997). No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ± 1.8°F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

75°F was identified as a WTI value because high levels of direct mortality to juvenile Chinook salmon reportedly result at this water temperature (Cech and Myrick 1999; Hanson 1991; Myrick and Cech 2001; Rich 1987b). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was identified because it was derived from experiments using Central Valley Chinook salmon and it is a more rigorous index value representing a more protective upper lethal water temperature level. Furthermore, the lethal level determined in Rich (1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan *et al.* 2000; McCullough *et al.* 2001; Myrick and Cech 2001). Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952; Orsi 1971), the Chinook Salmon Population Model (TID/MID 2013) identified an initial UILT mortality threshold of 77°F for Chinook salmon juveniles as a daily average water temperature. Note that the model also identified this same value for fry mortality.

Table 7. Chinook Salmon Juvenile Rearing and Downstream Movement WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F (15.6°C)	Optimum water temperature for Chinook salmon fry growth is between 55°F and 60°F (Seymour 1956). Water temperature range that produced optimum growth in juvenile Chinook salmon was between 54°F and 60°F (Rich 1987b). Water temperature criterion of less than or equal to 60°F for the protection of Sacramento River winter-run Chinook salmon from Keswick Dam to Bend Bridge (NMFS 1993b). Upper optimal water temperature limit of 61°F for Sacramento River fall-run Chinook salmon juvenile rearing (Marine 1997; Marine and Cech 2004). Upper water temperature limit of 60°F preferred for growth and development of spring-run Chinook salmon fry and fingerlings (NMFS 2000; NMFS 2002a). To protect salmon fry and juvenile Chinook salmon in the upper Sacramento River, daily average water temperatures should not exceed 60°F after September 30 (NMFS 1997b). A water temperature of 60°F appeared closest to the optimum for growth of fingerlings (Banks *et al.* 1971). Optimum growth of Nechako River Chinook salmon juveniles would occur at 59°F at a feeding level that is 60% of that required to satiate them (Brett *et al.* 1982). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
61°F (16.1°C)	A water temperature of 61°F (7DADM) was identified as the value for Chinook juvenile rearing for the San Joaquin River (CALFED 2009). A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 61°F (7DADM; early year) for salmon juvenile rearing (EPA 2003b).
64°F (17.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM; late year) for salmon juvenile rearing (EPA 2003b). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64°F are considered not ″properly functioning” by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64°F (EPA 2001). Optimal range for Chinook salmon survival and growth from 53°F to 64°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001).

Index Value	Supporting Literature
65°F (18.3°C)	Water temperatures between 45°F to 65°F are preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River (NMFS 2002a). Disease mortalities diminish at water temperatures below 65°F (Ordal and Pacha 1963). Fingerling Chinook salmon reared in water greater than 65°F contracted *C. columnaris* and exhibited high mortality (Johnson and Brice 1953). Water temperatures greater than 64.9°F identified as being stressful in the Columbia River Ecosystem (Independent Scientific Group 1996). Juvenile Chinook salmon have an optimum temperature for growth that appears to occur at about 66.2°F (Brett *et al.* 1982). Juvenile Chinook salmon reached a growth maximum at 66.2°F (Cech and Myrick 1999). Increased incidence of disease, reduced appetite, and reduced growth rates at 66.2 ± 1.4 °F (Rich 1987b). Bioenergetics modeling of growth based on consumption for 100 mm juvenile Chinook salmon in the Middle Fork American River watershed indicates that growth likely does not occur above about 65°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook salmon (Bratovich *et al.* 2012).
68°F (20°C)	Sacramento River juvenile Chinook salmon reared at water temperatures greater than or equal to 68°F suffer reductions in appetite and growth (Marine 1997; Marine and Cech 2004). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).
70°F (21.1°C)	No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ±1.8 °F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
75°F (23.9°C)	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2°F was determined to be 100% lethal due to hyperactivity and disease (Rich 1987b; Zedonis and Newcomb 1997). Lethal temperature threshold for fall-run juvenile Chinook salmon between 74.3°F and 76.1°F (McCullough 1999). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan *et al*. 2000; McCullough *et al*. 2001; Myrick and Cech 2001).
77°F (25°C)	The model associated with the Chinook Salmon Population Model Study, established an initial UILT mortality threshold of 77°F (daily average temperatures) for Chinook salmon fry and juveniles (Brett 1952 and Orsi 1971, as cited in TID/MID 2013).

Smolt Emigration

Juvenile Chinook salmon that exhibit extended rearing in a riverine environment are assumed to undergo the smoltification process and volitionally emigrate from the river as smolts. WTI values of 57°F, 59°F, 63°F, 68°F 72°F, and 77°F were identified for the Chinook salmon smolt emigration lifestage (Table 8).

A water temperature of 57°F (7DADM) was identified as the value for Chinook smolt migration for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 59°F (7DADM; late year) for salmon smolts (EPA 2003b).

A WTI value of 63°F was identified because water temperatures at or below this value allow for successful transformation to the smolt stage, and water temperatures above this value may result in impaired smoltification indices, inhibition of smolt development, and decreased survival and successful smoltification of juvenile Chinook salmon. Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997; Zedonis and Newcomb 1997). 62.6°F was rounded and used to support an index value of 63°F. A water temperature of 63°F (MWAT) was identified as the Upper Optimum Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).

Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989). A WTI value of 68°F was identified because water temperatures above 68°F prohibit successful smoltification (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook smolt migration for the Yuba Reintroduction Assessment for spring-run Chinook salmon (Bratovich *et al*. 2012).

Support for an index value of 72°F is provided from a study conducted by (Baker *et al.* 1995) in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests a 95% confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5°F to 75.4°F. In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).

Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952), the Chinook Salmon Population Model (TID/MID 2013) identified an initial mortality threshold of 77°F for Chinook salmon smolts as a daily average water temperature.

Table 8. Chinook Salmon Smolt Emigration WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
57°F (13.9°C)	A water temperature of 57°F (7DADM) was identified as the value for Chinook smolt migration for the San Joaquin River (CALFED 2009).
59°F (15°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 59°F (7DADM; late year) for salmon smolts (EPA 2003b).
63°F (17.2°C)	Acceleration and inhibition of Sacramento River Chinook salmon smolt development reportedly may occur at water temperatures above 63°F (Marine 1997; Marine and Cech 2004). Laboratory evidence suggest that survival and smoltification become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997). Juvenile Chinook salmon growth was highest at 62.6°F (Clarke and Shelbourn 1985). A water temperature of 63°F (MWAT) was identified as the Upper Optimum Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).
68°F (20°C)	Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).
72°F (22.2°C)	In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).
77°F (25°C)	The model associated with the Chinook Salmon Population Model Study, established an initial mortality threshold of 77°F (daily average temperatures) for Chinook salmon smolts (Brett 1952 as cited in TID/MID 2013).

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TID/MID Response to Comments on the Water Temperature Literature Review

Comment No.	Organization / Source	Comment	Response
1.	CDFW 11/3/16 email	It would be helpful to include in the Glossary of Terms definitions for both **acute** and **chronic** especially in terms to timeframes and implications.	Acute and chronic terms in addition to other terms have been updated in The Glossary of Terms document.
2.	CDFW 11/3/16 email	The literature review contains temperatures in both English and Metric units which is confusing. In the interest of clarity and consistency with established scientific literature we request that all temperatures be available Celsius.	As noted in the introduction of the literature review, subcommittee members supported use of an already published review as the basis for this assessment (i.e., Appendix A of Bratovich et al. 2012). Much of the narrative text was cited "as-is" from the existing document. However, for each of the life history tables (which summarize the narrative text at the end of each life history stage section) included in the literature review, Metric units have been added in parentheses alongside English units. Not all scientific or technical documents report temperature in °C. For example, the SWRCB's recently released Substitute Environmental Document uses °F. For future reference, we will make every effort to report in °F in whole integers, with °C provided in parentheses.
3.	CDFW 11/3/16 email	Water Temperature Indices - The literature review is unclear as to the purpose of water temperature index values. It is stated that they provide a gradation of potential effects but there is no indication as to what the index values will be used for.	Water temperature index values will be used to evaluate potential thermal habitat suitability for anadromous salmonid reintroduction in the Tuolumne River Basin.

Comment No.	Organization / Source	Comment	Response
4.	CDFW 11/3/16 email	The inclusion of water temperature criteria for other rivers and the EPA is helpful for comparison but, clarification as to how the Upper Optimum Value and Upper Tolerable Value are applied in the Yuba River would be helpful.	The Yuba Salmon Forum (YSF) conducted a summary assessment of potential spring-run Chinook salmon and steelhead habitat in the Yuba River Basin to provide information for use in reviewing potential options that warrant further investigation regarding reintroduction into the North, Middle, and South Yuba rivers, as well as portions of the mainstem Yuba River. Evaluations conducted by the YSF (2013) emphasized water temperature habitat suitability determinations. These evaluations utilized water temperature index (WTI) values specific to each of the species' lifestages, and the time periods throughout the year during which they occur. The WTI values selected for evaluation corresponded to lifestage-specific Upper Optimum and Upper Tolerable WTI values. The maximum weekly average (daily) water temperature (MWAT) was the metric applied to water temperature monitoring and modeling data, for various years and water year types, to identify when and where WTI values were exceeded. The estimated location when MWAT exceeded the specified WTI value was then used to identify the number of river miles of thermally suitable habitat for a particular species/lifestage.
5.	CDFW 11/3/16 email	The inclusion of data obtained from the Lower Tuolumne River swim tunnel study is inappropriate. Results obtained during the study are based on an acute response to temperature which does little to inform a fish's response to a chronic condition. CDFW has provided extensive comments on this study to HDR Inc. in a letter dated August 31, 2016.	The researchers responsible for this study indicate that it is incorrect to classify the Swim Tunnel study as an investigation of acute response to water temperature. The comments provided by CDFW have been addressed and will be provided in the final study filed with FERC which is scheduled to occur the week of November 28, 2016. The study represents the only site-specific study of wild juvenile *O. mykiss* in the Tuolumne River and is important to consider.

Deason, Jesse

From: John Wooster - NOAA Federal <john.wooster@noaa.gov>
Sent: Monday, November 07, 2016 4:16 PM
To: Le, Bao
Cc: Deason, Jesse; Staples, Rose; Steve Edmondson; Jean Castillo - NOAA Federal
Subject: Re: Change in Due Date for Comments on the Temp Criteria Subcommittee Oct 14 Conf Call Draft Notes
Attachments: BoughtonEtAl2015.pdf

Bao:

I think an important component for the temperature sub-group is to understand how the NMFS Science Center will treat the topic of thermal suitability in modeling habitat capacity in their study of the Upper Tuolumne watershed. Their approach for O.mykiss is currently likely to follow the approach used in this 2015 Boughton et al. paper that I am attaching to this email – with emphasis on the *Thermal Indicators of habitat suitability* section on pdf page 263. The Science Center has another technical memo in draft form that provides greater detail for this approach and the rationale / data behind it– once that memo is finalized I can pass it along too. The spring-run Chinook approach for the Tuolumne is still under development, although likely to follow a similar mechanistic/bio-energetic approach but maybe some adjustment to the temperature thresholds.

In short, they will not be taking a relatively simplistic approach of selecting one temperature metric and deciding if a reach is “suitable” or “not”. For O.mykiss, if a given day has a maximum temp >29C or average daily temp >25C then it is not suitable. Temperatures in the 21 to 25C range are considered stressful. What impacts those stressful temperatures have and whether the O.mykiss can utilize the habitat depends on several factors, including but not limited to: thermal refugia (e.g., stratified deep pools), food availability, growth potential, level of stress (e.g., function of the degrees above 20C and for how many hours), etc…

I also inquired about other useful references towards temperature and steelhead and the lab recommended these papers (in addition to the one I am attaching):

Rodnick, K. J., A. K. Gamperl, K. R. Lizars, M. T. Bennett, R. N. Rausch, and E. R. Keeley. 2004. Thermal tolerance and metabolic physiology among Redband Trout populations in southeastern Oregon. Journal of Fish Biology 64:310–335.

Sloat, M. R., and A. M. K. Osterback. 2013. Maximum stream temperature and the occurrence, abundance, and behavior of steelhead trout (Oncorhynchus mykiss) in a southern California stream. Canadian Journal of Fisheries and Aquatic Sciences 70:64–73.

Spina, A. P. 2007. Thermal ecology of juvenile steelhead in a warm-water environment. Environmental Biology of Fishes 80:23–34.

Zoellick, B. W. 1999. Stream temperatures and the elevational distribution of Redband Trout in southwestern Idaho. Great Basin Naturalist 59:136–143.

Regards,

John

On Mon, Oct 31, 2016 at 4:40 PM, Staples, Rose <Rose.Staples@hdrinc.com> wrote:

Please note correction in the date to provide comments on the draft meeting notes—it is Wednesday, November 30th. Thank you.

Temperature Criteria Subcommittee,

DRAFT NOTES from the October 14, 2016 Water Temperature Criteria Subcommittee call have been uploaded to the licensing website www.lagrange-licensing.com in the DOCUMENTS section and also as an attachment to the October 14, 2016 date on the website calendar.

Please provide any comments on the meeting notes by ~~Monday, November 28, 2016~~ Wednesday, November 30, 2016 to rose.staples@hdrinc.com. The Districts will incorporate any comments received and then post a final version of the meeting notes to the licensing website.

In addition, this email will be forwarded to the La Grange Project licensing email list stating that the draft meeting notes are available online.

If you have any difficulties locating and/or accessing the document, please let me know.

As a reminder, please provide any comments on the updated literature review and glossary of terms to rose.staples@hdrinc.com by November 1, 2016.

Thank you.

Rose Staples, CAP-OM, MOS

Executive Assistant

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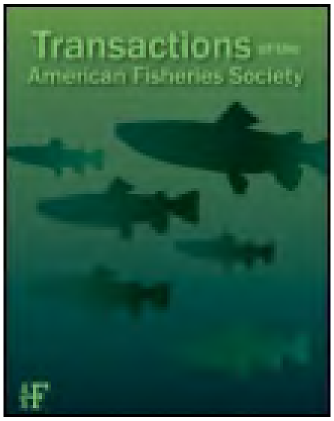

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Thermal Potential for Steelhead Life History Expression in a Southern California Alluvial River

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ARTICLE

Thermal Potential for Steelhead Life History Expression in a Southern California Alluvial River

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Abstract
Steelhead *Oncorhynchus mykiss* (anadromous Rainbow Trout) near the southern limit of the species' range commonly use shallow alluvial rivers for migration, spawning, and rearing. These rivers have been widely modified for water management, and an enduring question is whether their rehabilitation would create summer nursery habitat for steelhead. We used process-based models to evaluate the thermal potential for steelhead nursery habitat in the Santa Ynez River, California, a regulated alluvial river that currently supports few steelhead. We assessed (1) how well a calibrated model of river heat fluxes predicted summer temperature patterns for a warm year and an average year; (2) whether those patterns created thermal potential for the rapid growth that is characteristic of steelhead nursery habitat; and (3) whether manipulation of flows from an upstream dam significantly altered thermal potential. In the heat flux model, the root mean square error for 15-min temperatures was 1.51°C, about three times greater than that of the larger, deeper Sacramento River in northern California. Generally, the Santa Ynez River was thermally suitable but stressful for juvenile steelhead. Flow augmentation reduced the number of thermally stressful days only near the dam, but it reduced the intensity of thermal stress throughout the river. Daytime movement of steelhead into natural, thermally stratified pools would reduce stress intensity by similar levels. In this region, *O. mykiss* commonly pursue an anadromous (steelhead) life history by entering nursery habitat early in their first or second summer and rapidly growing to attain a threshold size for anadromy by fall. In the average year, the river was thermally suitable for the first-summer pathway under high food availability and for the second-summer pathway under medium food availability. The warm year also supported the second-summer pathway under high food availability. Currently, the Santa Ynez River's capacity to support these pathways does not appear to be limited by summer temperature, thus indicating a need to identify other limiting factors.

Steelhead *Oncorhynchus mykiss* (anadromous Rainbow Trout) in southern California near the southern limit of the species' native range historically migrated up wide, shallow alluvial rivers that drained arid mountain ranges (Figure 1). An enduring question is whether the summertime thermal patterns of these rivers constitute a fundamental control on

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FIGURE 1. Coastal California alluvial rivers currently or formerly used by steelhead (anadromous *Oncorhynchus mykiss*) near the southern limit of the species' native range (Boughton et al. 2005). Steelhead historically used alluvial rivers as migration corridors to upland creek habitat and possibly as spawning and rearing habitat. The alluvial rivers that are highlighted here are channels with gradients less than 1% and upstream watershed areas greater than 500 km^2 within the shrub-dominated coastal mountain ranges south of Monterey Bay.

productivity and life history diversity of *O. mykiss* in this region. Southern California steelhead are currently scarce and considered highly endangered, in part due to widespread human impacts but also to challenging climatic conditions that may limit the rivers' suitability (Boughton et al. 2009). Better insight into thermal factors that limit steelhead has implications for recovery potential in the region and, more broadly, for the responses of other steelhead populations to the impacts of climate change on rivers (e.g., Mantua et al. 2010; Benjamin et al. 2013).

Steelhead are stressed by or excluded from water that is warmer than specific tolerance limits (Jobling 1981; Eaton et al. 1995; Werner et al. 2005; Kammerer and Heppell 2013a), which indirectly links their geographic distribution to summer climate via river temperature (Mohseni et al. 2003). Water temperature also sets an upper limit on the potential growth of juveniles (Wurtsbaugh and Davis 1977; Kammerer and Heppell 2013b, 2013a), with implications for the fitness and expression of anadromous and nonanadromous (resident) life histories (Mangel and Satterthwaite 2008; McMillan et al. 2012; Sogard et al. 2012; Benjamin et al. 2013). Numerous other ecological factors and human impacts also influence distribution, abundance, and life history expression in *O. mykiss* (Busby et al. 1996) but only within the bounds of a river's thermal potential for the species. Thus, if a given river habitat lacks the basic thermal potential to support the anadromous life history, then there is little scope for steelhead recovery, irrespective of other factors. We used this premise to assess the recovery potential of steelhead in an alluvial main-stem river in southern California.

Southern California *O. mykiss* populations historically expressed both anadromous (steelhead) and resident (Rainbow Trout) life histories. Anadromous life histories appear to depend on habitats that produce large smolts, which survive well in the ocean and are disproportionately represented in adult spawning migrations (Bond 2006). Such areas qualify as nursery habitat—defined as rearing habitats for which the contribution per unit area to the production of recruits to the adult population is greater than the contributions from other habitats where juveniles occur (Beck et al. 2001). Thus, steelhead nursery habitats constitute the subset of juvenile rearing habitats that generate high numbers of adult steelhead per unit area, and these nursery habitats are important for maintaining population size and persistence (Beck et al. 2001). Hayes et al. (2008) identified three pathways by which juvenile *O. mykiss* use nursery habitat in coastal California to achieve sizes that are suitable for anadromous life histories; each of the pathways involves the use of summer habitats that are capable of sustaining rapid growth (Figure 2). In the "first-summer" pathway, age-0 steelhead enter nursery habitat in early summer and grow rapidly. By fall, they reach a size that enables them to exhibit more typical growth during winter yet still successfully smolt the following spring at age 1. In the "second-summer" pathway and the much rarer "third-summer" pathway, age-0

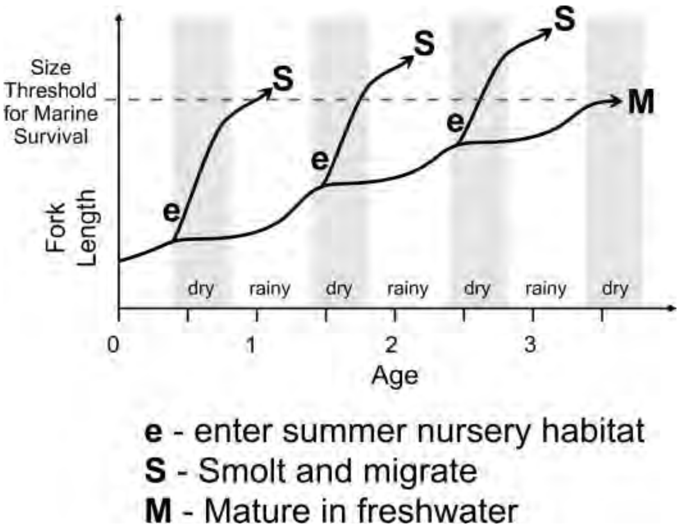

FIGURE 2. Conceptual model for *Oncorhynchus mykiss* life history pathways in stream systems of the California coast (adapted from Hayes et al. 2008; see also Bond 2006; Satterthwaite et al. 2009, 2012; and Beakes et al. 2010). Because marine survival is low for *O. mykiss* smaller than a certain size threshold (~150 mm FL), habitats only produce the anadromous life history form (steelhead) if the fish sustain rapid growth during the summer before smolting. Such habitats disproportionately contribute recruits to anadromous runs and thus fit the definition of steelhead nursery habitat (sensu Beck et al. 2001).

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steelhead remain in upland creeks for 1 or 2 years, where they grow slowly until entering nursery habitat in their second or third summer and then smolting the following spring at age 2 or age 3. Some fish also follow a resident pathway, maturing in freshwater as Rainbow Trout (Hayes et al. 2012).

Growth potential is probably a central feature distinguishing steelhead nursery habitat from Rainbow Trout nursery habitat. This is because body size correlates strongly with fitness components, such as habitat-specific survival (Ward et al. 1989; Bond 2006; Evans et al. 2014; Thompson and Beauchamp 2014) and female fecundity (Shapovalov and Taft 1954), and such fitness components evolutionarily favor anadromy in some environments and freshwater residency in others (Satterthwaite et al. 2009, 2010). Thus, although life histories are partly under genetic control (Thrower and Joyce 2004; McPhee et al. 2007; Heath et al. 2008; Pearse et al. 2014), natural selection should favor a conditional life history strategy that uses body size as an internal cue for whether and when to switch from freshwater habitat to marine habitat (Mangel and Satterthwaite 2008; Satterthwaite et al. 2009; McMillan et al. 2012; Sloat et al. 2014). At the same time, the growth and body size necessary to cue the switch are expected to (1) differ for males and females (Sloat et al. 2014); (2) vary regionally as a function of local survival in both the marine and freshwater environments; and (3) depend on the maximum attainable body size (asymptotic body size) in the two environments (Satterthwaite et al. 2010). For simplicity, we focus here on female life histories under the assumption that limits on anadromous production are more closely tied to female fecundity than to male fecundity. For some salmonid species in some environments, very rapid growth and large attainable body sizes for females in freshwater appear to favor resident life histories (i.e., maturation in freshwater; Sloat et al. 2014). For *O. mykiss* in coastal California, the combination of survival schedules and very rapid growth that favors such a strategy has not yet been observed (Hayes et al. 2008). Instead, rapid growth appears to evolutionarily favor an anadromous life history, whereas moderate growth apparently favors a resident life history (Satterthwaite et al. 2009). Feeding experiments suggest that the physiological "decision" to forsake a nonanadromous path and switch to marine habitats is made in the fall—after the summer growth period and before outmigration the next spring (Beakes et al. 2010). Thus, to a first approximation, a habitat's potential to generate the anadromous life history in coastal California simplifies to the potential to support survival and rapid growth of juvenile female *O. mykiss* during summer. In the context of thermal potential addressed here, survival will fail if temperatures become lethally warm, and rapid growth will fail if water temperatures are either too warm or too cool for the growth rate required to trigger smoltification and the switch to marine habitats.

The best-studied steelhead nursery habitats in the region are coastal estuaries (Bond 2006), which form dry-season lagoons that produce abundant large smolts. Coastal climate and inputs of marine wrack and invertebrates provide the appropriate combination of temperature and feeding opportunity for rapid growth, but the total productivity of estuaries is limited by their small spatial extent. Upland creek habitat is more widespread and supports abundant juvenile *O. mykiss* (e.g., Boughton et al. 2009). However, the channels must be well shaded to stay cool enough for the species (Boughton et al. 2012), whereas dense shade appears to limit instream primary productivity, creating a food-limited environment and low growth potential in summer (Hayes et al. 2008; Rundio and Lindley 2008; Sogard et al. 2009). Coastal estuaries are usually steelhead nurseries and upland creeks are usually not, but the nursery role of a third common habitat, alluvial rivers, remains an open question.

Lowland alluvial rivers, defined here as streams with low gradients (<1%) and large upstream watersheds (>500 km^2), are numerous and widespread at the species' southern range limit in California (Figure 1); therefore, these systems could potentially produce large steelhead runs if they are capable of functioning as nursery habitat. In summer, alluvial rivers are wide, shallow, and sparsely shaded, making them vulnerable to heating but also typically allowing them to support substantial algal growth, which suggests a physical basis for a productive food web and the high feeding opportunities necessary for rapid growth of juvenile fish. Summer air temperatures in this region routinely exceed 30°C, but river temperatures are reduced to varying extents by cool onshore winds and fog from the ocean and by hydrological exchange with large

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aquifers. These physical influences on temperature are spatially heterogeneous (e.g., Alagona et al. 2012; Booth et al. 2013), and the degree to which they keep rivers in the thermal zone required for rapid growth—or even survival—of juvenile *O. mykiss* is unclear. Unfortunately, the potential role of lowland alluvial rivers as summer nursery habitat is ambiguous due to an incomplete historical record and the extensive negative impacts from water development, adjacent land uses, and nonnative species (Marchetti et al. 2004; Klose et al. 2012; Cooper et al. 2013).

We used process-based models of river temperature and fish response to evaluate whether a representative alluvial river in southern California has the thermal potential to support anadromous life history expression by the local population of *O. mykiss*. The Santa Ynez River serves as a useful case study because it has a historical record of occasional (and perhaps frequent) large steelhead runs (Alagona et al. 2012) and because the existing river and its human impacts are representative of many other rivers in the region (Kondolf et al. 2013). We focused our analysis on three questions: (1) Do summer temperature patterns in the main stem of the river create thermal potential for steelhead survival and a first-summer or second-summer life history strategy?; (2) How much does the manipulation of water releases from an upstream dam alter the thermal potential of the river?; and (3) How much do cold patches of water in thermally stratified pools increase the thermal potential of the river by reducing thermal stress on steelhead?

STUDY AREA

The Santa Ynez River flows west about 110 km from tributaries in the Transverse Ranges of California to the Pacific Ocean just north of Point Conception. The reach we modeled was the lower 65-km section below Bradbury Dam (Figure 3). Historical data suggest that steelhead runs once numbered in the tens of thousands in some years but were nearly nonexistent in other years (Alagona et al. 2012). Currently, anadromous *O. mykiss* are consistently rare despite the predominance of anadromous genotypes in the local population (Pearse et al. 2014, cf. Salsipuedes and Hilton creeks) and more than a decade of rehabilitation efforts (Robinson et al. 2009). Bradbury Dam impounds a large reservoir near the middle of the basin and blocks steelhead migration 70 km upstream of the

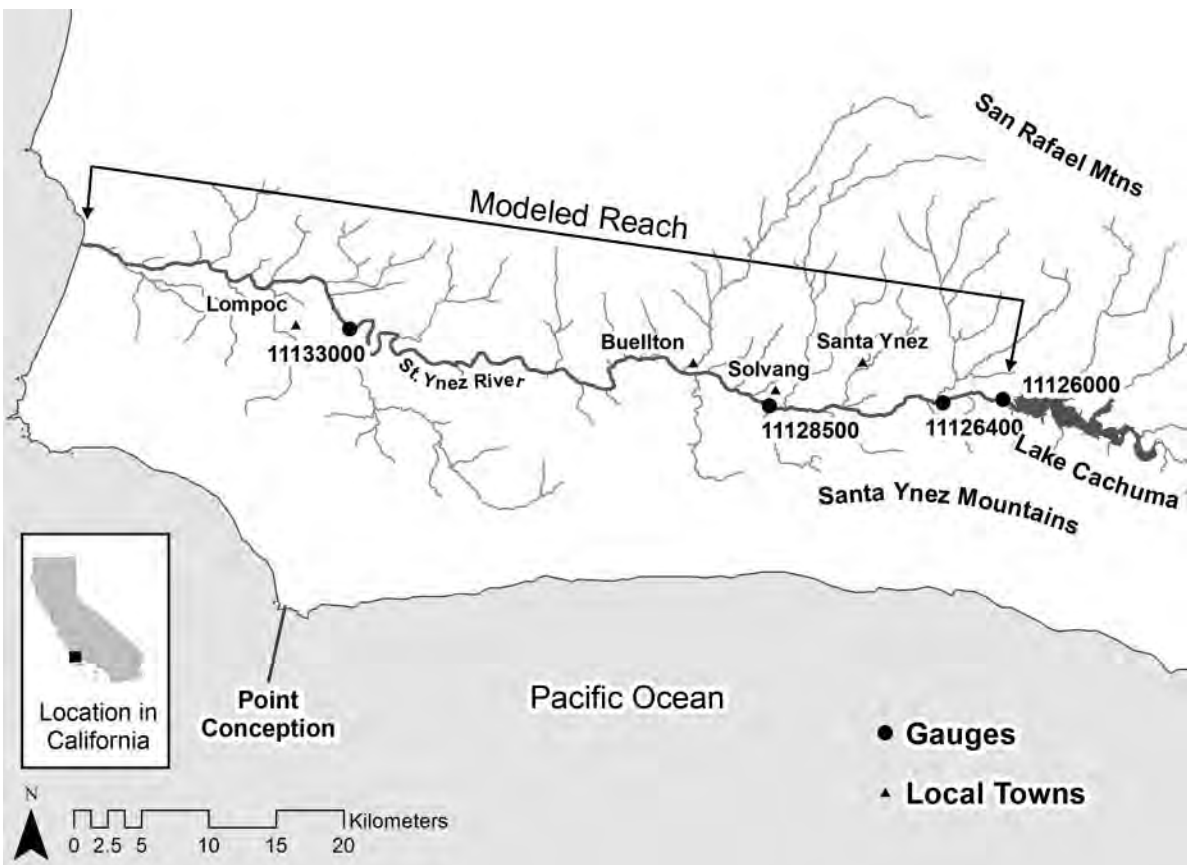

FIGURE 3. Map of the study area in the Santa Ynez River, showing landmarks and locations of stream gauges that recorded flow and temperature. U.S. Geological Survey (USGS) gauge 1112600 defined the upstream boundary conditions for the River Assessment for Forecasting Temperature model; USGS gauges 11126400, 11128500, and 11133000 were used to calibrate the parameters.

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estuary; about two-thirds of the basin's spawning and rearing habitat are located upstream of the dam and are therefore inaccessible (Alagona et al. 2012). Genetically similar but nonanadromous *O. mykiss* occupy the stream network upstream of the dam (Clemento et al. 2009; Pearse et al. 2014). Summertime flows below the dam are managed for multiple objectives, including steelhead rearing and continuous replenishment of aquifers tapped by agriculture. Summer flows typically range between 0.3 and 1.0 m^3/s but may be temporarily ramped up as high as 4 m^3/s to replenish the downstream aquifers.

Between Bradbury Dam and the town of Solvang (Figure 3), the Santa Ynez River has a gravel bed with alternating pool–riffle sequences and a sparsely vegetated floodplain. The channel migrates laterally during infrequent flood events, thereby scouring pools, shaping gravel bars, and recruiting coarse woody debris via bank migration. Together, these processes produce physical habitat complexity that is characteristic of the habitats typically used by steelhead. This complexity includes a diversity of water depths and velocities; visual cover provided by instream wood, undercut banks, and overhanging vegetation; and gravel beds suitable for spawning. During years between floods, dense shrubby vegetation colonizes the active channel margins, and the riverbed develops thick algal mats. Further downstream from Solvang, the Santa Ynez River shifts to a sand-bedded channel with fewer pool–riffle sequences and more closely resembles a braided river. Important human impacts include managed flow regimes, high nitrogen loading from agricultural activities, and a profusion of exotic fish species. Juvenile and adult Largemouth Bass *Micropterus salmoides* are especially abundant, occurring in the tens of thousands throughout the lower river during summer (Robinson et al. 2009).

In summer, juvenile steelhead are common in a few small tributaries of the lower Santa Ynez River; in the river itself, however, they are rare and confined to small coldwater patches associated with thermally stratified pools or groundwater seeps (Robinson et al. 2009). Thermal stratification occurs at low flows, when water velocities are slow enough to allow poorly mixed layers of water at different temperatures to develop in well-shaded pools, or in areas where groundwater seeps up from the bed. Geomorphically, the river seems suitable for steelhead rearing, yet rearing is rare; therefore, the key questions (and the motivation for this study) are whether the lack of steelhead rearing can be attributed to thermal constraints and whether such constraints are more closely linked to dam releases or to prevailing weather.

METHODS

River temperature.—We estimated fine-grained temperature dynamics in the Santa Ynez River by using the River Assessment for Forecasting Temperature (RAFT) model (Pike et al. 2013). The RAFT model was previously developed for the Sacramento River, a large, cool California river with managed summer flows that typically range from 180 to 520 m^3/s—or about 200–1,500 times greater than typical summer flows in the Santa Ynez River. The much shallower Santa Ynez River provides a more challenging system to model because heat fluxes with the riverbed and atmosphere are potentially large relative to the thermal capacity of the river. Pike et al. (2013) described the RAFT model in detail; below, we summarize aspects that are relevant to the challenge of simulating thermal processes in the Santa Ynez River.

The RAFT model assimilates data on meteorology, flow, and river temperature to simulate hydrological and thermal processes at a temporal resolution of 15 min and a spatial resolution of 1 km. A one-dimensional hydrodynamic model simulates the advection and diffusion of heat longitudinally in the river, coupled to physical models of all upward and downward heat fluxes with the atmosphere and streambed, respectively. For the Sacramento River, RAFT accurately predicted (root mean square error [RMSE] $< 0.5°C$) the magnitude and timing of diel temperature fluctuations over entire summers, including thermal artifacts, such as the phase–antiphase pattern of downstream temperature below a dam releasing water of constant temperature (Pike et al. 2013). The model requires channel bathymetry as input, which in this study comprised topographic cross-sections spaced at ~50-m intervals, derived from aerial LiDAR and ground surveys of the Santa Ynez River. Other required input included gridded hourly meteorological data and a time series of measured hourly temperature and flow at the upstream boundary of the modeled reach (U.S. Geological Survey [USGS] gauge 1112600, about 5 km downstream of Bradbury Dam; see Figure 3).

The model runs in either a hindcast or forecast mode. Hindcasts simply assimilate temperature observations to spatiotemporally infer a past temperature field that is encompassed by the time span of the data. Forecasts predict future temperature time series based on constructed flow and temperature scenarios at the upstream boundary. We used hindcasts to calibrate RAFT and reconstruct temperature fields from the recent past, and we used forecasts to predict the effects of hypothetical water release scenarios.

Calibration of the model benefits from the assimilation of flow records that include both large and small flows, so we focused on two recent summers (2006 and 2010) with flows spanning a relatively broad range (0.3 to 5.0 m^3/s). Based on daily temperatures at the Lompoc gauge (USGS gauge 11133000), 2006 had the hottest summer of the last decade, with a mean summer water temperature of 21.41°C (range of summer means for the last decade = 19.46–21.41°C; calculated for June 1–October 1 of each year from 2003 to 2012). In contrast, 2010 had a nearly average summer, with a mean water temperature of 20.48°C (mean of summer means for the last decade = 20.56°C).

For each summer, the RAFT model was calibrated by adjusting several tunable parameters to achieve a best fit with 15-min water temperatures at three gauges downstream of

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Bradbury Dam (USGS gauges 11126400, 11128500, and 11133000; Figure 3). Tunable parameters included the depth of the streambed (affecting the rate of bed heat conduction), the temperature of the deep groundwater reservoir (assumed to be constant over time), and coefficients for the rate of evaporative cooling relative to wind speed.

After calibration, we simulated alternative flow scenarios by using the same data used for hindcasts, altering only the flow. Seven scenarios of constant flow (0.14, 0.28, 0.71, 1.4, 2.8, 4.3, and 5.7 m^3/s [5, 10, 25, 50, 100, 150, and 200 ft^3/s]) were simulated for the dry season (May 1–October 1).

Thermal indicators of habitat suitability.—To evaluate how river temperature was likely to affect southern California steelhead, we developed a set of biological indicators. A review of the literature suggested that steelhead in various regions can persist in streams if short-term maximum temperatures remain below 30°C or perhaps 29°C (Zoellick 1999; Rodnick et al. 2004; Huff et al. 2005; Werner et al. 2005; Sloat and Osterback 2013), which is similar to laboratory estimates of the critical thermal maximum, a measure of short-term physiological tolerance for high temperature (Myrick and Cech 2004; Rodnick et al. 2004; Hasnain et al. 2013). However, at temperatures above 22–24°C, feeding and agonistic behaviors decline in frequency (Sloat and Osterback 2013), and the fish show signs of stress (Werner et al. 2005). Laboratory estimates of incipient lethal temperature (50% mortality after long exposure) vary across studies but average around 25°C. Steelhead start to concentrate in thermal refugia, if available, when temperatures exceed 21°C, and they almost completely retreat to refugia when temperatures are around 24°C (Nielsen et al. 1994; Ebersole et al. 2001; Baird and Krueger 2003; Sutton et al. 2007). Many southern California streams that support steelhead do not provide such refugia, and steelhead actively feed in the temperature range of 21–24°C, which is presumably stressful (Spina 2007; Sloat and Osterback 2013).

Based on this review, we define thermal indicators as follows. A day is "thermally suitable" if maximum daily temperature stays below 29°C *and* mean daily temperature stays below 25°C. However, a day is "thermally stressful" if temperature rises above 21°C at any time, with the daily stress intensity quantified as degree-hours above 21°C (i.e., for each day, $\Sigma[T_t - 21]\Delta t$).

Thermal growth potential.—We defined thermal growth potential as the maximum attainable growth of an individual fish, a function of the river's thermal regime and food availability. Thermal growth potential was estimated using the bioenergetics model for *O. mykiss* described by Railsback and Rose (1999), as modified by Satterthwaite et al. (2010) and Arriaza (2013). Individual growth arises from the difference between energy intake and energy expenditure (Rand et al. 1993; Railsback and Rose 1999; Satterthwaite et al. 2010), which are modeled as weight- and temperature-dependent functions for food consumption and respiration, respectively (see Arriaza [2013] for details). The functional form of the growth response to temperature is hump-shaped after Thornton and Lessem (1978) for coldwater species; the functional form was parameterized for California steelhead as in Railsback and Rose (1999). Expressions for maximum food intake and respiration costs in the basic model were modified by functions simulating the energy cost of activity and the difficulty of finding food in a wild habitat, in accordance with recommendations made by Andersen and Riis-Vestergaard (2004) and Bajer et al. (2004). Higher activity increases food consumption, but total energetic cost also increases. For simplicity, we assumed that fish choose a unique activity level that optimizes growth given all other parameters (Arriaza 2013). In the resulting model, the growth rate depends on fish size and food availability but generally peaks in the range of 15–17°C and becomes negative at temperatures above 22–24°C.

We applied the bioenergetics model to temperature output from RAFT scenarios in combination with assumptions about food availability. For *O. mykiss* in the Santa Ynez River (either in its current state or under hypothetical flow scenarios), the level of difficulty in finding food is unknown although presumably low, as judged from the great abundance of juvenile Largemouth Bass and other exotic fish in the river. For simplicity, we assumed that the difficulty of finding food over the summer was constant, and uncertainty was represented by simulating low, medium, and high food availability as drawn from parameter estimates for the same model when applied to two alluvial rivers in California's Central Valley over various years and seasons (Satterthwaite et al. 2010).

Nursery potential.—Growth potential was used to evaluate whether thermal patterns in the Santa Ynez River were sufficient to support either a first-summer or second-summer pathway to anadromy. Growth of age-0 and age-1 *O. mykiss* from June 1 to October 1 was simulated at daily time steps by using mean daily temperature from the RAFT scenarios. Weights of juveniles on June 1 were assumed to be 1.9 g for age-0 fish and 13.6 g for age-1 fish (D. Rundio, National Oceanic and Atmospheric Administration, Southwest Fisheries Science Center, personal communication).

Thermal growth potential was judged to be sufficient for steelhead nursery habitat if fish had grown past a smolting criterion, defined as the minimum FL on October 1 associated with successful anadromy. In the spring, FLs greater than 150 mm are associated with successful anadromy (i.e., a high smolting rate and high marine survival; Ward et al. 1989; Bond 2006; Evans et al. 2014; Thompson and Beauchamp 2014). We examined two versions of the October 1 criterion to account for uncertainty. The "high" smolting criterion was an October 1 FL exceeding 150 mm, which makes the very conservative assumption that growth is negligible in the intervening winter. The "typical" smolting criterion was an October 1 FL greater than 100 mm; this criterion is more apt because it assumes that growth in the intervening winter is typical of upland creeks in the region, which would produce fish larger than the 150-mm threshold by the following spring (Satterthwaite et al. 2009).

Stratified pools.—To assess the extent to which thermally stratified pools might reduce thermal stress, we deployed vertical arrays of temperature loggers in five sections of the Santa Ynez River during summer 2011. Sites were chosen on the basis of accessibility and wide geographic distribution. Stratified pools have been observed in California rivers with large gravel bars, flow separation, extensive intergravel flow, groundwater seeps, and pools that are forced by large woody debris or boulders (Nielsen et al. 1994). Based largely on these findings, we selected pools within each section that possessed at least three geomorphic and hydrologic criteria indicating a high potential for stratification. We identified 16 such pools. In each pool, we positioned a fence post vertically at the deepest point (either by driving it into the substrate or placing it in a manufactured concrete base) and attached three Hobo pendant loggers (Onset Corporation) housed by gray plastic sunshields. One logger was placed 10 cm below the water's surface, another logger was placed against the streambed, and the third logger was deployed midway between the first two. The period of record was July 1–October 1, except for three loggers that were not deployed until the second week of July.

The pools were snorkel surveyed for the presence of steelhead in late summer (August 16–18). Standard methods (e.g., Boughton et al. 2009) were used for the survey, including visual assignment of fish to three general size-classes (<100, 100–200, or >200 mm FL). Such methods generally achieve per-fish observation probabilities around 0.70–0.85.

Complete data sets were recovered from 14 pools. In many cases, declining flows exposed the upper (surface) temperature logger; in the remaining cases, the records of the middle and surface loggers were nearly identical, so records from the middle logger were taken to represent the main flow. Pools were defined as stratified if they showed an absolute difference greater than 1°C between middle and bottom loggers for at least 5% of the period of record. Mean daily stress intensity was calculated for the middle and bottom logger positions in each pool.

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RESULTS

Performance of the RAFT Model

Each RAFT hindcast produced 14,689 temperature predictions for the 153 d from midnight on May 1 to midnight on October 1. The RMSE of 15-min temperatures was 1.51°C in both years, with the RMSE of daily means being slightly smaller and the RMSE of daily maximums being slightly larger (Table 1). The RMSE broken down by USGS gauge and flow showed a negative relationship with flow but not consistently; the lower flows generally involved prediction error ranging from 1°C to 2°C. Thermal stress had an RMSE of 14.8 degree-hours in 2006 and 11.0 degree-hours in 2010, which were comparable in magnitude to the predicted daily stress itself (see below).

TABLE 1. Performance metrics for the River Assessment for Forecasting Temperature hindcasts estimated from three downstream temperature gauges in the Santa Ynez River, California (RMSE = root mean square error).

	RMSE		Bias	
Metric	2006	2010	2006	2010
15-min temperature (°C)	1.51	1.51	−0.04	0.30
Daily mean temperature (°C)	1.03	0.80	−0.04	0.30
Daily maximum temperature (°C)	1.70	2.00	−0.24	1.60

Mean biases in 15-min and daily temperatures were small (≤0.3°C; Table 1). The bias in maximum daily temperature was about five times larger than the bias in mean daily temperature for each year (Table 1). Bias as a function of flow tended to be hump-shaped, with a relatively small or negative bias at low and high flows and a positive bias at intermediate flows.

Thermal Suitability and Thermal Stress

The seven flow scenarios altered the mean daily river temperature relative to the temperature records of the recent past (Figure 4A, C). The lowest flow (0.14 m^3/s) raised temperature by as much as 1.25°C but only in the vicinity of Bradbury Dam; effects were less than 0.5°C further than 10 km from the dam and were negligible beyond 20 km from the dam. The highest flow (5.7 m^3/s) lowered temperature by as much as −2.6°C in 2006 and −1.6°C in 2010, with effects persisting further downstream (40–50 km); however, less extreme scenarios (1.4 m^3/s or less) always had negligible effects further than 20 km below the dam.

In contrast, the seven flow scenarios had larger and more extensive effects on mean maximum daily temperature (Figure 4B, D). The largest effects were close to the dam and ranged from +2.5°C to −4.6°C for the lowest and highest flow scenarios, respectively. However, effects ranging between about +0.8°C and −1.7°C persisted as far as 60 km from the dam, much further than the effects for mean daily temperature.

Based on the recent temperature data and based on the scenarios, no part of the river became thermally unsuitable for steelhead, with one small exception. In 2006, at the lowest flow (0.14 m^3/s), 3 km of the lower river became unsuitable for 1 d in late summer.

In general, nearly all summer days were thermally stressful throughout the entire river except for the area immediately below Bradbury Dam (Figure 5A, C). Higher water releases could expand this less-stressful zone downstream, but the highest release could only create a truly low-stress zone a few kilometers long just below the dam. However, dam releases had large effects on the intensity of stressful days, and these effects persisted much further downstream, especially for the three largest releases (Figure 5B, D).

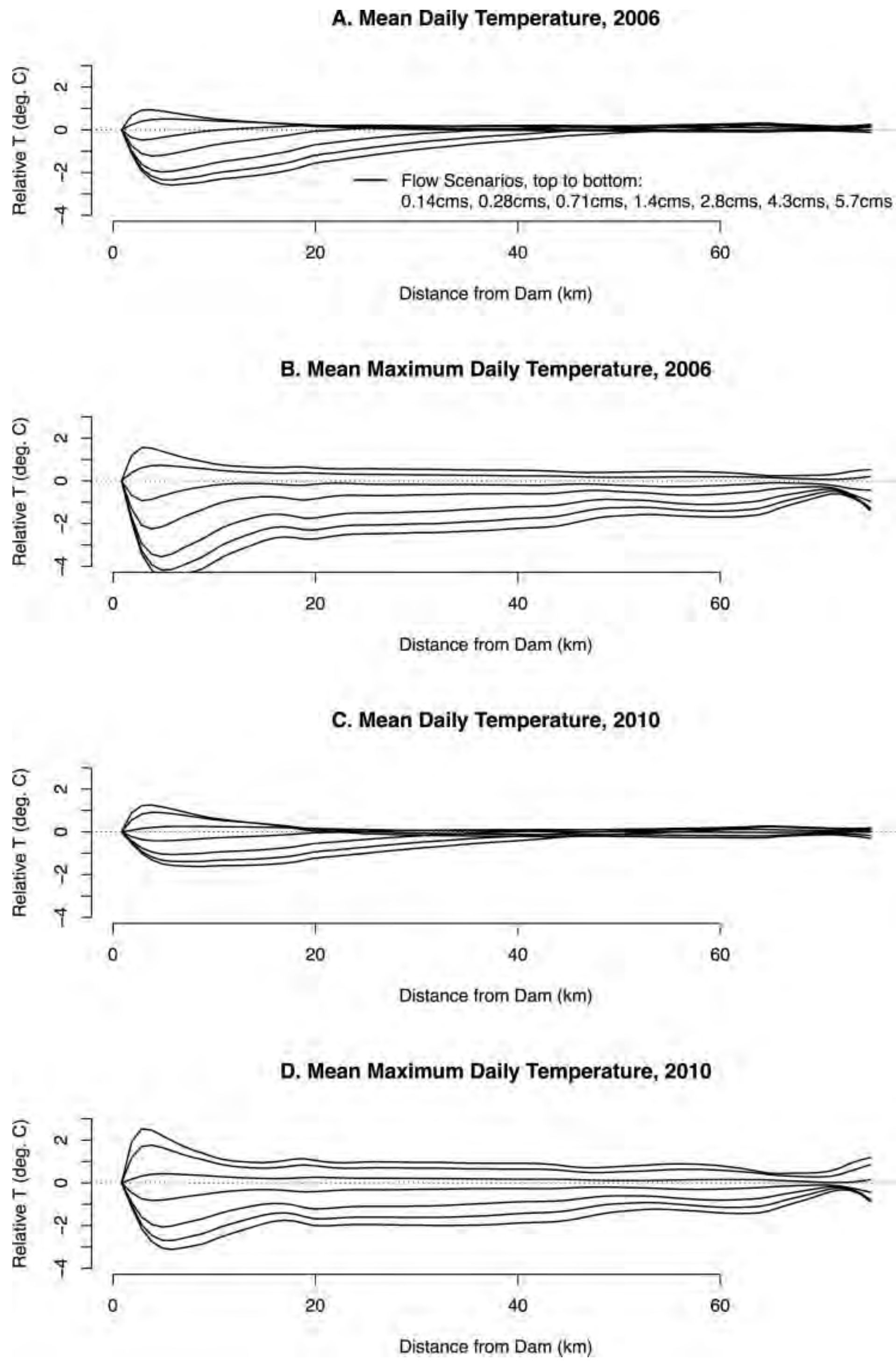

FIGURE 4. Effects of flow levels (simulated dam releases; cms = cubic meters per second) on temperatures (*T*) downstream of Bradbury Dam on the Santa Ynez River relative to the calibration scenario (hindcast temperature from actual flow releases occurring in 2006 and 2010). The mean of mean daily temperature and mean maximum daily temperature for the summer release season (May 1–October 1) are shown.

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Nursery Potential

For clarity, nursery potential results from the various scenarios are reported in terms of relative final mass, calculated as the final mass of fish on October 1 divided by the corresponding final mass projected under the actual summer flows of 2006 and 2010.

Age-0 fish.—In 2010, the average year, medium to high food availability produced fish with masses greater than the

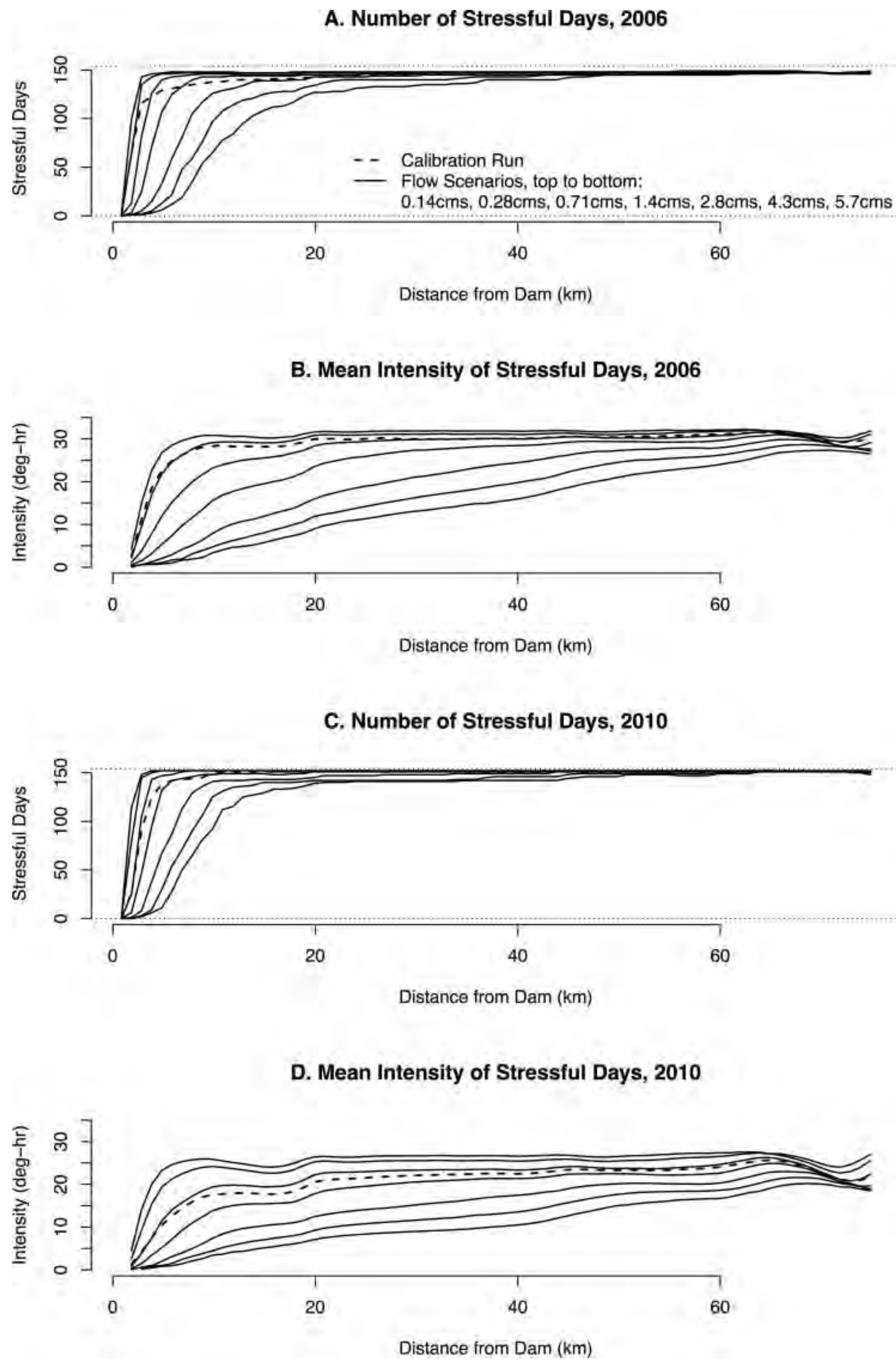

FIGURE 5. Number of days that were thermally stressful for steelhead and the mean stress intensity (degree-hours) under various simulated flow levels (cms = cubic meters per second) in the Santa Ynez River during the summer season (May 1–October 1).

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typical smolting criterion throughout the entire river and regardless of flow scenario (Figure 6A, B). For other combinations (high food availability plus high smolting criterion; or low food availability plus typical smolting criterion), fish only reached smolting size near the dam (Figure 6A, C). The size of the potential nursery zone near the dam ranged from 3 to 20 km depending on the flow scenario examined (Figure 6A, C). If the high smolting criterion was used in combination with medium or low food availability, the first-summer pathway was not supported in any area of the river.

The year 2006, a hot year, had results similar to those for 2010 except that at intermediate food availability under the typical smolting criterion, the first-summer strategy was not supported throughout the entire river (Figure 6D). Instead, a nursery zone was present below the dam, and the size of the zone varied greatly (5–42 km) depending on the flow scenario. Very high flows (>4 m^3/s) were necessary to expand the nursery zone to a length greater than 20 km.

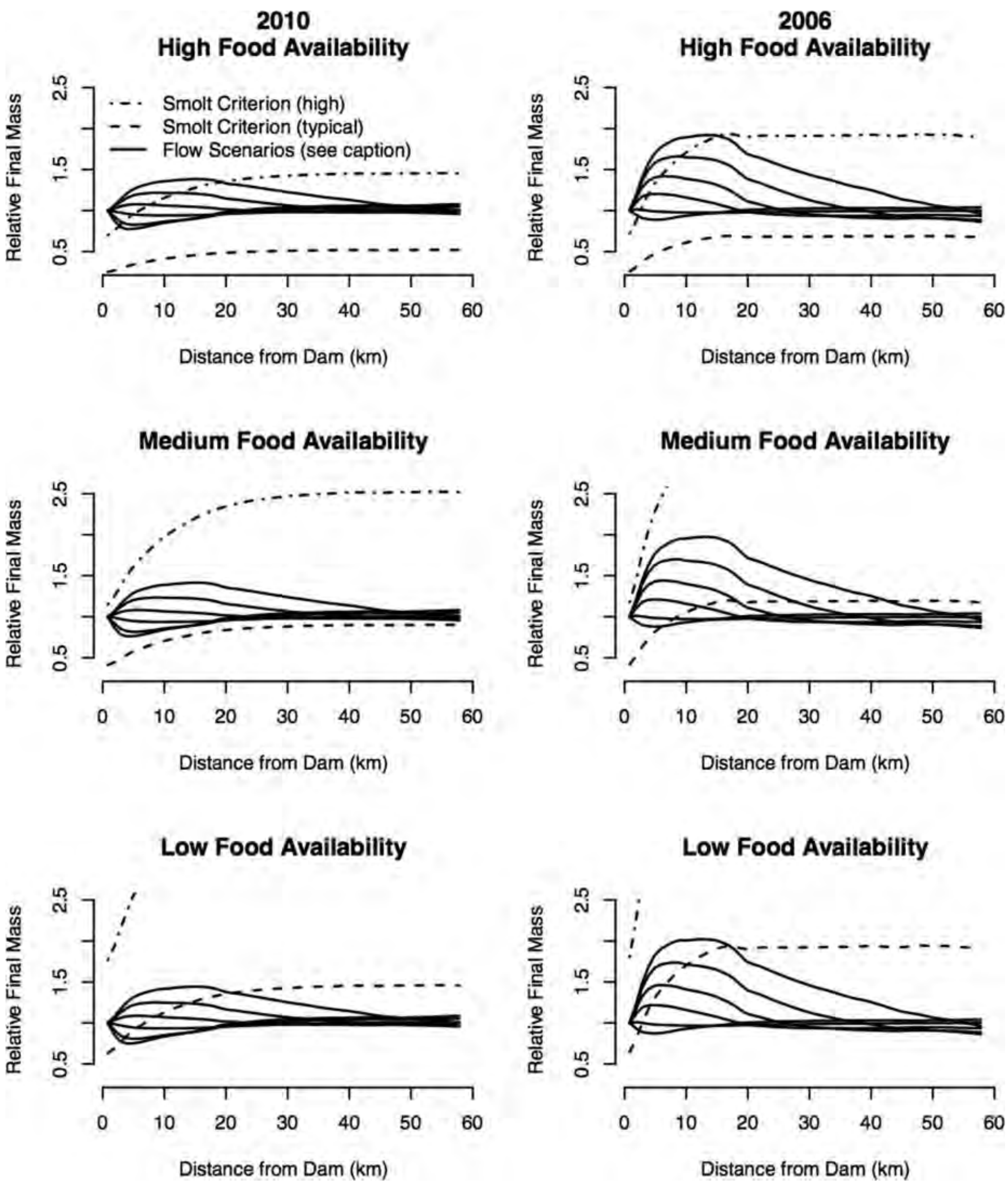

FIGURE 6. Relative final mass for age-0 steelhead on October 1 as modeled for various flow scenarios (solid lines), years (columns), and levels of food availability (rows) at locations downstream of Bradbury Dam on the Santa Ynez River. The "typical" smolt criterion describes the final mass on October 1 that is assumed necessary to trigger smolting and out-migration during the following spring, given typical winter growth conditions. The "high" smolt criterion conservatively assumes zero winter growth. Flow scenarios (lines from top to bottom) are 5.7, 4.3, 2.8, 1.4, 0.71, and 0.28 m^3/s.

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Age-1 fish.—In 2010, the entire river could support the second-summer pathway under a typical smolting criterion, regardless of food availability (Figure 7A, C, E). Under the high smolting criterion, the area supporting the second-summer pathway was still the entire river if food availability was high (Figure 7A), but the area shrank to a flow-dependent zone near the dam if food availability was intermediate (Figure 7C). The year 2006 gave similar overall results except

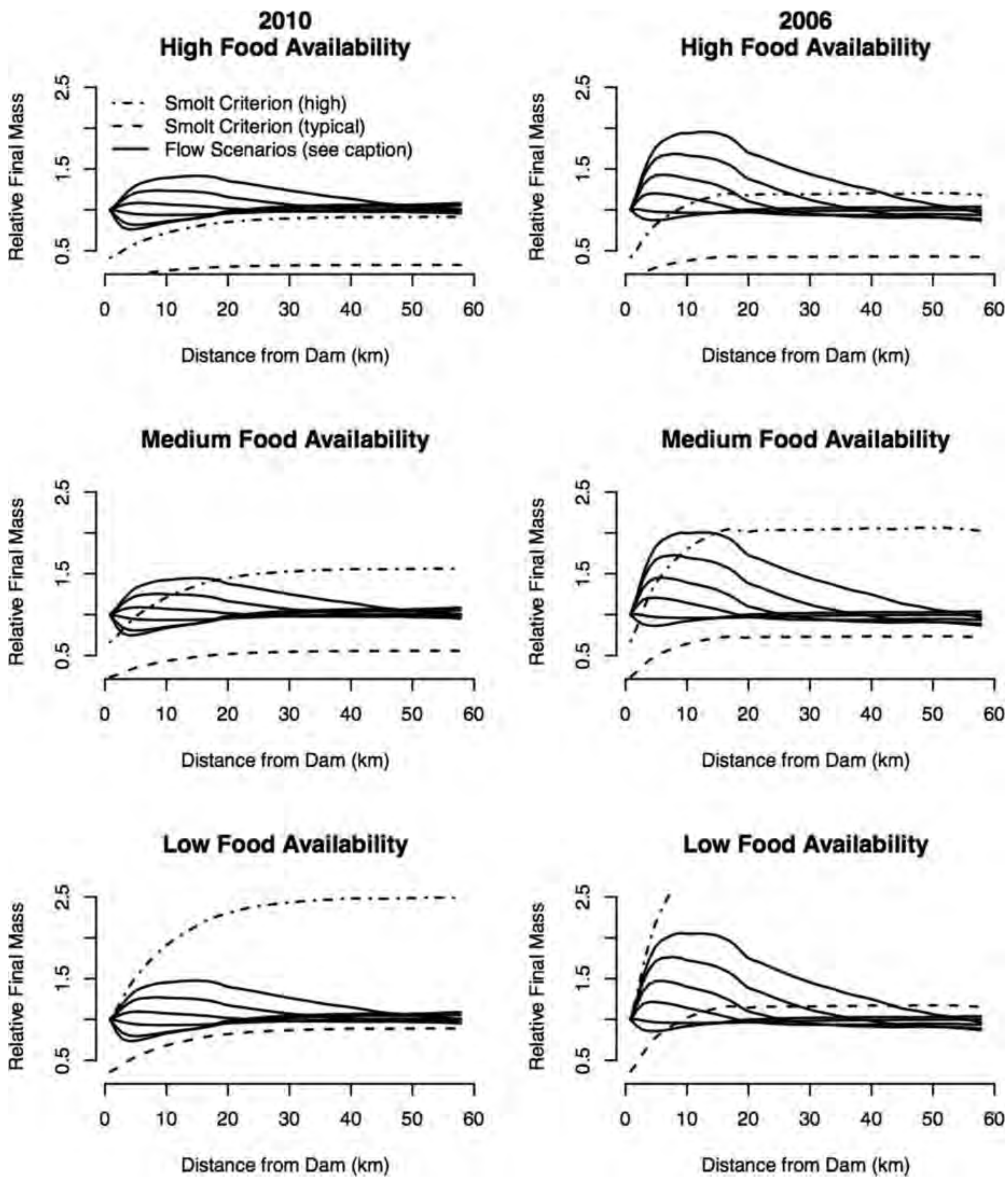

FIGURE 7. Relative final mass for age-1 steelhead on October 1 as modeled for various flow scenarios (solid lines), years (columns), and food availability (rows) at locations downstream of Bradbury Dam on the Santa Ynez River. The “typical” smolt criterion describes the final mass on October 1 that is assumed necessary to trigger smolting and out-migration during the following spring, given typical winter growth conditions. The “high” smolt criterion conservatively assumes zero winter growth. Flow scenarios (lines from top to bottom) are 5.7, 4.3, 2.8, 1.4, 0.71, and 0.28 m^3/s.

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that reaches supporting a second-summer pathway shrank from the entire river to the zone below the dam for two scenarios: (1) high food availability plus the high smolting criterion (Figure 7B); and (2) low food availability plus the typical smolting criterion (Figure 7F). The size of the nursery zone generally ranged from 5 to 18 km depending on flow; however, for very high flows (>4 m^3/s), the zone could extend as far as 43 km downstream.

In no case did a flow scenario convert the entire river into potential nursery habitat—either the combination of year (meteorological conditions) and food availability produced riverwide nursery habitat or the flow scenarios created a nursery zone near the dam that disappeared downstream as the river reached thermal "quasi-equilibrium" with meteorological conditions. Only for flows greater than 4 m^3/s was the nursery zone ever longer than approximately 20 km.

Stratified Pools

Of the 14 pools that were successfully monitored, eight (~60%) were thermally stratified. Neither the bottom nor the main flow of any pool became thermally unsuitable for steelhead during the study, but water temperatures were often stressful. Mean daily stress intensity was consistently lower at the bottoms of stratified pools (Figure 8).

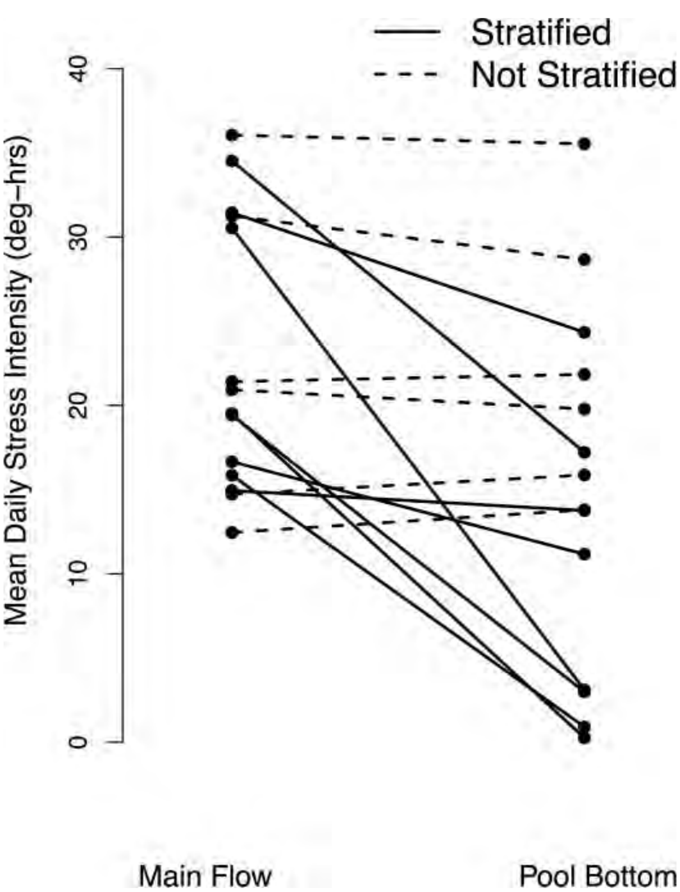

FIGURE 8. Mean daily intensity of thermal stress (degree-hours) for steelhead, as measured in the main flow and at the bottom of thermally stratified and unstratified pools in the Santa Ynez River during summer 2011.

Only five of the pools were thermally stratified on the day of their fish survey; of these pools, three harbored juvenile *O. mykiss*, whereas only one of the nine unstratified pools harbored *O. mykiss* (one-tailed z-test: $P = 0.027$).

DISCUSSION

Thermal Potential for Steelhead Life Histories

The simulations suggested that even during relatively hot summers, a coastal alluvial river in southern California was thermally suitable for juvenile steelhead. Nevertheless, nearly every summer day in both 2006 (the hot year) and 2010 (the average year) was thermally stressful throughout the Santa Ynez River, with stress intensity about 20% higher during 2006 than during 2010. Increasing the flow did not reduce the number of thermally stressful days except in an area just downstream of Bradbury Dam, but it did reduce the stress intensity throughout the entire river (Figure 5). Our data suggest that fish movement into stratified pools when temperatures exceed 21°C would tend to reduce stress intensity by an amount comparable to that achieved by increasing the flow (10–20 degree-hours/d; Figure 8). Presumably, this retreat to stratified pools would lower the rearing capacity for the river as a whole. However, juvenile steelhead appear to be able to use thermal refugia as a base from which to exploit the wider river during cool times of day (Brewitt and Danner 2014), so overall rearing capacity would be considerably larger than the pools themselves. Increasing the water releases from the dam might have additional benefits beyond stress reduction, such as increasing the river's capacity for first-summer life histories relative to second-summer life histories, thus supporting a greater life history diversity overall.

Predictions for potential steelhead nursery habitat can be summarized as follows. If the Santa Ynez River system supports typical winter growth, the second-summer pathway will be thermally available throughout the entire lower river but will be sensitive to climate if summer feeding opportunity is low. The first-summer pathway will also be thermally available but will become sensitive to climate when feeding opportunity is intermediate. In such situations, the pathways to anadromy can become thermally restricted to a tailwater zone below Bradbury Dam. On the other hand, if the river system produces neglible winter growth, then nursery habitat usually will be restricted to the tailwater or will be completely absent, depending on food availability.

In the simulations, flow scenarios did not determine whether the entire Santa Ynez River was nursery versus nonnursery habitat. Flow only altered the spatial extent of the tailwater zone when the river was otherwise physically unsuited to producing rapid growth of *O. mykiss*. Downstream of this

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zone, the river temperature became more equilibrated to local microclimate and riverbed conditions. Thus, temperature presumably became shaped much more by natural processes than by upstream dam releases and therefore was more similar to what would generally be considered an unimpaired thermal regime for this climate. In general, temperatures tended to stay above the range for maximum growth (15–17°C) but below the threshold for thermal exclusion (mean daily temperature <25°C, maximum temperature <29°C). Whether the river is thermally suitable for steelhead production (as opposed to producing *O. mykiss* that grow slowly and mature in freshwater) appears to depend more on annual weather than on flow, at least for the 2 years studied. This result accords with historical information for the late-19th and early 20th centuries, which suggests that annual runs of adult steelhead in the Santa Ynez River numbered in the thousands during some years and in the single digits during other years (Alagona et al. 2012).

Recent annual runs of steelhead in the Santa Ynez River have consistently stayed below approximately 10 fish since intensive monitoring began in the 1990s (Robinson et al. 2009). Our results suggest that water temperatures are not so high that they eliminate the potential for considerable smolt production; this indicates the existence of some other factor that keeps current steelhead production depressed relative to the production observed a century ago. Recent snorkel surveys conducted in the summer usually have found juvenile *O. mykiss* to be few and concentrated in stratified pools (Robinson et al. 2009), suggesting that very few fish currently pursue a first-summer or second-summer strategy in the lower main stem. The capacity for the second-summer pathway could also be limited by a lack of suitable upland creek habitat that can support successful spawning by anadromous *O. mykiss* and successful rearing of their progeny up to the second summer. Currently, most such habitat occurs upstream of the dam, where it is inaccessible to anadromous steelhead although commonly used by Rainbow Trout.

Exotic fish species almost certainly impact steelhead rearing in the Santa Ynez River. In particular, Largemouth Bass are quite abundant in the lower river (Robinson et al. 2009), occupy a thermal niche that broadly overlaps with the thermal niche of steelhead (Currie et al. 1998, 2004), and may both compete with and prey on juvenile steelhead (Hodgson et al. 1991; Christensen and Moore 2008, 2010; Braun and Walser 2011). Prior to the introduction of exotic fishes, southern California steelhead would have been the only medium-to-large bodied fish (>150 mm TL) feeding on invertebrates and other fishes in the Santa Ynez River and in nearby streams, where steelhead remain the only such fish and are observed to behave normally in water temperatures up to around 24°C (Spina 2007; Sloat and Osterback 2013). One explanation for the rarity of steelhead in the Santa Ynez River may be the competitive or predatory dominance of introduced fish (e.g., Largemouth Bass) that are adapted to the high end of the steelhead's thermal niche.

Shallow-River Heat Dynamics

Changing climate is generally expected to decrease summer flows relative to winter flows in western U.S. rivers that are occupied by Pacific salmonids; mechanisms include less water storage in deep soil, increased water demand by vegetation, greater surface evaporation, and especially the loss of snowpack (Mantua et al. 2010; Null et al. 2010). Although decreased summer flow affects heat fluxes by a variety of mechanisms, for simplicity these are often omitted from assessments (Mantua et al. 2010; Wenger et al. 2011; Benjamin et al. 2013). Instead, water temperature is assumed to track air temperature; this assumption relies on equilibrium assumptions that are only valid at relatively large flows and at a resolution of weekly (or coarser) average temperature (Bogan et al. 2003). Finer-grained temperature patterns, such as daily maximum temperature or degree-hours above some temperature threshold, are often biologically important but are poorly predicted by equilibrium assumptions. For example, Caissie et al. (2001) used statistical techniques to predict maximum daily creek temperature from air temperature and found that the empirical coefficient linking stream temperature and air temperature varied seasonally and was not independent of flow within seasons.

In general, subdaily temperature patterns should be sensitive to flow because for a given channel geometry and microclimate, flow establishes the scaling between heat fluxes and the thermal mass, or responsiveness, of the stream. Heat fluxes tend to scale to areas (surface area, streambed area, and cross-sectional area), whereas thermal mass, which describes the temperature response to a given flux, scales to water volume. In contrast to deep rivers, such as those fed by snowmelt, a wide, shallow river like the Santa Ynez River will have a cross-sectional area and volume that are quite small relative to horizontal surface areas; thus, longitudinal flux and thermal mass will be small relative to vertical energy fluxes. Longitudinal heat flux is reduced even further by slow water velocities in shallow rivers due to a greater effect of bed roughness. This situation would tend to decouple a shallow river from upstream conditions and raise the river's responsiveness to vertical heat exchange with the immediate riverbed and atmosphere. Since thermal mass acts as a sort of "smoother" on the temperature response, a RAFT hindcast for a shallow river such as the Santa Ynez River should involve greater error than a hindcast for a deeper river with a relatively high thermal mass; indeed, this is what we observed (RMSE = 1.5°C for the Santa Ynez River, whereas RMSE = 0.5°C for the Sacramento River; Pike et al. 2013).

Our results suggest that when the thermal mass of the water itself becomes small relative to vertical heat flux, the thermal mass of the riverbed becomes an important smoother of subdaily fluctuations. In the RAFT model, heat exchange between water and bed passively follows thermal gradients and thus reduces the temperature response to the diurnal fluctuations in atmospheric heat fluxes. When we conducted RAFT

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simulations with the streambed flux turned off (results not reported here), we found that this mechanism was essential to accurately hindcasting the temperatures of the lower Santa Ynez River. In our results, each doubling (or halving) of flow changed the maximum daily temperature by less than 1°C in most of the river (Figure 4), suggesting that a large amount of water must be released to add enough thermal mass to significantly augment what the riverbed already provides. In general, heat exchanges between rivers and their beds are often highly heterogeneous due to various mechanisms (Constantz 1998; Arscott et al. 2001; Arrigoni et al. 2008; Burkholder et al. 2008; Westhoff et al. 2010; Boughton et al. 2012). Anticipation of such heterogeneity may be important in identifying rivers with greater thermal resilience to the loss of summer flow, which is expected to result from climate change.

In our case study, changes in flow altered summer thermal habitat in the Santa Ynez River by two mechanisms: (1) the release of water that was out of thermal equilibrium with the local climate directly downstream of the dam; and (2) modulation of the mean depth—and thus thermal mass—of the entire river. Mechanism 1 produced a zone near the dam that functioned as a heat sink, with thermal properties that attenuated rapidly downstream, whereas mechanism 2 produced a heat buffer throughout the river. Steelhead indices that were sensitive to fine-grained fluctuations in temperature (e.g., stress intensity) responded to flow scenarios throughout the entire river (Figure 5). In contrast, the indices that integrated temperature effects over multiple days (e.g., potential growth) only responded strongly to flow scenarios within 20 km of Bradbury Dam (Figures 6, 7) or to extremely high-flow scenarios (>2.8 m^3/s [>100 ft^3/s]) that would probably not be characteristic of the river if the dam was absent. By decreasing upstream temperature, increasing mean depth, and raising water velocities, large enough summer releases from the dam might expand steelhead life history diversity in the Santa Ynez River, especially by enabling more steelhead to pursue a first-summer pathway, although it remains unclear whether this first-summer expression would be characteristic of the river in the absence of dams.

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	UOWTI	UTWTI	Incip Lethal WTI	Other WTI Values?	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fall-run Chinook Salmon																
Adult Upstream Migration																
Adult Spawning																
Egg Incubation and Fry Emergence																
In-River Rearing (Age 0+)																
Smolt Outmigration																
Spring-run Chinook Salmon																
Adult Upstream Migration																
Adult Holding																
Adult Spawning																
Egg Incubation and Fry Emergence																
Fry Rearing																
Juvenile Rearing and Downstream Movement																
Smolt Outmigration																
Steelhead																
Adult Upstream Migration																
Adult Spawning																
Egg Incubation and Fry Emergence																
Fry Rearing																
Juvenile Rearing and Downstream Movement																
Smolt Outmigration																

UOWTI = Upper Optimum Water Temperature Index
UTWTI = Upper Tolerance Water Temperature Index

Thermal Suitability Considerations for Anadromous Salmonid Reintroduction

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

December 1, 2016

Evaluating Thermal Habitat Suitability

- A fundamental component in determining the feasibility of a reintroduction program for anadromous salmonids.
- An initial step in evaluating physical habitat suitability and availability.
  - If habitat is not thermally suitable then it will not be suitable from other habitat perspectives.
- Purpose – To establish the technical basis to evaluate water temperature regimes for anadromous salmonid reintroduction into the Tuolumne River upstream of Don Pedro Reservoir.

Process Overview

- **Literature Review**
  - Conduct a comprehensive literature review of species/lifestage-specific water temperature relationships.
- **Water Temperature Indices**
  - Identify a suite of water temperature index (WTI) values representing a summarization of the literature review. A WTI value is an integer in a sequence characterizing thermally-related physiologic and behavioral responses.
- **Water Temperature Metrics**
  - Identify water temperature metrics and metric application to water temperature monitoring and/or modeling data. Water temperature metrics provide a reproducible measure of temperature over a period of time that can be used in combination with WTIs to determine thermal suitability.
- **Water Temperature Evaluation Guidelines**
  - Select water temperature guidelines (WTIs and metrics) for each species/lifestage-specific period for reintroduction evaluation.
- **Evaluation Methodology**
  - Identify water temperature evaluation methodological approach.

Literature Review

Water Temperature Effects

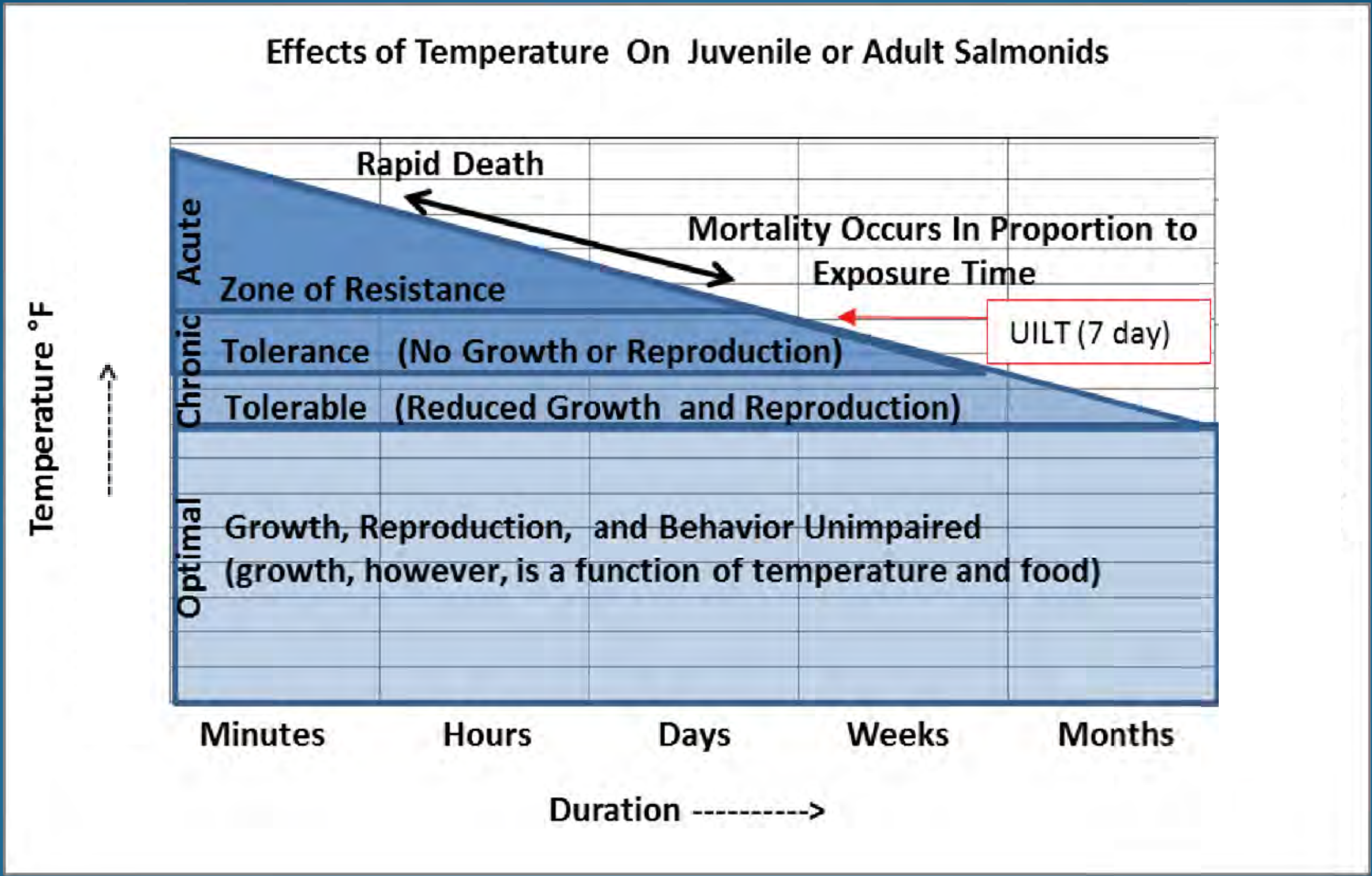

Illustration of Acute, Chronic, and Optimal Temperature Zones (adapted from Sullivan et al. 2000).

Water Temperature

LETHAL – temperatures at which direct mortality occurs.

X

Critical Thermal Maximum – Very short duration (minutes) mortality after acute temperature exposure.

Acute – Temperatures at which short-term exposure (<7days) results in rapid mortality. Mortality occurs in proportion to magnitude and duration of exposure.

Upper Incipient Lethal (UILT) – Boundary between lower end of acute temperature exposure range and upper end of chronic temperature exposure range. Temperature at which 50% mortality occurs after 7 days.

Sublethal – Temperatures that can result in indirect mortality, or that may reduce the survival and fitness of offspring. Associated with reduced disease resistance, reproductive success, juvenile growth and survival. Interference with physiological processes (e.g., metabolism, smoltification). Reduced competitive ability and altered behaviors (e.g., migration).

Suboptimal – Does not cause direct mortality, but may result in a higher probability of diminished success of a particular life stage due to sublethal effects (e.g., reduced fitness, viability, competitive ability or growth, and increased susceptibility to disease) .

Chronic – Long-term (> 7 days) exposure associated with reduced growth and reproduction. With increasing magnitude and duration of exposure, increasing potential for no growth and reproduction, and increased mortality.

Upper Tolerable (UT) – Upper boundary of the range of water temperatures at which fish can survive indefinitely, without experiencing substantial detrimental effects to physiological and biological functions such that survival occurs, but growth and reproduction success are reduced below optimal.

Upper Optimal (UO) – Upper boundary of the optimal temperature range where physiological processes (growth, reproduction, disease resistance) and behavior are not stressed by temperature.

OPTIMAL – temperatures at which physiological processes (growth, reproduction, disease resistance) and behavior are not stressed.

Water Temperature Metrics

- Designed to provide a reproducible index of water temperature over a period of time that can be used in combination with index values to determine habitat suitability for reintroduction.

- Metrics for potential application to the WTI values
  - ADT - Average Daily Temperature
  - 7DADM - Maximum of the Running 7-Day Average of the Daily Maxima for a specified time period
  - MWAT - Maximum of the Running Weekly (7-Day) Average Daily Temperature for a specified time period

Water Temperature Metrics

Average Daily Temperature

- Average daily temperature (ADT) could be considered for application because a majority of data in the literature review are based on ADT or continuous (constant) temperature.

- ADT can be used to determine the number of days (duration) that a water temperature index is exceeded, and duration of exceedance can be compared among specific geographic areas.

Water Temperature Metrics

Maximum 7-Day Average of the Daily Maxima

- The EPA (2003) recommends the maximum 7-day average of the daily maxima (7DADM)… "*because it describes the maximum temperatures in a stream, but is not overly influenced by the maximum temperature of a single day*".

- 7DADM is calculated by summing the daily maximum temperatures at a site for 7 consecutive days and dividing by 7.

Water Temperature Metrics

Maximum Weekly Average Temperature

- Maximum Weekly Average (Daily) Temperature (MWAT) is a summary measurement of instream water temperature variation that may occur on a daily or seasonal basis, and is used to evaluate chronic (sub-lethal) water temperature impacts.

- MWAT is found by calculating the mathematical mean of multiple, equally spaced, daily water temperatures over a 7-day consecutive period. The MWAT is defined as the highest value calculated for all possible consecutive 7-day periods over a given time period.

Lifestage & Water Temperature Indices

Steelhead

Lifestage	WTI Identified in Literature Review	WTIs for Reintroduction Consideration
Adult Upstream Migration	52°F, 56°F, 61°F, 64°F, 65°F, 68°F, 70°F	?
Adult Spawning	46°F, 52°F, 54°F, 55°F, 57°F, 59°F, 60°F	?
Egg Incubation and Fry Emergence	46°F, 52°F, 54°F, 55°F, 57°F, 59°F, 60°F	?
Fry Rearing	61°F, 63°F, 64°F, 65°F, 68°F, 72°F, 75°F, 77°F	?
Juvenile Rearing and Downstream Movement	61°F, 63°F, 64°F, 65°F, 68°F, 72°F, 75°F, 77°F	?
Smolt Outmigration	52°F, 55°F, 57°F, 59°F, 77°F	?

Lifestage & Water Temperature Indices

Spring-run Chinook Salmon

Lifestage	WTIs Identified in Literature Review	WTIs for Reintroduction Consideration
Adult Upstream Migration	60°F, 61°F, 64°F, 65°F, 68°F, 70°F	?
Adult Holding	60°F, 61°F, 64°F, 65°F, 68°F, 70°F	?
Adult Spawning	55°F, 56°F, 58°F, 60°F, 62°F	?
Egg Incubation and Fry Emergence	55°F, 56°F, 58°F, 60°F, 62°F	?
Fry Rearing	60°F, 61°F, 64°F, 65°F, 68°F, 70°F, 75°F, 77°F	?
Juvenile Rearing & Downstream Movement	60°F, 61°F, 64°F, 65°F, 68°F, 70°F, 75°F, 77°F	?
Smolt Outmigration	57°F, 59°F, 63°F, 68°F 72°F, 77°F	?

Lifestage & Water Temperature Indices

Fall-run Chinook Salmon

Lifestage	WTI Identified in Literature Review	WTIs for Reintroduction Consideration
Adult Upstream Migration	60°F, 61°F, 64°F, 65°F, 68°F, 70°F	?
Adult Spawning	55°F, 56°F, 58°F, 60°F, 62°F	?
Egg Incubation and Fry Emergence	55°F, 56°F, 58°F, 60°F, 62°F	?
In-River Rearing (Age 0+)	60°F, 61°F, 64°F, 65°F, 68°F, 70°F, 75°F, 77°F	?
Smolt Outmigration	57°F, 59°F, 63°F, 68°F 72°F, 77°F	?

Process Overview

- **Literature Review**
  - Conduct a comprehensive literature review of species/lifestage-specific water temperature relationships.
- **Water Temperature Indices**
  - Identify a suite of WTI values representing a summarization of the literature review.
- **Water Temperature Metrics**
  - Identify potential water temperature metrics for application to water temperature monitoring and/or modeling data.
- **Water Temperature Evaluation Guidelines**
  - Select water temperature guidelines (WTIs and metrics) for each species/lifestage-specific period for reintroduction evaluation.
- **Determine Species/Run-Specific Lifestage Periodicities**
  - Establish the time period associated with each lifestage.
- **Evaluation Methodology**
  - Compare temperature guidelines to monitored and/or modeled data.
  - Quantify the length of river with suitable species/run lifestage-specific water temperatures.

Thermal Suitability Considerations for Anadromous Salmonid Reintroduction

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

December 1, 2016

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

REINTRODUCTION ASSESSMENT FRAMEWORK GOALS SUBCOMMITTEE IN-PERSON MEETING

DECEMBER 1, 2016

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Reintroduction Goals Subcommittee Meeting

Thursday, December 1, 2016
2:30 pm to 4:00 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	Steve Boyd	Turlock Irrigation District
2	Paul Bratovich	HDR, consultant to the Districts
3	Jean Castillo	National Marine Fisheries Service
4	Calvin Curtin	Turlock Irrigation District
5	Jesse Deason	HDR, consultant to the Districts
6	John Devine*	HDR, consultant to the Districts
7	Greg Dias	Modesto Irrigation District
8	Nann Fangue*	U.C. Davis, consultant to the Districts
9	Dana Ferreira	Office of U.S. Congressman Jeff Denham
10	Mark Gard*	U.S. Fish and Wildlife Service
11	Art Godwin	Turlock Irrigation District
12	Andy Gordus	California Department of Fish and Wildlife
13	Chuck Hanson	Hanson Environmental, consultant to the Districts
14	Zac Jackson	U.S. Fish and Wildlife Service
15	Bill Ketscher	Private citizen
16	Patrick Koepele*	Tuolumne River Trust
17	Bao Le	HDR, consultant to the Districts
18	Ellen Levin*	City and County of San Francisco
19	Lonnie Moore	Private citizen
20	Marco Moreno	Latino Community Roundtable
21	Gretchen Murphey	California Department of Fish and Wildlife
22	Bill Paris	Modesto Irrigation District
23	Amanda Ransom	HDR, consultant to the Districts
24	Bill Sears*	City and County of San Francisco
25	Samantha Wookey	Modesto Irrigation District
26	John Wooster*	National Marine Fisheries Service
27	Ron Yoshiyama	City and County of San Francisco

* Attended by phone.

On December 1, 2016, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the third Reintroduction Goals Subcommittee (Goals Subcommittee) meeting for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials. This meeting began after the conclusion of the Water Temperature Subcommittee meeting, held earlier that day from 1:00 pm to 2:30 pm. Notes from the Water Temperature Subcommittee meeting are available as a separate document.

Mr. Bao Le (HDR) reviewed the background of why the Plenary Group formed the Goals Subcommittee. Mr. Le said in April 2016, the Districts were tasked with crafting a simple narrative goals statement to help begin discussions. The resulting statement is included in the agenda from the October 20, 2016, Goals Subcommittee meeting. [Narrative draft statement, as provided in the October 20, 2016 meeting agenda: "*Identify and evaluate, in collaboration with stakeholders, reasonable efforts which may enhance and assist in the recovery of ESA listed salmonids in the Central Valley*".]

Mr. Le summarized discussions held during the October 20, 2016 meeting. He noted that since that meeting, the Districts have received no feedback on the draft goals statement. Given that no feedback was received, the Goals Subcommittee has made little progress since the October 20 meeting.

Mr. Le said reported that at the October meeting two points were made by participants: (1) that the draft goals statement represented a broad, overarching goal of the reintroduction program but possibly the addition of corollary statements could help provide greater specificity; and (2) a potential source of information to identify potential quantitative metrics to define recovery success may be found in Lindley (2007). Mr. Le said after review of Lindley (2007), a possible quantitative metric to define a successful recovery program might be achieving low extinction risk, which equates to an average of 2,500 adults over 3 years, with an annual effective population size of not less than 500 adults. Mr. Le asked if Mr. John Wooster (National Marine Fisheries Service) or others had thoughts on this. Mr. Wooster said NMFS views reintroduction differently than recovery. For example, you may have a system where the recovery goal is a certain population size, but the reintroduction goal is just a fraction of the recovery goal because the reintroduced population can be thought of as just a subset of the overall recovered population. Mr. Wooster said this may not be the case for the Tuolumne River (i.e., reintroduction and recovery may be the same), given that there are no spring-run Chinook and the steelhead population is very small.

Dr. Chuck Hanson (Hanson Environmental, consultant to the Districts) said Lindley (2007) contains criteria that state multiple independent populations are preferred over having just one population. Prior to development of the NMFS Recovery Plan, a guidance document was prepared that reviewed the criteria, approaches, and metrics that NMFS should consider when developing the Recovery Plan. Dr. Hanson said he believes the Recovery Plan has all the components necessary to inform the quantitative metrics needed to support a reintroduction goals statement. Mr. Wooster noted that Lindley (2007) is a much shorter document than the Recovery Plan and that the Recovery Plan leans heavily on Lindley (2007). Mr. Paul Bratovich (HDR) said the Recovery Plan speaks directly to the recovery of populations and talks about evolutionarily significant units (ESUs), diversity groups, and how many viable populations in each diversity group would constitute recovery. Mr. Bratovich said the Recovery Plan also uses the simpler criteria provided in Lindley et al. (2007) to define a viable population.

Dr. Hanson said during the planning phase of the San Joaquin River restoration effort, how far populations needed to be from one another to be considered independent was defined. In addition, for a population to be considered recovered, it must meet the cumulative criteria, which states there is no more than a 5 percent probability of extinction in 100 years. Dr. Hanson said the simpler criteria were developed because implementation of a population viability analysis (PVA) for each river was not feasible.

Ms. Gretchen Murphey (California Department of Fish and Wildlife) asked how steelhead on the Tuolumne River would be considered from the point of view of reintroduction, given that there are *O. mykiss* already above and below the dams. Ms. Murphey asked if those populations would be added together when considering whether the population is viable. Dr. Hanson said it is likely that both populations would be considered as one, given that they would not meet the distance criteria to be considered as two independent populations. Interbreeding would also be assumed. Mr. Bratovich noted that there is also a percent hatchery contribution criteria in the Recovery Plan. Mr. Wooster said he agrees that from a recovery perspective, the upper and lower Tuolumne River *O. mykiss* populations would be considered to be a single population. Mr. Wooster said it may be that the lower river group would have a different status than the upper river group. Dr. Hanson said that would be similar to what occurred for the San Joaquin River, where NMFS made spring-run Chinook an experimental/non-essential population from the perspective of the Endangered Species Act (ESA).

Regarding low extinction number, Mr. Bill Paris (Modesto Irrigation District) asked if for example 10,000 fish is the number needed to avoid extinction, does that mean 10,000 fish is the goal or that the goal is more than 10,000 fish. Mr. Bratovich said the low extinction risk number is based on the simpler criteria. One way to define the simpler criteria is an average of 833 fish over three years, no less than 500 fish per year, and a limit on hatchery contributions. Another component of the Recovery Plan states that the goal for a recovered population ranges from the abundance associated with low extinction risk up to carrying capacity. Dr. Hanson wondered how that criteria might apply if carrying capacity is less than the low extinction risk number.

Mr. John Devine (HDR) asked if it is correct to state that if a population is not viable and does not meet the effective population number, it would not add to recovery of the ESU or DPS. Dr. Hanson and Mr. Bratovich both said Mr. Devine is correct. Dr. Ron Yoshiyama (City and County of San Francisco) said it is possible that fish could be introduced into the upper river without there being enough habitat to support an effective population, but that population could be supplemented by the lower river population in order to achieve an effective population. Mr. Bratovich said that raises the question of how to define a population as independent, because if the lower river population is a metapopulation of strays and hatchery fish, it may not be independent. In that case, the question would be whether combining the lower river population with the upper river population results in a single independent population.

Mr. Le said an additional question regarding steelhead is protecting a population versus protecting a behavior. For example, in the Pacific Northwest, the intent of listing bull trout was to protect the migratory form. The resident form is not protected and is not considered when evaluating recovery success. Mr. Wooster said in California, resident fish do not have the same level of protection under ESA as the do the anadromous fish. Mr. Wooster said the population numbers from Lindley (2007) only consider the anadromous form, and the resident population is not taken into account. Ms. Murphey asked if there is consideration that resident fish are taking up part of the carrying capacity, especially when it comes to juvenile fish. Mr. Wooster said he does not know the answer to that question, but he thinks resident fish would contribute towards the carrying capacity goal, and not take away from it. Mr. Wooster said regarding juvenile steelhead, there is no way to differentiate between anadromous and resident fish. Mr. Le said it seems as though different life stages would require different criteria. Mr. Bratovich said regarding the Yuba Salmon Forum, thermally suitable habitat for spawning adult spring-run Chinook salmon was most limiting, whereas thermally suitable habitat during the over-summer rearing period was most limiting for steelhead.

Regarding the draft goals statement, Mr. Le said, the Districts made an effort to develop a statement that represented the diversity of positions on the issue of reintroduction. Mr. Le said given today's discussion, it appears that Lindley (2007) and the NMFS Recovery Plan contain information that would be helpful for developing additional objectives and quantitative metrics.

In addition to contributing to the recovery of ESA listed salmonids in the Central Valley, Mr. Le said socioeconomic and economic concerns are also captured in the draft goal statement. Mr. Le said in the past, individuals have stated that it would not be prudent for the Districts to spend millions of dollars to benefit just a handful of fish. Mr. Le asked meeting participants to provide feedback on this topic.

Mr. Devine said the phrases “establish a viable population” and “at fair cost” or “at reasonable cost” could be added to the draft statement after “Identify and evaluate, in collaboration with stakeholders, reasonable efforts to…”. Mr. Devine asked if an updated draft goals statement might be to *“Contribute to the recovery of ESA listed salmonids in the Central Valley by establishing viable populations in the Tuolumne River at fair and reasonable cost.”* Ms. Jean Castillo (NMFS) asked if “viable population” is a quantifiable metric. Mr. Devine said it is quantifiable. Ms. Castillo said “fair and reasonable cost” is open to interpretation, and we need to be clear on what that phrase really means. Mr. Le said there the subcommittee could further define both “viable population” and “fair and reasonable cost” in corollary statements. Ms. Castillo asked if the first two parts of the goals statement were met, does cost matter? Mr. Devine said that from the Districts’ perspective, the cost matters, even if it does achieve a viable population. For example, if the cost to achieve a viable population is a billion dollars, the Districts would certainly question whether the program is worth doing. Mr. Lonnie Moore (private citizen) said “fair and reasonable” is very debatable, but possibly “cost effective” is a better way to phrase it. Mr. Bill Ketscher (private citizen) said it is important to consider impacts to the local economy. If the program costs a certain amount of money to achieve a viable population, the cost may still not be reasonable because the impacts to the local economy are so great. Ms. Murphey suggested using something more vague, such as “economic feasibility”, and that the Socioeconomic Study might produce information that could be developed into a corollary statement. Mr. Moore said the group could look at the costs of similar projects to determine what is “cost effective.” Mr. Devine said such true cost data would very likely be hard to come by, that it would be difficult to compare projects to one another, and that “cost effective” is also a phrase open to debate.

Mr. Paris requested that the new draft statement be sent out to the group. Mr. Le said the Districts will send the statement out to allow time for folks to consider it and provide their thoughts. Mr. Bratovich noted that the draft narrative goal statement is meant to be an overarching statement that addresses a number of different elements at a high level. Given the discussion of better defining terms and identifying quantifiable metrics to better measure recovery success, a potential next step might be to develop a series of objectives that support the draft goal statement. Mr. Le stated that he sees these objective statements as being synonymous to corollary statements. Mr. Moore asked if the Districts would be drafting corollary statements. Mr. Le suggested it might be better as a first step for participants to review the new draft statement and provide any further input. In the course of this review, suggestions for potential corollary statements would be helpful as well. Dr. Yoshiyama asked that language be added to the end of the statement that would lead into the corollaries, such as “specific issues and concerns are addressed in more detail in the following corollaries”. Mr. Le agreed that such additional language could be added.

Meeting participants discussed a date for next meeting. Mr. Le said he send out a Doodle poll.

The meeting concluded.

<u>Action Items</u>

1. The Districts will circulate the revised draft narrative goals statement to the Goals Subcommittee for review and comment (complete)

2. The Districts will send out a Doodle poll (complete)

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Water Temperature/Reintroduction Goals Subcommittees – In-person Meeting

Thursday, December 1, 2016, 1:00 pm to 4:00 pm

Modesto Irrigation District, 1231 11th St., Modesto, CA 95354
Conference Line: 1-866-583-7984; Passcode: 814-0607

Meeting Objectives:

1. Review and discuss updated water temperature literature review summary, glossary of terms/acronym list based upon comments received.
2. Presentation and discussion on relevant temperature terms.
3. Discuss water temperature indices (WTI) when considering anadromous fish reintroduction in the Upper Tuolumne River.
4. Discuss next steps and schedule for WTI selection.
5. Review, discuss and modify draft narrative reintroduction goals statement.
6. Discuss next steps and schedule for finalizing a reintroduction goals statement.

TIME	TOPIC
1:00 pm – 1:10 pm	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
1:10 pm – 2:30 pm	Water Temperature Subcommittee Topics (All) a. Updated Literature Review Summary and Acronym List– comments received (Districts) b. Presentation and discussion on relevant temperature terms (Districts) c. Subcommittee discussion of potential WTI values (All) - NMFS Input
2:30 pm – 3:50 pm	Reintroduction Goals Subcommittee Topics (All) a. Additional discussion on current draft narrative reintroduction goals statement (All) b. Subcommittee discussion of further development of draft narrative goal statement (All) - Additional corollary statements? - Quantitative input (Lindley 2007)?
3:50 pm – 4:00 pm	Next Steps (All) a. Schedule next call and agenda topics b. Action items from this call

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

FISH PASSAGE FACILITIES ALTERNATIVES ASSESSMENT
WATER TEMPERATURE SUBCOMMITTEE MEETING

JANUARY 26, 2017

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Water Temperature Subcommittee Meeting

Thursday, January 26, 2017
1:00 pm to 2:30 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	David Avila	Western Dairy Design
2	Allison Boucher	Tuolumne River Conservancy
3	David Boucher	Tuolumne River Conservancy
4	Steve Boyd	Turlock Irrigation District
5	Anna Brathwaite	Modesto Irrigation District
6	Larry Byrd	Modesto Irrigation District
7	Jean Castillo	National Marine Fisheries Service
8	Jesse Deason	HDR, consultant to the Districts
9	John Devine*	HDR, consultant to the Districts
10	Dana Ferreira	Office of U.S. Congressman Jeff Denham
11	Bill Foster	National Marine Fisheries Service
12	Art Godwin	Turlock Irrigation District
13	Andy Gordus	California Department of Fish and Wildlife
14	Kelsey Gowans	Modesto Irrigation District
15	Fred Kelly Grant	Fred Kelly Grant LTD
16	Chuck Hanson	Hanson Environmental, consultant to the Districts
17	Patrick Koepele*	Tuolumne River Trust
18	Bao Le	HDR, consultant to the Districts
19	Ellen Levin*	City and County of San Francisco
20	Lonnie Moore	Citizen
21	Gretchen Murphey	California Department of Fish and Wildlife
22	Bill Paris	Modesto Irrigation District
23	Bill Sears	City and County of San Francisco
24	Charles R. Shetvon	Citizen
25	Chris Shutes	California Sportfishing Protection Alliance
26	Josh Weimer	Turlock Irrigation District
27	Samantha Wookey	Modesto Irrigation District
28	John Wooster*	National Marine Fisheries Service
29	Ron Yoshiyama	City and County of San Francisco
30	Allen Zanker	Citizen

* Attended by phone.

On January 26, 2017, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the fourth Water Temperature Subcommittee (Temperature Subcommittee) meeting for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials. After this meeting concluded, a Reintroduction Goals Subcommittee meeting began. Notes from the Reintroduction Goals Subcommittee meeting are available as a separate document.

Mr. Bao Le (HDR, consultant to the Districts) welcomed meeting attendees. Mr. Le said the Temperature Subcommittee was formed to identify numeric values for temperature that could be used in the Upper Tuolumne River Basin Temperature Monitoring and Modeling Study to evaluate temperature suitability in the upper river. As part of the Temperature Subcommittee, the Districts produced a literature review. The literature review was circulated to the Temperature Subcommittee for review. Since the last Temperature Subcommittee meeting, one comment has been received on the literature review. At the previous Temperature Subcommittee meeting, held on December 1, 2016, Dr. Andy Gordus (California Department of Fish and Wildlife [CDFW]) requested that the graphic about the effects of temperature on juvenile and adult salmonids be added to the literature review. Mr. Le said the graphic has now been added to the literature review. Mr. Le said in addition to adding the graphic, the Districts made a minor change to the Swim Tunnel Study Report reference that is included in the literature review. The study, which was conducted by the Districts, was originally cited in the literature review as a Districts' study. Given that the study has since been peer-reviewed and accepted into the academic literature, the reference has been updated. Other than adding the figure and updating the Swim Tunnel Study reference, no other changes have been made to the literature review. The literature review is a living document, and as comments are received, the Districts will attempt to address them.

Mr. John Wooster (National Marine Fisheries Service [NMFS]) asked that the new Swim Tunnel Study academic article be circulated to the Temperature Committee. Mr. John Devine (HDR) said he will circulate the article.

Mr. Le said at the last Temperature Subcommittee meeting, Mr. Wooster provided a summary of Boughton (2015), a study completed by the NMFS Science Center (Science Center) that evaluated thermal suitability as it pertains to carrying capacity. Meeting attendees discussed how Boughton (2015) looked at a gradation of effects, as opposed to a binomial or suitable-unsuitable approach. Mr. Le said during that discussion, Mr. Wooster noted that Boughton (2015) is the first of a series of studies using the same methodology, and that subsequent study reports, like the forthcoming Russian River Memo, would provide additional details about the methodology. Mr. Le said a number of action items arose from the discussion of Boughton (2015). One action item was for Mr. Paul Bratovich (HDR) to review Boughton (2015) and to try and draw some relationships between the methodology and analysis presented in the paper and information developed in the Temperature Subcommittee literature review. Mr. Le said Mr. Bratovich reviewed Boughton (2015) and tried to relate it back to the thermal response information previously produced by the Temperature Subcommittee. Mr. Le said Mr. Bratovich's review, which was circulated to the Temperature Subcommittee prior to this meeting, concluded that Boughton (2015) described some temperature values and associated responses that seem to be in conflict with some of the temperature values and responses that already exist in the literature. Mr. Le asked if attendees had reviewed Mr. Bratovich's review and had any questions or comments. There were none.

Mr. Le asked Mr. Wooster for a schedule of when the Russian River Memo would be available for review by the Temperature Subcommittee. Mr. Wooster said the Russian River Memo has been finalized and should be available any day now for distribution to the Temperature Subcommittee. Mr. Devine said the Russian River Memo is of interest to the Temperature Subcommittee because it will provide more detail about the analysis used in Boughton (2015). Mr. Wooster cautioned that he has not seen the final version of the memo and did not know the level of detail provided about the analysis and methodology. Mr. Le asked if Dr. Boughton authored the Russian River Memo. Mr. Wooster confirmed that Dr. Boughton is one of several authors of the memo. Mr. Wooster said he will circulate the Russian River Memo to the Temperature Subcommittee when the memo becomes available.

Mr. Le summarized discussions at the previous Temperature Subcommittee meeting related to temperature criteria in the lower and upper Tuolumne River. During the previous meeting, attendees discussed how in the lower Tuolumne River, a specific temperature criteria is implemented. In the upper

Tuolumne River, temperature criteria do not exist. Mr. Le said attendees discussed whether it was appropriate to apply different temperature criteria to different reaches of the same river. Mr. Devine said the question is still outstanding of whether it is appropriate to apply one set of suitable temperatures upstream and a different set of suitable temperatures downstream, which would mean having two different temperatures for the same fish at the same life stage.

Ms. Dana Ferreira (Office of U.S. Congressman Jeff Denham) asked if the Russian River Memo will provide temperatures that could be used in the Framework process, and if future progress by the Temperature Subcommittee is dependent upon the memo being released. Mr. Le said that during the last Temperature Subcommittee meeting, NMFS had characterized Boughton (2015) as the approach NMFS would take to evaluate thermal suitability as it relates to carrying capacity. Mr. Le said although NMFS stated the methodology used in Boughton (2015) is not intended to identify temperature criteria, the Temperature Subcommittee is still interested to understand how NMFS' approach can be integrated into what the Temperature Subcommittee is working on. Mr. Le said in that sense, the Temperature Subcommittee is waiting on the release of the Russian River Memo so the Science Center methodology can be assessed further. Mr. Wooster said he agreed with Mr. Le's characterization that the Science Center approach is not meant to determine a specific temperature. Instead, the approach is aimed at modeling the effects of temperature on growth as a gradation of effects. Mr. Le said the Science Center approach will result in a suite of temperatures that are suitable, and the Temperature Subcommittee would like to know if and how that suite of temperatures can be used in the Framework process.

Mr. David Avila (Western Dairy Design) asked if the Russian River study is being applied to the Tuolumne River. Mr. Wooster said the general methodology being implemented for the Russian River would also be applied to the Tuolumne River. Mr. Avila said given the numerous differences between the Russian River and the Tuolumne River, such as differences in flow and snow pack, he questioned how modeling results from the Russian River could be applied to the Tuolumne River. Mr. Wooster said although he has not participated first-hand in the modeling being completed by the Science Center, he did know that the model incorporated many river-specific inputs, such as terrain, topography, and inflow. Mr. Avila asked how the Russian River Memo will be used by the Temperature Subcommittee. Mr. Wooster said the Temperature Subcommittee was interested to have more information on how temperature influences growth, foraging for food, and other behavior. Mr. Wooster said Boughton (2015) did not have much information on the Science Center's methodology, but he thinks the Russian River Memo will provide more details on this topic.

Ms. Ferreira asked what is the cost of the Russian River study. Mr. Wooster said the study budget is $100,000. Ms. Ferreira asked if there are additional costs associated with the study above the $100,000. Mr. Wooster said the $100,000 budget does not include the salaries of the staff who work on the project.

Mr. Le said the Science Center applied a methodology to the Santa Ynez River and now are applying the same methodology, with refinements, to the Russian River and the Tuolumne River. Mr. Le said understanding the approach is important, including what types of site-specific data are used in the model. Mr. Le asked what types of site-specific data from the Tuolumne River would be used in the model. Mr. Wooster said for the Tuolumne River, site-specific data such as water depth, flow, meteorological conditions, topography, and other physical habitat factors will be used.

Mr. Le asked if there are any further comments or questions about Boughton (2015) or the Russian River Memo. There were none.

Mr. Le said the Districts released a water temperature and timing working document for the previous Temperature Subcommittee meeting, as a first step in trying to generate discussion about temperatures to be used to evaluate thermal suitability of habitats in the upper river. Periodicities for three species are being considered. Mr. Le said the Districts released the working document and requested comments by January 13. No feedback was received. Mr. Le asked if any attendees would like to provide feedback on the working document or temperature values during this meeting. Ms. Gretchen Murphey (California Department of Fish and Wildlife) asked how the periodicity for spring-run Chinook was derived. Mr. Le said the periodicity was derived using the NMFS Recovery Plan and CDFW documentation, as well as the observations of researchers who have worked with the species in the Central Valley. The references used can be found in Technical Memorandum No. 1.

Mr. Shutes said he recommended minor revisions be made to the temperature and timing working document. Mr. Shutes said the timing for the spring-run Chinook upstream migration should be expanded to June because similar timing has been observed in the Yuba River during wet years. Mr. Shutes also said there should be an overlap between adult holding and spawning, and spawning should be expanded through September. Mr. Le said the Districts will discuss Mr. Shutes' input with team biologists.

Meeting adjourned.

Action Items

1. The Districts will circulate the new Swim Tunnel Study academic article to the Temperature Subcommittee.

2. Mr. Wooster will circulate the Russian River Memo to the Temperature Subcommittee once the Memo becomes available.

3. The Districts will review Mr. Shutes' input on the temperature and timing working document with team biologists.

WATER TEMPERATURE SUBCOMMITTEE MEETING
THURSDAY, JANUARY 26, 2017
MEETING NOTES

ATTACHMENT A

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Water Temperature/Reintroduction Goals Subcommittees – In-person Meeting

Thursday, January 26, 2017, 1:00 pm to 4:00 pm
Modesto Irrigation District
1231 11th St., Modesto, CA 95354

By Phone - Conference Line: 1-866-583-7984; Passcode: 814-0607

Meeting Objectives:

1. Review and discuss updated water temperature information based upon comments received.
2. Continue discussion of Boughton et al. approach in relation to current Updated Literature Review Summary.
3. Discuss next steps and schedule for WTI selection (Water Temperature Working Document).
4. Review and discuss comments received on draft narrative reintroduction goals statement and finalize statement.
5. Discuss developing objective/corollary statements in support of a reintroduction goals statement.

TIME	TOPIC
1:00 pm – 1:10 pm	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
1:10 pm – 2:30 pm	Water Temperature Subcommittee Topics (All) a. Updated Literature Review Summary – comments received (Districts) b. Boughton approach as applied to Updated Literature Review Summary (Districts) c. Water Temperature Working Document – discussion (All)
2:30 pm – 3:50 pm	Reintroduction Goals Subcommittee Topics (All) a. Additional discussion on current draft narrative reintroduction goals statement – comments received and finalization (All) b. Subcommittee discussion of further development of objective/corollary statements to support narrative goal statement (All)
3:50 pm – 4:00 pm	Next Steps (All) a. Schedule next call and agenda topics b. Action items from this call

TID/MID Response to Comments on the Water Temperature Literature Review

Comment No.	Organization / Source	Comment	Response
1.	CDFW 11/3/16 email	It would be helpful to include in the Glossary of Terms definitions for both **acute** and **chronic** especially in terms to timeframes and implications.	Acute and chronic terms in addition to other terms have been updated in The Glossary of Terms document.
2.	CDFW 11/3/16 email	The literature review contains temperatures in both English and Metric units which is confusing. In the interest of clarity and consistency with established scientific literature we request that all temperatures be available Celsius.	As noted in the introduction of the literature review, subcommittee members supported use of an already published review as the basis for this assessment (i.e., Appendix A of Bratovich et al. 2012). Much of the narrative text was cited "as-is" from the existing document. However, for each of the life history tables (which summarize the narrative text at the end of each life history stage section) included in the literature review, metric units have been added in parentheses alongside English units. Not all scientific or technical documents report temperature in °C. For example, the SWRCB's recently released Substitute Environmental Document uses °F. For future reference, we will make every effort to report in °F in whole integers, with °C provided in parentheses.
3.	CDFW 11/3/16 email	Water Temperature Indices - The literature review is unclear as to the purpose of water temperature index values. It is stated that they provide a gradation of potential effects but there is no indication as to what the index values will be used for.	As noted, the water temperature index values included in the literature review represent the gradation of potential effects. A primary objective of the water temperature subcommittee process is to identify a value (or set of values) and metrics that will be used to evaluate potential thermal habitat suitability for anadromous salmonid reintroduction in the Tuolumne River.

Comment No.	Organization / Source	Comment	Response
4.	CDFW 11/3/16 email	The inclusion of water temperature criteria for other rivers and the EPA is helpful for comparison but, clarification as to how the Upper Optimum Value and Upper Tolerable Value are applied in the Yuba River would be helpful.	The Yuba Salmon Forum (YSF) conducted a summary assessment of potential spring-run Chinook salmon and steelhead habitat in the Yuba River Basin to provide information for use in reviewing potential options that warrant further investigation regarding reintroduction into the North, Middle, and South Yuba rivers, as well as portions of the mainstem Yuba River. Evaluations conducted by the YSF (2013) emphasized water temperature habitat suitability determinations. These evaluations utilized water temperature index (WTI) values specific to each of the species' lifestages, and the time periods throughout the year during which they occur. The WTI values selected for evaluation corresponded to lifestage-specific Upper Optimum and Upper Tolerable WTI values. The maximum weekly average (daily) water temperature (MWAT) was the metric applied to water temperature monitoring and modeling data, for various years and water year types, to identify when and where WTI values were exceeded. The estimated location when MWAT exceeded the specified WTI value was then used to identify the number of river miles of thermally suitable habitat for a particular species/lifestage.
5.	CDFW 11/3/16 email	The inclusion of data obtained from the Lower Tuolumne River swim tunnel study is inappropriate. Results obtained during the study are based on an acute response to temperature which does little to inform a fish's response to a chronic condition. CDFW has provided extensive comments on this study to HDR Inc. in a letter dated August 31, 2016.	The researchers responsible for this study indicate that it is incorrect to classify the Swim Tunnel study as an investigation of acute response to water temperature. The comments provided by CDFW have been addressed and will be provided in the final study filed with FERC. The study represents the only site-specific study of thermal capability of wild juvenile *O. mykiss* in the Tuolumne River and is important to consider.
6.	CDFW 12/1/16 subcommittee meeting	Andrew Gordus requested that a figure describing the effects of temperature on juvenile or adult salmonids be added to the Water Temperature Literature Review document.	This figure has been added to the Water Temperature Literature Review document.

UPPER TUOLUMNE RIVER REINTRODUCTION ASSESSMENT FRAMEWORK
WATER TEMPERATURE SUBCOMMITTEE

LIFESTAGE-SPECIFIC WATER TEMPERATURE BIOLOGICAL EFFECTS AND INDEX TEMPERATURE VALUES

Literature Review Summary

INTRODUCTION

The La Grange Hydroelectric Project (La Grange Project), owned and operated by the Turlock Irrigation District and Modesto Irrigation District (TID/MID, or the Districts), is currently undergoing the Federal Energy Regulatory Commission (FERC) Integrated Licensing Process. As part of this process, the Districts are implementing a FERC-approved Fish Passage Facilities Alternatives Assessment which consists of developing general design criteria and design considerations applicable to upstream and downstream fish passage facilities at the La Grange Project. Design criteria and considerations include items such as: site-specific physical and operational parameters; applicable regulatory requirements; National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and California Department of Fish and Wildlife (CDFW) biological and engineering design criteria; site-specific biological/habitat information relevant to the sizing and configuration of facilities; and any other information gaps that may affect siting, sizing, general design parameters, capital cost, and operating requirements of potential fish passage facilities.

To make certain that detailed, site-specific information is available to support and adequately inform decisions regarding fish reintroduction and fish passage, TID, MID, and licensing participants came to a consensus on the need for and utility of an Upper Tuolumne River Reintroduction Assessment Framework (Framework). The Framework is intended to provide a comprehensive, collaborative, and transparent approach for evaluating the full range of potential issues associated with the future reintroduction of anadromous salmonids to the upper Tuolumne River. In addition to considering aspects of the technical feasibility of building and operating fish passage facilities, the Framework considers the interrelated issues of ecological feasibility, biological constraints, economics, regulatory implications, and other considerations of reintroduction. Elements of the Framework are interconnected, with fish passage construction and operational requirements needing to properly reflect biological constraints, ecological considerations, and economic cost-benefit assessments.

Water temperature considerations are a primary component of assessing any potential anadromous salmonid reintroduction effort. In support of the Framework, the Districts and licensing participants established a Water Temperature Subcommittee to begin investigating water temperature considerations pertinent to anadromous salmonid reintroduction opportunities in the accessible reaches of the Tuolumne River upstream of Don Pedro Reservoir (upper Tuolumne River). On September 15, 2016, the Districts hosted the first conference call for the Water Temperature Subcommittee (draft meeting notes from this call were distributed on October 3 for a 30-day comment period). On the conference call, attendees discussed the need for a comprehensive literature review of regional and site-specific information to inform the selection of water temperature index (WTI) values to be used in an evaluation of the water temperature-related reintroduction potential in the reaches of the upper Tuolumne River. Meeting attendees agreed that the literature review performed for the Yuba Salmon Forum (Appendix A; Bratovich *et al.* 2012) to support the anadromous salmonid reintroduction assessment in this watershed coupled with site-specific temperature studies or data for the Tuolumne River, if available, would be a good basis for this effort. The following represents and updated literature review summary and is provided to the Water Temperature Subcommittee to support selection of water temperature index values for the Framework.

The WTI values presented herein represent a gradation of potential biological effects from optimal to lethal water temperatures for each lifestage. Literature on salmonid water temperature requirements generally reports water temperature thresholds using various descriptive terms including "optimal", "preferred", "suitable", "suboptimal", "tolerable", "stressful – chronic and acute", "sublethal", "incipient lethal", and "lethal". Water temperature effects on salmonids are often discussed in terms of "lethal" and "sublethal" effects, and depend on the both the magnitude and the duration of exposure (Sullivan *et al.* 2000), as well as acclimation water temperature. Acute, chronic, and optimal growth zones are displayed in Figure 1.

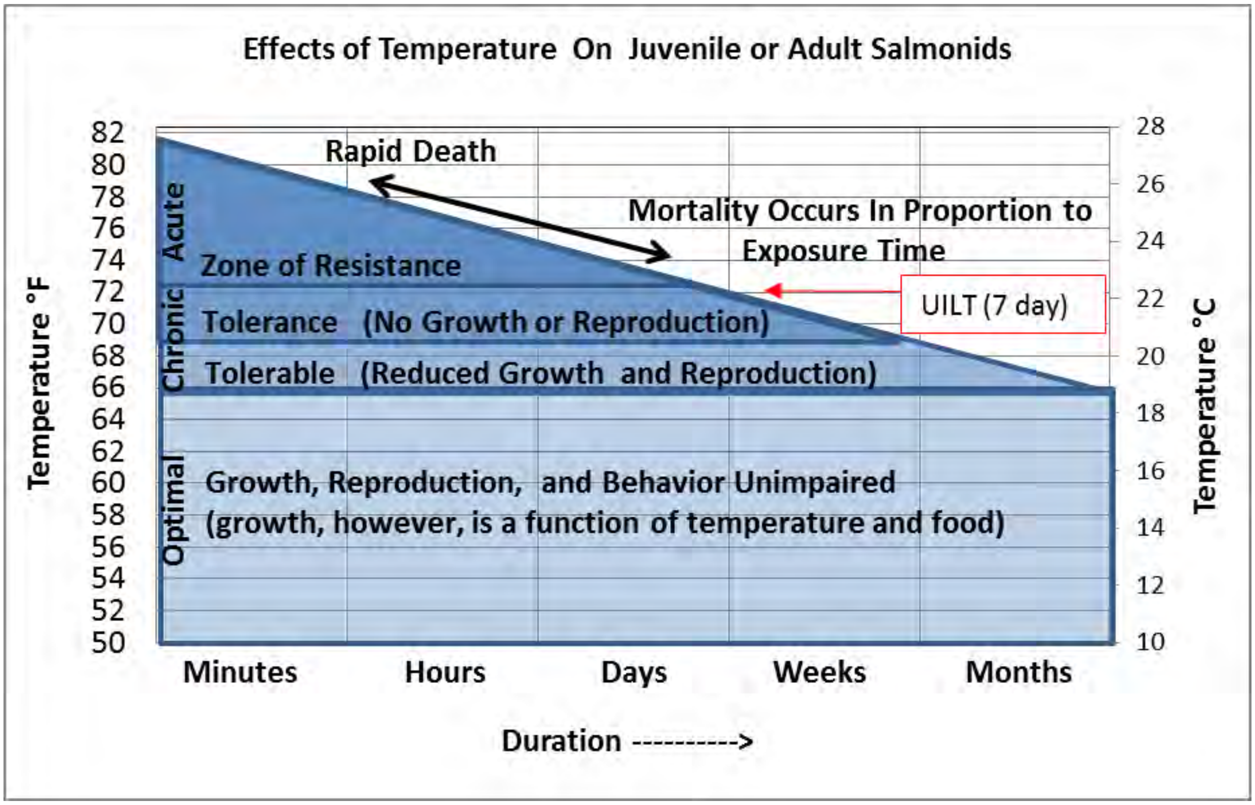

Figure 1. Illustration of acute, chronic, and optimal temperature zones (adapted from Sullivan et al. 2000).

STEELHEAD LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Adult Immigration and Holding

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. Yuba County Water Agency (YCWA) *et al.* (2007) suggests that few studies have been published examining the effects of water temperature on either steelhead immigration or steelhead holding, and none of the available studies were recent (Bruin and Waldsdorf 1975; McCullough *et al.* 2001). The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid-50°F range, and that immigration will be delayed if water temperatures approach approximately 70°F (Table 1). WTI values of 52°F, 56°F, 61°F, 64°F, 65°F, 68°F and 70°F were identified because they provide a gradation of potential water temperature effects, and the available literature provided the strongest support for these values.

Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of WTI values could not be achieved. 52°F was identified as a WTI value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (McEwan and Jackson 1996; NMFS 2000; NMFS 2002), and "optimum" (Reclamation 1997a) water temperature for steelhead adult immigration. Increasing levels of thermal stress to this lifestage may reportedly occur above the 52°F WTI value. 56°F was identified as a WTI value because 56°F represents a water temperature above which adverse effects to migratory and holding steelhead begin to arise (Bruin and Waldsdorf 1975; Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 50-59°F is referred to as the "preferred" range of water temperatures for California summer steelhead holding (Moyle *et al.* 1995). Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS 1995a). A water temperature of 64°F (7DADM) was identified as the value for steelhead adult lifestage for the San Joaquin River (CALFED 2009) and as the Upper Optimum Value for steelhead adult migration (MWAT) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" migration (EPA 2003b). 65°F was identified as a WTI value because steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Additionally, over 93% of steelhead detections occurred in the 65.3-71.6°F range, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006) and/or may modify migration timing due to holding in coldwater refugia (High *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). A water temperature of 68°F was found to drop egg fertility in vivo to 5% after 4.5 days (McCullough *et al*. 2001). Additionally, empirical adult *O. mykiss* population data from the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon rivers were collected in 2007-2009 were plotted against temperature (Figure 4 of Bratovich *et al*. 2012). The data show a population density break at about 68°F. Although smaller population densities occurred at higher temperatures, the largest population densities occurred at temperatures near 68.0°F or less. 70°F was identified as the highest WTI value because the literature suggests that water temperatures near and above 70.0°F may result in a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001) and are water temperatures referred to as "stressful" to upstream migrating steelhead in the Columbia River (Lantz 1971 as cited in Beschta *et al.* 1987). Further, Coutant (1972) found that the upper incipient lethal temperature (UILT) for adult steelhead was 69.8°F and temperatures between 73-75°F are described as "lethal" to holding adult steelhead in Moyle (2002).

As part of the Framework, TID and MID, in collaboration with stakeholders developed a table of WTI values from select salmon and steelhead programs in the Central Valley (Temperature Criteria Matrix; presented at the September 15, 2016 Water Temperature Subcommittee conference call). The table was developed to support the Framework's Water Temperature Subcommittee whose purpose is to establish a technical basis to evaluate water temperature regimes for target anadromous salmonid reintroduction into the Tuolumne River upstream of Don Pedro Reservoir. For steelhead adult immigration, the Temperature Criteria Matrix identified 64°F for the San Joaquin (CALFED 2009) and 64°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). For steelhead adult holding, the Temperature Criteria Matrix identified 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Table 1. Steelhead Adult Immigration and Holding WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F (11.1°C)	Preferred range for adult steelhead immigration of 46.0°F to 52.0°F (NMFS 2000; NMFS 2001a; SWRCB 2003). Optimum range for adult steelhead immigration of 46.0°F to 52.1°F[1] (Reclamation 1997a). Recommended adult steelhead immigration temperature range of 46.0°F to 52.0°F (Reclamation 2003).
56°F (13.3°C)	To produce rainbow trout eggs of good quality, brood fish must be held at water temperatures not exceeding 56.0°F (Leitritz and Lewis 1980). Rainbow trout brood fish must be held at water temperatures not exceeding 56°F for a period of 2 to 6 months before spawning to produce eggs of good quality (Bruin and Waldsdorf 1975). Holding migratory fish at constant water temperatures above 55.4°F to 60.1°F may impede spawning success (McCullough *et al.* 2001).
61°F (16.1°C)	Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter- run steelhead (USFWS 1995a). Preferred range of water temperature for holding California summer steelhead occurs between 50-59°F (Moyle 1995). A water temperature of 61°F was identified as the Upper Optimum Value for steelhead adult holding, MWAT, for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
64°F (17.8°C)	Steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Over 93% of steelhead detections occurred in the 65.3-71.6°F, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006). A water temperature of 64°F was identified as the value for steelhead adult lifestage, 7DADM, for the San Joaquin River (CALFED 2009) and as the Upper Optimum Value for steelhead adult migration, MWAT, for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" migration (EPA 2003b).
65°F (18.3°C)	A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). A water temperature of 68°F was found to drop egg fertility in vivo to 5% after 4.5 days (McCullough *et al.* 2001).
70°F (21.1°C)	Migration barriers have frequently been reported for pacific salmonids when water temperatures reach 69.8°F to 71.6°F (McCullough *et al.* 2001). Snake River adult steelhead immigration was blocked when water temperatures reached 69.8 (McCullough *et al.* 2001). The UILT for adult steelhead was determined to be 69.8°F (Coutant 1972).

[1] Similar to Bratovich *et al*. 2012, rounded whole integers were identified for index values to avoid unwarranted specificity.

Spawning and Embryo Incubation

Relatively few studies have been published directly addressing the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979; Rombough 1988). Because anadromous steelhead and non-anadromous rainbow trout are genetically and physiologically similar, studies on non-anadromous rainbow trout also were considered in the development of WTI values for steelhead spawning and embryo incubation (Moyle 2002; McEwan 2001). From the available literature, water temperatures in the low 50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high 50°F range and above (Table 2). Water temperatures in the 45-50°F range have been referred to as the "optimum" for spawning steelhead (FERC 1993).

WTI values of 46°F, 52°F, 54°F, 55°F, 57°F, 59°F and 60°F were identified for two reasons. First, the available literature provided the strongest support for WTI values at or near these integers. Second, the index values reflect a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead spawning and embryo incubation. Some literature suggests water temperatures ≤ 50°F are when steelhead spawn (Orcutt *et al.* 1968) and/or are optimal for steelhead spawning and embryo survival (FERC 1993; Myrick and Cech 2001; Timoshina 1972) and temperatures between 39-52°F are "preferred" by spawning steelhead (IEP Steelhead Project Work Team (no date); McEwan and Jackson 1996). Orcutt *et al.* (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F. A larger body of literature suggests optimal conditions occur at water temperatures ≤ 52°F (Humpesch 1985; NMFS 2000; NMFS 2001a; NMFS 2002; Reclamation 1997b; SWRCB 2003; USFWS 1995b). Further, water temperatures between 48-52°F were referred to as "optimal" (FERC 1993; McEwan and Jackson 1996; NMFS 2000) and "preferred" (Bell 1986) for steelhead embryo incubation. Therefore, 52°F was identified as the lowest WTI value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation lifestage may reportedly occur above the 52°F WTI value.

54°F was identified as the next index value, because although most of the studies conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions, and conditions that cause negative effects to steelhead spawning and embryo incubation. Further, water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning and egg incubation (EPA 2003b). For steelhead spawning and embryo incubation in the Yuba River, the Framework Temperature Criteria Matrix identified 54°F and 57°F for Upper Optimum and Upper Tolerable values, respectively (Bratovich *et al.* 2012). 57°F was identified as an index value because embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57°F. Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50% hatch under incubation temperatures ranging from 33.8°F to 60.8°F that demonstrated a two-fold increase in mortality for embryos incubated at 57.2°F, compared to embryos incubated at 53.6°F.

In a laboratory study using gametes from Big Qualicum River, Vancouver Island, steelhead mortality increased to 15% at a constant temperature of 59.0°F, compared to less than 4% mortality at constant temperatures of 42.8°F, 48.2°F, and 53.6°F (Rombough 1988). Also, alevins hatching at 59°F were considerably smaller and appeared less well developed than those incubated at the lower temperature treatments. From fertilization to 50% hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56% survival when incubated at 59.0°F (Kwain 1975).

As part of the Don Pedro Hydroelectric Project FERC relicensing process, the Districts conducted an *O. mykiss* Population Study (TID/MID 2014) for the Lower Tuolumne River below La Grange Diversion Dam. The goal of the study is to provide a quantitative population model to investigate the relative influences of various factors on the lifestage-specific production of *O. mykiss* in the Tuolumne River including water temperature effects on population response for specific in-river lifestages. The study noted that although no literature information could be identified regarding upper temperature limits for spawning initiation, maximum temperature limits for spawning are assumed to be on the order of 15°C (59°F) inferred from egg mortality thresholds for resident *O. mykiss* (Velsen 1987) as well as steelhead (Rombough 1988). Similarly, for egg incubation, the model allowed for a broad range of flow and water temperature conditions using the completed model, an initial acute mortality threshold of 15°C (59°F) was included based upon a literature review by Myrick and Cech (2001).

From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). Myrick and Cech (2001) similarly described water temperatures >59°F as "lethal" to incubating steelhead embryos, although FERC (1993) suggested that water temperatures exceeding 68°F were "stressful" to spawning steelhead and "lethal" when greater than 72°F.

Table 2. Steelhead Spawning and Embryo Incubation WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
46°F (7.8°C)	Orcutt *et al*. (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F.
52°F (11.1°C)	Rainbow trout from Mattighofen (Austria) had highest egg survival at 52.0°F compared to 45.0°F, 59.4°F, and 66.0°F (Humpesch 1985). Water temperatures from 48.0°F to 52.0°F are suitable for steelhead incubation and emergence in the American River and Clear Creek (NMFS 2000; NMFS 2001a; NMFS 2002a). Optimum water temperature range of 46.0°F to 52.0°F for steelhead spawning in the Central Valley (USFWS 1995b). Optimum water temperature range of 46.0°F to 52.1°F for steelhead spawning and 48.0°F to 52.1°F for steelhead egg incubation (Reclamation 1997a). Upper limit of preferred water temperature of 52.0°F for steelhead spawning and egg incubation (SWRCB 2003).
54°F (12.2°C)	Big Qualicum River steelhead eggs had 96.6% survival to hatch at 53.6°F (Rombough 1988). Highest survival from fertilization to hatch for *Salmo gairdneri* incubated at 53.6°F (Kamler and Kato 1983). Emergent fry were larger when North Santiam River (Oregon) winter steelhead eggs were incubated at 53.6°F than at 60.8°F (Redding and Schreck 1979). The upper optimal water temperature regime based on constant or acclimation water temperatures necessary to achieve full protection of steelhead is 51.8°F to 53.6°F (EPA 2001). From fertilization to hatch, rainbow trout eggs and larvae had 47.3% mortality (Timoshina 1972). Survival of rainbow trout eggs declined at water temperatures between 52.0 and 59.4°F (Humpesch 1985). The optimal constant incubation water temperature for steelhead occurs below 53.6°F (McCullough *et al.* 2001). A water temperature of 54°F (MWAT) was identified as the Upper Optimum Value for steelhead spawning and embryo incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
55°F (12.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning and egg incubation (EPA 2003b). Water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993).
57°F (13.9°C)	From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). A sharp decrease in survival was observed for rainbow trout embryos incubated above 57.2°F (Kamler and Kato 1983). A water temperature of 57°F (MWAT) was identified as the Upper Tolerable Value for steelhead spawning and embryo incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
59°F (15°C)	Based on egg mortality thresholds for steelhead, maximum temperature limits for spawning are assumed to be 59°F (Rombaugh 1988 as cited in TID/MID 2014). A water temperature of 59°F was identified as the initial acute mortality threshold for steelhead egg incubation (Myrick and Cech 2001 as cited in TID/MID 2014). From fertilization to 50% hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56% survival when incubated at 59.0°F (Kwain 1975).
60°F (15.6°C)	Water temperatures >59°F are described as "lethal" to incubating steelhead embryos (Myrick and Cech 2001), From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987).

Juvenile Rearing & Downstream Movement

Water temperature index values were developed to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages. Some steelhead may rear in freshwater for up to three years before emigrating as yearling+ smolts, whereas other individuals move downstream shortly after emergence as post- emergent fry, or rear in the river for several months and move downstream as juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals continue to rear and grow in downstream areas and undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are assessed in this Technical Memorandum using the fry and juvenile rearing WTI values.

The growth, survival, and successful smoltification of juvenile steelhead are controlled largely by water temperature. The duration of freshwater residence for juvenile steelhead is long relative to that of Chinook salmon, making the juvenile lifestage of steelhead more susceptible to the influences of water temperature, particularly during the over-summer rearing period. Central Valley juvenile steelhead have high growth rates at water temperatures in the mid-60°F range, but reportedly require lower water temperatures to successfully undergo the transformation to the smolt stage.

WTI values of 61°F, 63°F, 64°F, 65°F, 68°F, 72°F, 75°F, and 77°F were identified to represent a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead juvenile rearing (Table 3). A water temperature of 61°F (7DADM) was identified as the value for steelhead juvenile rearing for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 61°F (7DADM) for "salmon and trout" core juvenile rearing. The WTI value of 63°F was identified because Myrick and Cech (2001) describe 63°F as the "preferred" water temperature for wild juvenile steelhead, whereas "preferred" water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" juvenile rearing (EPA 2003b). 65°F was also identified as a WTI value because NMFS (2000; 2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the optimum water temperature range for juvenile growth (i.e., 59-66°F) (Myrick and Cech 2001), and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999). Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F WTI value.

Kaya *et al.* (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F. Cherry *et al.* (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech and Myrick (1999) and FERC (1993). Growth for 200 mm juvenile *O. mykiss* versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%) was evaluated. The average empirically derived percent of maximum consumption in the Middle Fork American Fork River was 50% (Hanson *et al.* 1997). Positive growth only occurs up to approximately 68°F. Because of the literature describing 68°F as both an upper preferred and an avoidance limit for juvenile *O. mykiss*, and because of the empirical fish population data and bioenergetics growth data, 68°F was identified as an upper tolerable WTI value.

A WTI value of 72°F was identified because symptoms of thermal stress in juvenile steelhead have been reported to arise at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen *et al.* 1994). Also, 72°F was identified as a WTI value because 71.6°F has been reported as an upper avoidance water temperature (Kaya *et al.* 1977) and an upper thermal tolerance water temperature (Ebersole *et al.* 2001) for juvenile rainbow trout. The WTI value of 75°F was identified because NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75°F (EPA 2002; NMFS 2001b). Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al.* 2000; McCullough 2001).

A swim tunnel study conducted on the Lower Tuolumne River (Verhille et al. 2016) generated high quality field data on the physiological performance of Tuolumne River *O. mykiss* acutely exposed to a temperature range of 13 to 25°C (55.4°F to 77°F). The data indicated that wild juvenile *O. mykiss* represents an exception to the expected based on the 7DADM criterion for juvenile rearing set out by EPA (2003b) for Pacific Northwest *O. mykiss*. The study recommended that a conservative upper aerobic performance limit of 71.6°F, instead of 64.4°F (EPA), be considered in re-determining a 7DADM for this population.

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified the UILT for *O. mykiss* juveniles has been estimated at 22.8–25.9ºC (73–79°F) (Threader and Houston 1983). In the model, an initial mortality threshold of 25°C (77°F) daily average temperature was identified for *O. mykiss* juveniles. Note also that both fry rearing and resident adult rearing lifestages of *O. mykiss* also had UILT values of 77°F to support the model.

For steelhead juvenile rearing, the Temperature Criteria Matrix identified 65°F for the Lower American River (Water Forum 2007); 61°F for the San Joaquin (CALFED 2009); and 65°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al.* 2012).

Table 3. Steelhead Juvenile Rearing WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
61°F (16.1°C)	A water temperature of 61°F (7DADM) was identified as the value for steelhead juvenile rearing for the San Joaquin River (CALFED 2009).
63°F (17.2°C)	Preferred water temperature for wild juvenile steelhead is reportedly 63°F, whereas preferred water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. Myrick and Cech (2001)
64°F (17.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" juvenile rearing (EPA 2003b).
65°F (18.3°C)	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). The final preferred water temperature for rainbow fingerlings was between 66.2 and 68°F (Cherry *et al.* 1977). Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). A water temperature of 65°F (daily average temperature) was identified as the value for steelhead juvenile rearing for the Lower American River (Water Forum 2007). A water temperature of 65°F (MWAT) was identified as the Upper Optimum Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry *et al.* 1977). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). FERC (1993) referred to 68°F as "stressful" to juvenile steelhead. Empirical fish population and water temperature data in the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon Rivers (Figure 4 of Bratovich *et al.* 2012) indicate a sharp reduction in O. *mykiss* population densities when temperatures exceed 68°F for greater than one week. Bioenergetics modeling of growth based on consumption (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above 68°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
72°F (22.2°C)	Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen *et al.* 1994). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole *et al.* 2001). A swim tunnel study conducted on the Lower Tuolumne recommended a conservative upper aerobic performance limit of 71.6°F for *O. mykiss* juvenile rearing (Verhille et al. 2016).
75°F (23.9°C)	The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (EPA 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole *et al.* 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al.* 2000; McCullough 2001).
77°F (25°C)	In the model associated with the Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014), an initial mortality threshold of 77°F daily average temperature was identified for *O. mykiss* juveniles.

Smolt Emigration

Laboratory data suggest that smoltification, and therefore successful emigration of steelhead smolts, is directly controlled by water temperature (Adams *et al.* 1975) (Table 4). WTI values of 52°F and 55°F were identified to evaluate the steelhead smolt emigration lifestage, because most literature on water temperature effects on steelhead smolting suggest that water temperatures less than 52°F (Adams *et al.*1975; Myrick and Cech 2001; Rich 1987a) or less than 55°F (EPA 2003a; McCullough *et al.* 2001; Wedemeyer *et al.* 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur. Adams *et al.* (1973) tested the effect of water temperature (43.7°F, 50.0°F, 59.0°F or 68.0°F) on the increase of gill microsomal Na^+-, K^+-stimulated ATPase activity associated with parr-smolt transformation in steelhead and found a two-fold increase in Na^+-, K^+-ATPase at 43.7 and 50.0°F, but no increase at 59.0°F or 68.0°F. In a subsequent study, the highest water temperature where a parr-smolt transformation occurred was at 52.3°F (Adams *et al.* 1975). The results of Adams *et al.* (1975) were reviewed in Myrick and Cech (2001) and Rich (1987b), which both recommended that water temperatures below 52.3°F are required to successfully complete the parr-smolt transformation. Further, Myrick and Cech (2001) suggest that water temperatures between 43-50°F are the "physiologically optimal" temperatures required during the parr-smolt transformation and necessary to maximize saltwater survival. The 52°F WTI value identified for the steelhead smolt emigration lifestage is the index value generally reported in the literature as the upper limit of the water temperature range that provides successful smolt transformation thermal conditions. Increasing levels of thermal stress to this lifestage may reportedly occur above the 52°F WTI value.

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead. They found ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by the EPA to provide temperature water quality standards for the protection of Northwest native salmon and trout, water temperatures greater than 54.5°F were identified as an impairment to smoltification for juvenile steelhead (EPA 2003b). Water temperatures are considered "unsuitable" for steelhead smolts at >59°F (Myrick and Cech 2001) and "lethal" at 77°F (FERC 1993).

For steelhead smolt emigration, the Temperature Criteria Matrix identified 57°F for the San Joaquin (CALFED 2009) and 52°F (Upper Optimum Value) and 55°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich et al. 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 57°F (7DADM) for steelhead smoltification.

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified an initial UILT mortality threshold of 77°F daily average temperature for *O. mykiss* smolts on the basis of literature reviews by Myrick and Cech (2001).

Table 4. Steelhead Smolt Emigration WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F (11.1°C)	Steelhead successfully smolt at water temperatures in the 43.7°F to 52.3°F range (Myrick and Cech 2001). Steelhead undergo the smolt transformation when reared in water temperatures below 52.3°F, but not at higher water temperatures (Adams *et al.* 1975). Optimum water temperature range for successful smoltification in young steelhead is 44.0°F to 52.3°F (Rich 1987a). A water temperature of 52°F (MWAT) was identified as the Upper Optimum Value for steelhead smolt emigration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
55°F (12.8°C)	ATPase activity was decreased and migration reduced for steelhead at water temperatures greater than or equal to 55.4°F (Zaugg and Wagner 1973). Water temperatures should be below 55.4°F at least 60 days prior to release of hatchery steelhead to prevent premature smolting and desmoltification (Wedemeyer *et al.* 1980). In winter steelhead, a temperature of 54.1°F is nearly the upper limit for smolting (McCullough *et al.* 2001; Zaugg and Wagner 1973). Water temperatures less than or equal to 54.5°F are suitable for emigrating juvenile steelhead (EPA 2003b). Water temperatures greater than 55°F prevent increases in ATPase activity in steelhead juveniles (Hoar 1988). Water temperatures greater than 56°F do not permit smoltification in summer steelhead (Zaugg *et al.* 1972). A water temperature of 55°F (MWAT) was identified as the Upper Tolerable Value for steelhead smolt emigration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
57°F (13.9°C)	A water temperature of 57°F (7DADM) was identified as the value for steelhead smolt emigration for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 57°F (7DADM) for steelhead smoltification (EPA 2003b).
59°F (15°C)	Yearling steelhead held at 43.7°F and transferred to 59°F had a substantial reduction in gill ATPase activity, indicating that physiological changes associated with smoltification were reversed (Wedemeyer *et al.* 1980).
77°F (25°C)	A water temperature of 77°F (daily average temperature) was identified as UILT mortality threshold for *O. mykiss* smolts (Myrick and Cech 2001 as cited in TID/MID 2014).

CHINOOK SALMON LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

It has been suggested that separate water temperatures standards should be developed for each run-type of Chinook salmon. For example, McCullough (1999) states that spring-run Chinook salmon immigrate in spring and spawn in 3rd to 5th order streams and, therefore, face different migration and adult holding temperature regimes than do summer- or fall-run Chinook salmon, which spawn in streams of 5th order or greater . However:(1) there is a general paucity of literature specific to each lifestage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the WTI values derived from all the literature pertaining to Chinook salmon for a particular lifestage will be sufficiently protective of that lifestage for each run-type; and (4) all run- types overlap in timing of adult immigration and holding and in some cases are not easily distinguished (Healey 1991). Information distinctly applicable to spring-run or fall-run Chinook salmon is identified where run-specific information is available.

Adult Immigration and Holding

The adult immigration and staging lifestages for fall-run Chinook salmon are evaluated together, because they are believed to not spend significant amounts of time after immigrating and prior to spawning. The adult immigration and holding lifestages are evaluated separately for spring-run Chinook salmon, because of the potential extended duration of holding after immigrating and prior to spawning.

The WTI values reflect a gradation of potential water temperature effects that range between those reported as “optimal” to those reported as “lethal” for adult Chinook salmon during upstream spawning migrations and holding. The WTI values identified for the Chinook salmon adult immigration and holding lifestage are 60°F, 61°F, 64°F, 65°F, 68°F and 70°F (Table 5). Although 56°F is referenced in the literature frequently as the upper “optimal” water temperature limit for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, Boles *et al.* (1988), Marine (1992), and NMFS (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for adult Chinook salmon immigration. However, Hinze (1959) is a study examining the effects of water temperature on incubating Chinook salmon eggs in the American River Basin. Further, water temperatures between 38-56°F are considered to represent the “observed range” for upstream migrating spring-run Chinook salmon (Bell 1986).

The lowest WTI value identified was 60°F because in a previous NMFS biological opinion for the proposed operation of the Central Valley Project (CVP) and State Water Project (SWP), 59°F to 60°F is reported as…“*The upper limit of the optimal temperature range for adults holding while eggs are maturing*” (NMFS 2000). Also, NMFS (1997b) states…“*Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F*". Oregon Department of Environmental Quality (ODEQ; 1995) reports that “*…many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F*.” Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b).

Ward and Kier (1999) designated temperatures <60.8°F as an “optimum” water temperature threshold for holding Battle Creek spring-run Chinook salmon. EPA (2003a) chose a holding value of 61°F (7DADM) based on laboratory data various assumptions regarding diel temperature fluctuations. The 61°F WTI value identified for the Chinook salmon adult immigration and holding lifestage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this lifestage may reportedly occur above the 61°F WTI value.

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 64°F (7DADM) for “salmon and trout” adult migration. A water temperature of 64°F (MWAT) was identified as the Upper Optimum Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al*. 2012).

An index value of 65°F was identified because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 65°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults that ranged from 63.5°F to 66.2°F. During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6 of Bratovich *et al.* 2012). Tracy McReynolds (pers. comm. October 2011) suggested that an upper tolerable holding temperature of 65°F was reasonable. A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

An index value of 68°F was identified because the Butte Creek data and the literature suggests that thermal stress at water temperatures greater than 68°F is pronounced, and severe adverse effects to immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1997; NMFS 1997b; Ward *et al.* 2004).
Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68°F (Marine 1992). Water temperatures of 68°F resulted in nearly 100% mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Water temperatures between 70-77°F are reported as the range of maximum temperatures for holding pool conditions used by spring-run Chinook salmon in the Sacramento-San Joaquin system (Moyle *et al*. 1995). Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al*. 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).
For spring-run Chinook salmon adult immigration, the Framework Temperature Criteria Matrix identified 64°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al*. 2012). For spring-run Chinook salmon adult holding, the Framework Temperature Criteria Matrix identified 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al.* 2012).

Table 5. Chinook Salmon Adult Immigration and Holding WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F (15.6°C)	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59°F to 60°F (NMFS 1997b). Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NMFS 2000). Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60°F (ODEQ 1995). Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b).
61°F (16.1°C)	A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon.
64°F (17.8°C)	A water temperature of 64°F (MWAT) was identified as the Upper Optimum Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" adult migration (EPA 2003b).
65°F (18.3°C)	Acceptable range for adults migrating upstream is from 57°F to 67°F (NMFS 1997b). Disease risk becomes high at water temperatures above 64.4°F (EPA 2003b). Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5°F to 66.2°F (Berman 1990). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6 of Bratovich *et al.* 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992). Water temperatures of 68°F resulted in nearly 100% mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
70°F (21.1°C)	Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al.* 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).

Spawning and Embryo Incubation

The adult spawning and embryo (i.e., eggs and alevins) incubation lifestages share one set of WTI values because spawning and embryonic survival and development typically are considered concurrently in the literature on the effects of water temperature. Spawning and incubation evaluations are conducted separately due to differences in their temporal distributions.

The WTI values identified for the Chinook salmon spawning and embryo incubation lifestages are 55°F, 56°F, 58°F, 60°F, and 62°F (Table 6). Anomalously, FERC (1993) refers to 50°F as the "optimum" water temperature for spawning and incubating Chinook salmon. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning, egg incubation, and fry emergence (EPA 2003b). A water temperature of 55°F (7DADM) was identified as the value for Chinook incubation for the San Joaquin River fall-run Chinook salmon (CALFED 2009).

Additionally, for the adult spawning lifestage, FERC (1993) reports "stressful" and "lethal" water temperatures occurring at >60°F and >70°F, respectively, whereas for incubating Chinook salmon embryos, water temperatures are considered to be "stressful" at <56°F or "lethal" at >60°F. Much literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. NMFS (1993b) reported that optimum water temperatures for egg development are between 43°F and 56°F. Similarly, Myrick and Cech (2001) reported the highest egg survival rates occur between water temperatures of 39-54°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. Bell (1986) recommends water temperatures ranging between 42-57°F for spawning Chinook salmon, and water temperatures between 41-58°F for incubating embryos. USFWS (1995a) reported a water temperature range of 41°F to 56°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. The preferred water temperature range for Chinook salmon egg incubation in the Sacramento River was suggested as 42°F to 56°F (NMFS 1997a). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NMFS (2002a) reported 56°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F WTI value identified for the Chinook salmon spawning and embryo incubation lifestage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this lifestage may reportedly occur above the 56°F WTI value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58°F. For example, (Reclamation Unpublished Work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs (1957) concluded constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002a) suggests 53°F to 58°F is the preferred water temperature range for Chinook salmon eggs and fry. The model associated with the Chinook Salmon Population Model Study (TID/MID 2013), established an initial acute egg/alevin mortality threshold of 58°F. A water temperature of 58°F (MWAT) was identified as the Upper Tolerable Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Johnson (1953) found consistently higher Chinook salmon egg losses resulted at water temperatures above 60°F than at lower temperatures. In order to protect late incubating Chinook salmon embryos and newly emerged fry NMFS (1993a) determined that a water temperature criterion of less than or equal to 60°F be maintained in the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. Seymour (1956) provides evidence that

100% mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60°F. For Chinook salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957), however, found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F/month). The Chinook Salmon Population Model (TID/MID 2013) established an initial estimate of 60.4°F as the upper limit for initiation of spawning (Groves and Chandler 1999); also interpreted as the temperature at which spawning habitat will be considered usable by spawners.

The literature largely agrees that 100% mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to about 62°F (Hinze 1959; Myrick and Cech 2003; Seymour 1956; USFWS 1999). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Geist *et al.* (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

For Chinook salmon spawning and incubation, the Framework Temperature Criteria Matrix identified 60°F or less (as early in October as possible) and 56°F or less (as early in November as possible) as water temperature targets for lower American River fall-run Chinook salmon (Water Forum 2007); 64°F (spawning) and 55°F (incubation) for San Joaquin fall-run Chinook salmon (CALFED 2009); 56°F for Shasta River winter and spring-run Chinook salmon (SWRCB 2016); and 56°F (Upper Optimum Value) and 58°F (Upper Tolerable Value) in the Yuba River Basin (Bratovich *et al*. 2012).

Table 6. Chinook Salmon Spawning and Embryo Incubation WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
55°F (12.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning, egg incubation, and fry emergence (EPA 2003b). A water temperature of 55°F (7DADM) was identified as the value for Chinook incubation for the San Joaquin River fall-run Chinook salmon (CALFED 2009).
56°F (13.3°C)	Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (Reclamation Unpublished Work). Optimum water temperatures for egg development are between 43°F and 56°F (NMFS 1993b). Upper value of the water temperature range (i.e., 41°F to 56°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS 1995b). Upper value of the range (i.e., 42°F to 56°F) given for the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS 1997a). Incubation temperatures above 56°F result in significantly higher alevin mortality (USFWS 1999). 56°F is the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River (NMFS 2002a). Water temperatures averaged 56.5°F during the week of fall-run Chinook salmon spawning initiation on the Snake River (Groves and Chandler 1999). A water temperature of 56°F or less (daily average temperature), as early in November as possible, was identified as the value for fall-run Chinook salmon spawning and incubation for the lower American River (Water Forum 2007). A water temperature of 56°F (daily average temperature) was identified as the value for Chinook spawning and incubation for the Shasta River winter- and spring-run Chinook (SWRCB 2016). A water temperature of 56°F (MWAT) was identified as the Upper Optimum Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
58°F (14.4°C)	Upper value of the range given for preferred water temperatures (i.e., 53°F to 58°F) for eggs and fry (NMFS 2002a). Constant egg incubation temperatures between 42.5°F and 57.5°F resulted in normal development (Combs and Burrows 1957). The natural rate of mortality for alevins occurs at 58°F or less (Reclamation Unpublished Work). The model associated with the Chinook Salmon Population Model Study, established an initial acute egg/alevin mortality threshold of 58°F (TID/MID 2013). A water temperature of 58°F (MWAT) was identified as the Upper Tolerable Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Index Value	Supporting Literature
60°F (15.6°C)	100% mortality can occur to late incubating Chinook salmon embryos (yolk-sac stage) if temperatures are 60°F or greater (Seymour 1956). An October 1 to October 31 water temperature criterion of less than or equal to 60°F in the Sacramento River from Keswick Dam to Bend Bridge has been determined for protection of late incubating larvae and newly emerged fry (NMFS 1993b). Mean weekly water temperature at first observed Chinook salmon spawning in the Columbia River was 59.5°F (Dauble and Watson 1997). Consistently higher egg losses resulted at water temperatures above 60°F than at lower temperatures (Johnson and Brice 1953). For Chinook Salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F/month). A water temperature of 60°F or less (daily average temperature), as early in October as possible, was identified as a target value for Chinook spawning and incubation for the lower American River fall-run Chinook (Water Forum 2007). The model associated with the Chinook Salmon Population Model Study (TID/MID 2013), established an initial estimate of 60.4°F as the upper limit for initiation of spawning (Groves and Chandler 1999).
62°F (16.7°C)	100% mortality of fertilized Chinook salmon eggs after 12 days at 62°F (Reclamation Unpublished Work). Incubation temperatures of 62ºF to 64°F appear to be the physiological limit for embryo development resulting in 80 to 100% mortality prior to emergence (USFWS 1999). 100% loss of eggs incubated at water temperatures above 62°F (Hinze 1959). 100% mortality occurs during yolk-sac stage when embryos are incubated at 62.5°F (Seymour 1956). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Geist *et al*. (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

Juvenile Rearing and Downstream Movement

WTI values were developed to evaluate the Chinook salmon rearing (fry and juvenile) and juvenile downstream movement lifestages. Some Chinook salmon juveniles, both fall-run and spring-run, move downstream shortly after emergence as post- emergent fry, or rear in the river for several months and move downstream as YOY juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are presented in this Technical Memorandum using the fry and juvenile rearing WTI values.

The WTI values of 60°F, 61°F, 64°F, 65°F, 68°F, 70°F,75°F, and 77°F were identified for the Chinook salmon juvenile rearing and downstream movement lifestage. The lowest index value of 60°F was identified because regulatory documents as well as several source studies, including ones conducted on Central Valley Chinook salmon fry and juveniles, report 60°F as an optimal water temperature for growth (Banks *et al.* 1971; Brett *et al.* 1982; Marine 1997; NMFS 1997b; NMFS 2000; NMFS 2001a; NMFS 2002; Rich 1987b) (Table 7). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but were not identified as index values, because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990b; Taylor 1990a). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

The 60°F WTI value identified for the Chinook salmon juvenile rearing and downstream movement lifestage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of spring-run Chinook salmon fry and fingerlings. NMFS (2002a) identified 60°F as the "preferred" water temperature for juvenile spring-run Chinook salmon in the Central Valley. Increasing levels of thermal stress to this lifestage may reportedly occur above the 60°F WTI value.

A water temperature of 61°F (7DADM) was identified as the value for Chinook juvenile rearing for the San Joaquin River (CALFED 2009). A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 61°F (7DADM; early year) for salmon juvenile rearing (EPA 2003b).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM; late year) for salmon juvenile rearing (EPA 2003b). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64°F are considered not ″properly functioning" by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64°F (EPA 2001). Optimal range for Chinook salmon survival and growth from 53°F to 64°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001).

The index value of 65°F was identified because it represents an intermediate value between 64°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (EPA 2003a; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987a). Conversely, numerous studies report that temperatures between 64.0°F and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett *et al.* 1982; Cech and Myrick 1999; Clarke and Shelbourn 1985; EPA 2003a; Myrick and Cech 2001; NMFS 2002; USFWS 1995b). Maximum growth of juvenile fall-run Chinook salmon has been reported to occur in the American River at water temperatures between 56-59°F (Rich 1987b) and in Nimbus Hatchery spring-run Chinook salmon at 66°F (Cech and Myrick 1999). Bioenergetics modeling of growth based on consumption for 100 mm juvenile Chinook salmon in the Middle Fork American River watershed indicates that growth likely does not occur above about 65°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook juvenile rearing for the Yuba Reintroduction

Assessment for both fall- and spring-run Chinook salmon (Bratovich *et al.* 2012).

A WTI value of 68°F was identified because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).

Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at temperatures close to 70.0°F and has been reported to be completely prohibited at 70.5°F (Brett *et al.* 1982; Marine 1997). No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ± 1.8°F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

75°F was identified as a WTI value because high levels of direct mortality to juvenile Chinook salmon reportedly result at this water temperature (Cech and Myrick 1999; Hanson 1991; Myrick and Cech 2001; Rich 1987b). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was identified because it was derived from experiments using Central Valley Chinook salmon and it is a more rigorous index value representing a more protective upper lethal water temperature level. Furthermore, the lethal level determined in Rich (1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan *et al.* 2000; McCullough *et al.* 2001; Myrick and Cech 2001). Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952; Orsi 1971), the Chinook Salmon Population Model (TID/MID 2013) identified an initial UILT mortality threshold of 77°F for Chinook salmon juveniles as a daily average water temperature. Note that the model also identified this same value for fry mortality.

Table 7. Chinook Salmon Juvenile Rearing and Downstream Movement WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F (15.6°C)	Optimum water temperature for Chinook salmon fry growth is between 55°F and 60°F (Seymour 1956). Water temperature range that produced optimum growth in juvenile Chinook salmon was between 54°F and 60°F (Rich 1987b). Water temperature criterion of less than or equal to 60°F for the protection of Sacramento River winter-run Chinook salmon from Keswick Dam to Bend Bridge (NMFS 1993b). Upper optimal water temperature limit of 61°F for Sacramento River fall-run Chinook salmon juvenile rearing (Marine 1997; Marine and Cech 2004). Upper water temperature limit of 60°F preferred for growth and development of spring-run Chinook salmon fry and fingerlings (NMFS 2000; NMFS 2002a). To protect salmon fry and juvenile Chinook salmon in the upper Sacramento River, daily average water temperatures should not exceed 60°F after September 30 (NMFS 1997b). A water temperature of 60°F appeared closest to the optimum for growth of fingerlings (Banks *et al.* 1971). Optimum growth of Nechako River Chinook salmon juveniles would occur at 59°F at a feeding level that is 60% of that required to satiate them (Brett *et al.* 1982). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
61°F (16.1°C)	A water temperature of 61°F (7DADM) was identified as the value for Chinook juvenile rearing for the San Joaquin River (CALFED 2009). A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 61°F (7DADM; early year) for salmon juvenile rearing (EPA 2003b).
64°F (17.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM; late year) for salmon juvenile rearing (EPA 2003b). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64°F are considered not ″properly functioning” by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64°F (EPA 2001). Optimal range for Chinook salmon survival and growth from 53°F to 64°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001).

Index Value	Supporting Literature
65°F (18.3°C)	Water temperatures between 45°F to 65°F are preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River (NMFS 2002a). Disease mortalities diminish at water temperatures below 65°F (Ordal and Pacha 1963). Fingerling Chinook salmon reared in water greater than 65°F contracted *C. columnaris* and exhibited high mortality (Johnson and Brice 1953). Water temperatures greater than 64.9°F identified as being stressful in the Columbia River Ecosystem (Independent Scientific Group 1996). Juvenile Chinook salmon have an optimum temperature for growth that appears to occur at about 66.2°F (Brett *et al.* 1982). Juvenile Chinook salmon reached a growth maximum at 66.2°F (Cech and Myrick 1999). Increased incidence of disease, reduced appetite, and reduced growth rates at 66.2 ± 1.4 °F (Rich 1987b). Bioenergetics modeling of growth based on consumption for 100 mm juvenile Chinook salmon in the Middle Fork American River watershed indicates that growth likely does not occur above about 65°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook salmon (Bratovich *et al.* 2012).
68°F (20°C)	Sacramento River juvenile Chinook salmon reared at water temperatures greater than or equal to 68°F suffer reductions in appetite and growth (Marine 1997; Marine and Cech 2004). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).
70°F (21.1°C)	No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ± 1.8 °F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
75°F (23.9°C)	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2°F was determined to be 100% lethal due to hyperactivity and disease (Rich 1987b; Zedonis and Newcomb 1997). Lethal temperature threshold for fall-run juvenile Chinook salmon between 74.3°F and 76.1°F (McCullough 1999). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan *et al.* 2000; McCullough *et al.* 2001; Myrick and Cech 2001).
77°F (25°C)	The model associated with the Chinook Salmon Population Model Study, established an initial UILT mortality threshold of 77°F (daily average temperatures) for Chinook salmon fry and juveniles (Brett 1952 and Orsi 1971, as cited in TID/MID 2013).

Smolt Emigration

Juvenile Chinook salmon that exhibit extended rearing in a riverine environment are assumed to undergo the smoltification process and volitionally emigrate from the river as smolts. WTI values of 57°F, 59°F, 63°F, 68°F 72°F, and 77°F were identified for the Chinook salmon smolt emigration lifestage (Table 8).

A water temperature of 57°F (7DADM) was identified as the value for Chinook smolt migration for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 59°F (7DADM; late year) for salmon smolts (EPA 2003b).

A WTI value of 63°F was identified because water temperatures at or below this value allow for successful transformation to the smolt stage, and water temperatures above this value may result in impaired smoltification indices, inhibition of smolt development, and decreased survival and successful smoltification of juvenile Chinook salmon. Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997; Zedonis and Newcomb 1997). 62.6°F was rounded and used to support an index value of 63°F. A water temperature of 63°F (MWAT) was identified as the Upper Optimum Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).

Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989). A WTI value of 68°F was identified because water temperatures above 68°F prohibit successful smoltification (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook smolt migration for the Yuba Reintroduction Assessment for spring-run Chinook salmon (Bratovich *et al*. 2012).

Support for an index value of 72°F is provided from a study conducted by (Baker *et al.* 1995) in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests a 95% confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5°F to 75.4°F. In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).

Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952), the Chinook Salmon Population Model (TID/MID 2013) identified an initial mortality threshold of 77°F for Chinook salmon smolts as a daily average water temperature.

Table 8. Chinook Salmon Smolt Emigration WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
57°F (13.9°C)	A water temperature of 57°F (7DADM) was identified as the value for Chinook smolt migration for the San Joaquin River (CALFED 2009).
59°F (15°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 59°F (7DADM; late year) for salmon smolts (EPA 2003b).
63°F (17.2°C)	Acceleration and inhibition of Sacramento River Chinook salmon smolt development reportedly may occur at water temperatures above 63°F (Marine 1997; Marine and Cech 2004). Laboratory evidence suggest that survival and smoltification become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997). Juvenile Chinook salmon growth was highest at 62.6°F (Clarke and Shelbourn 1985). A water temperature of 63°F (MWAT) was identified as the Upper Optimum Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).
68°F (20°C)	Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).
72°F (22.2°C)	In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).
77°F (25°C)	The model associated with the Chinook Salmon Population Model Study, established an initial mortality threshold of 77°F (daily average temperatures) for Chinook salmon smolts (Brett 1952 as cited in TID/MID 2013).

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	UOWTI	UTWTI	Incip Lethal WTI	Other WTI Values?	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fall-run Chinook Salmon																
Adult Upstream Migration																
Adult Spawning																
Egg Incubation and Fry Emergence																
In-River Rearing (Age 0+)																
Smolt Outmigration																
Spring-run Chinook Salmon																
Adult Upstream Migration																
Adult Holding																
Adult Spawning																
Egg Incubation and Fry Emergence																
Fry Rearing																
Juvenile Rearing and Downstream Movement																
Smolt Outmigration																
Steelhead																
Adult Upstream Migration																
Adult Spawning																
Egg Incubation and Fry Emergence																
Fry Rearing																
Juvenile Rearing and Downstream Movement																
Smolt Outmigration																

UOWTI = Upper Optimum Water Temperature Index
UTWTI = Upper Tolerance Water Temperature Index

January 2017

REARING JUVENILE STEELHEAD
WATER TEMPERATURE INDEX VALUES & BIOLOGICAL EFFECTS

In support of the Upper Tuolumne River Reintroduction Assessment Framework (Framework), the Turlock Irrigation District and Modesto Irrigation District (TID/MID, or the Districts) and licensing participants established a Water Temperature Subcommittee to investigate water temperature considerations pertinent to anadromous salmonid reintroduction opportunities in the Tuolumne River. On December 1, 2016, the Districts hosted the third subcommittee meeting, and in advance of the meeting distributed a comprehensive literature review[1] of regional and site-specific information to inform the selection of water temperature index (WTI) values to be used to evaluate water temperature-related reintroduction potential. The literature review identified lifestage-specific WTI values for Chinook salmon and steelhead.

Water temperature index values were identified to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages, separate from the smolt lifestage. WTI values of 61°F, 63°F, 64°F, 65°F, 68°F, 72°F, 75°F, and 77°F were identified from the literature to represent a gradation of potential water temperature effects ranging between suitable to lethal conditions for steelhead juvenile rearing (see Table, below). The WTI values are intended to serve as the basis for continued discussions by the Water Temperature Subcommittee to evaluate water temperature-related reintroduction potential.

John Wooster (National Marine Fisheries Service [NMFS]) provided some additional references for the literature review as well as Boughton et al. (2015), which was distributed ahead of the December 1, 2016 meeting. Mr. Wooster characterized Boughton et al. (2015) as the approach that the NMFS Science Center (Science Center) will likely use to evaluate temperature suitability in the Tuolumne River.

Boughton et al. (2015) developed thermal indicators of habitat suitability to evaluate how water temperature was likely to affect southern California juvenile steelhead. They reported that a day is "*thermally suitable*" if maximum daily temperature stays below 29°C (84.2°F) and mean daily temperature stays below 25°C (77°F).

However, Boughton et al. (2015) also reported that laboratory estimates of incipient lethal temperature (50% mortality after long exposure) vary across studies but average around 25°C (77°F). That has been supported by the Water Temperature Subcommittee literature review:

- Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a).
- NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75°F (EPA 2002; NMFS 2001b).

[1] References are available in the literature review summary document titled *Lifestage-Specific Water Temperature Biological Effects and Index Temperature Values*, prepared for the Upper Tuolumne River Reintroduction Assessment Framework Water Temperature Subcommittee, November 2016.

- Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001).

- The upper incipient lethal temperature (UILT) for juvenile *O. mykiss* (rainbow trout), based on numerous studies, is between 75-79°F (Sullivan et al. 2000; McCullough 2001).

- The lower Tuolumne River *O. mykiss* population study (TID/MID 2014) reported that the UILT for *O. mykiss* juveniles has been estimated at 22.8–25.9ºC (73–79°F) (Threader and Houston 1983).
    - In the model, an initial mortality threshold of 25°C (77°F) daily average temperature was identified for *O. mykiss* juveniles, and that the fry rearing lifestage of *O. mykiss* also had a UILT value of 77°F to support the model.

Boughton et al. (2015) also report that a day is "*thermally stressful*" if temperature rises above 21°C (69.8°F) at any time, with the daily stress intensity quantified as degree-hours above 21°C (69.8°F). They estimated thermal growth potential of juvenile steelhead using a bioenergetics model, within which growth rate depends on fish size and food availability, but generally peaks in the range of 15–17°C (59-62.6°F) and becomes negative at temperatures above 22–24°C (71.6 – 75.2°F).

DISCUSSION

At the December 1, 2016 Water Temperature Subcommittee meeting a discussion by subcommittee members focused on trying to gain additional understanding on how the NMFS Science Center proposes to apply Boughton et al. (2015) as the approach to evaluate water temperature suitability in the Tuolumne River for anadromous salmonid reintroduction considerations. John Wooster noted that in addition to Boughton et al. (2015) which studies steelhead on the Santa Ynez River, the Science Center has used this approach to study steelhead in the Bay area (Russian River) and that this memo should be available soon and this memo provides more detail about the modeling approach. In order for the subcommittee to further evaluate the application of this methodology, it would be valuable to review the Russian River memo as soon as it is available.

Regarding reintroduction potential:

- It would be particularly helpful to further understand the context in which a day could be considered "*thermally suitable*" if mean daily temperature stays below 25°C (77°F), the temperature identified as lethal, or as incipient lethal - by definition the temperature which results in 50% mortality to the exposed population.

- Although the concept of a "*stress index*" could be a useful approach to address gradation of thermal effect, it would be informative to discuss how "*stressful*" water temperatures ranging from 21°C (69.8°F) to 25°C (77°F) could be considered potentially suitable for reintroduction when growth rate reportedly becomes negative at temperatures exceeding 22–24°C (71.6 – 75.2°F).

Steelhead Juvenile Rearing WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
61°F (16.1°C)	A water temperature of 61°F (7DADM) was identified as the value for steelhead juvenile rearing for the San Joaquin River (CALFED 2009).
63°F (17.2°C)	Preferred water temperature for wild juvenile steelhead is reportedly 63°F, whereas preferred water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. Myrick and Cech (2001)
64°F (17.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" juvenile rearing (EPA 2003b).
65°F (18.3°C)	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). The final preferred water temperature for rainbow fingerlings was between 66.2 and 68°F (Cherry *et al.* 1977). Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). A water temperature of 65°F (daily average temperature) was identified as the value for steelhead juvenile rearing for the Lower American River (Water Forum 2007). A water temperature of 65°F (MWAT) was identified as the Upper Optimum Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry *et al.* 1977). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al*. 1977). FERC (1993) referred to 68°F as "stressful" to juvenile steelhead. Empirical fish population and water temperature data in the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon Rivers (Figure 4 of Bratovich *et al.* 2012) indicate a sharp reduction in O. *mykiss* population densities when temperatures exceed 68°F for greater than one week. Bioenergetics modeling of growth based on consumption (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above 68°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
72°F (22.2°C)	Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen *et al.* 1994). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole *et al.* 2001). A swim tunnel study conducted on the Lower Tuolumne recommended a conservative upper aerobic performance limit of 71.6°F for *O. mykiss* juvenile rearing (Verhille et al. 2016).
75°F (23.9°C)	The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (EPA 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole *et al.* 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al*. 2000; McCullough 2001).
77°F (25°C)	In the model associated with the Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014), an initial mortality threshold of 77°F daily average temperature was identified for *O. mykiss* juveniles.

La Grange Hydroelectric Project Licensing (FERC No. 14581)
Fish Passage Facilities Alternatives Assessment
Reintroduction Goals Subcommittee Meeting

Thursday, January 26, 2017
2:30 pm to 4:00 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	David Avila	Western Dairy Design
2	Allison Boucher	Tuolumne River Conservancy
3	David Boucher	Tuolumne River Conservancy
4	Steve Boyd	Turlock Irrigation District
5	Anna Brathwaite	Modesto Irrigation District
6	Larry Byrd	Modesto Irrigation District
7	Jean Castillo	National Marine Fisheries Service
8	Jesse Deason	HDR, consultant to the Districts
9	John Devine*	HDR, consultant to the Districts
10	Dana Ferreira	Office of U.S. Congressman Jeff Denham
11	Bill Foster	National Marine Fisheries Service
12	Art Godwin	Turlock Irrigation District
13	Andy Gordus	California Department of Fish and Wildlife
14	Kelsey Gowans	Modesto Irrigation District
15	Fred Kelly Grant	Fred Kelly Grant LTD
16	Chuck Hanson	Hanson Environmental, consultant to the Districts
17	Patrick Koepele*	Tuolumne River Trust
18	Bao Le	HDR, consultant to the Districts
19	Ellen Levin*	City and County of San Francisco
20	Lonnie Moore	Citizen
21	Gretchen Murphey	California Department of Fish and Wildlife
22	Bill Paris	Modesto Irrigation District
23	Bill Sears	City and County of San Francisco
24	Charles R. Shetvon	Citizen
25	Chris Shutes	California Sportfishing Protection Alliance
26	Josh Weimer	Turlock Irrigation District
27	Samantha Wookey	Modesto Irrigation District
28	John Wooster*	National Marine Fisheries Service
29	Ron Yoshiyama	City and County of San Francisco
30	Allen Zanker	Citizen

* Attended by phone.

On January 26, 2017, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the fourth Reintroduction Goals Subcommittee (Goals Subcommittee) meeting for the La Grange Hydroelectric Project (La Grange Project) Fish Passage Facilities Alternatives Assessment and Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials. This meeting began after the conclusion of the Water Temperature Subcommittee meeting, held earlier in the day. Notes from the Water Temperature Subcommittee meeting are available as a separate document.

Mr. Bao Le (HDR, consultant to the Districts) welcomed meeting attendees. Mr. Le said the Goals Subcommittee was formed to develop a reintroduction goals statement, under the rationale that to determine whether it is feasible to introduce fish into a system where they currently do not exist, it is important to first define what is trying to be achieved, and how success is defined and measured. At the previous Goals Subcommittee meeting, held on December 1, 2016, attendees reviewed a draft goals statement previously drafted and circulated by the Districts: *"Identify and evaluate, in collaboration with stakeholders, reasonable efforts which may enhance and assist in the recovery of ESA listed salmonids in the Central Valley."* Attendees discussed revisions to the statement as well as the use of corollary statements or objectives to provide detail about or clarify the goals statement. The Districts revised the goals statement per discussions at the December 1 meeting and circulated a new draft for review: *"Contribute to the recovery of ESA listed salmonids in the Central Valley by establishing viable populations in the Tuolumne River at fair and reasonable cost. Specific objectives consistent with the goal statement include the following:"*. Mr. Le said that since the revised goals statement was circulated to subcommittee members, one comment was received prior to the comment deadline of February 13, 2017. Mr. Le said Mr. John Buckley (Central Sierra Environmental Resource Center) said he was concerned with the language *fair and reasonable* because the term is subjective and hard to define. Mr. Le said the Districts prepared a response to Mr. Buckley's comment, which was circulated to the Goals Subcommittee prior to today's meeting (Attachment A).

Mr. John Devine (HDR) noted that Mr. Buckley was particularly concerned about using *fair* in the statement. Mr. Devine said it is the Districts' perspective that although *fair* is not something that can be measured, *fair* generally means *just* and *appropriate*. The Districts drafted the statement with the intent to represent the interests of a diverse group of individuals and organizations, and the Districts think using *fair* is appropriate. Mr. Lonnie Moore (citizen) said using *fair and reasonable* in the goals statement raises some concerns. Mr. Moore said using that term moves the goals statement away from the scientific and technical approach of the studies to a more philosophical approach. Mr. Moore said trying to determine what may be *fair and reasonable* brings up a new set of questions compared to the science-based approach to the goals statement. Mr. Moore said it is unlikely that all attendees could reach consensus that an action is *fair and reasonable*. Ms. Anna Brathwaite (Modesto Irrigation District [MID]) said she agrees that it will be difficult to achieve a consensus on whether something is *fair and reasonable*. Ms. Brathwaite said she agrees the term is not scientific and she appreciates feedback from attendees on the phrase.

Mr. Devine said he thinks individuals generally have a common understanding of what it means to say something is *fair and reasonable*. Mr. Devine said the goals statement is meant to represent a broad set of interests. *Fair and reasonable* provides for consideration of cost. Mr. Devine said if something has a very high cost, it should have a high probability of success. Mr. Devine said if something does not have a high probability of success, he thinks most people would question whether it is fair or reasonable to spend a lot of money on it. Mr. Moore said he thinks it is important to consider that what may be required to achieve success may not be reasonable to some people, so in some ways this is a philosophical issue. Mr. Moore said having the goals statement hinge on population requirements for viability as compared to what is fair and reasonable seems like two entirely different approaches. Mr. Moore said he is interested in continuing to participate in the Goals Subcommittee regardless of approach. Mr. Devine said the Recovery Plan and Lindley (2007) both contain narrative statements and judgment calls, neither of which can be captured solely using numbers.

Mr. Patrick Koepele (Tuolumne River Trust) said he agrees that cost should be a consideration in deciding whether or not to proceed with reintroduction. Mr. Koepele asked where in the process cost factors into the Fish Passage Facilities Alternatives Assessment. Mr. Koepele asked if the sequence is first a fish passage facility is designed and then cost is calculated, or if cost is first agreed upon, and then a facility is designed within that budget. Mr. Koepele said there appear to be two parts to the goals statement: one part is relevant to designing the fish passage facility and the other part is relevant to deciding whether or not to build it. Cost is a consideration for both. Mr. Koepele said he thinks the fish passage facility goal should be based on what is needed to recover ESA listed salmonids. Mr. Moore said he agreed with Mr. Koepele. Mr. Devine said the Districts believe the goal of the fish passage facility and the decision of whether or not to build it are one in the same, and cost considerations must be considered concurrently, and not in sequence. Mr. Devine said at the previous Goals Subcommittee meeting, Mr. Moore suggested that success be viewed from the lens of cost effectiveness. Mr. Devine said his response to Mr. Moore's comment was that it is just as hard to answer what is or is not cost effective. Mr. Devine said he thinks the amount of risk that comes with a project must also be considered concurrently. Mr. Devine said the reintroduction goals statement is meant to encompass all considerations, and at fair and reasonable cost. Mr. Devine said he does not think the term *cost benefit* adequately captures considerations such as the risk of the project and whether the project is affordable for those who have to pay for it. Mr. Devine said Anderson (2014), a paper authored by individuals at NMFS and Washington and Oregon fish and wildlife agencies, suggests that socioeconomic and economic considerations be a critical element of a decision about whether or not to reintroduce fish.

Mr. Moore asked if the technical studies must first be completed to determine whether the action is fair and reasonable. Mr. Devine replied that yes, the cost must be available in order to judge whether it is fair and reasonable, and calculating cost is dependent on completing the design of the facility, which in turn is dependent on run targets and other factors laid out in Technical Memorandum No. 1. Mr. Devine said in addition to the cost estimate based on the facility layout and design, project risk must also be assessed. Mr. Moore agreed with Mr. Devine's characterization and volunteered to lead the final study.

Mr. Le said the goals statement is meant to be a general overarching statement, while corollary statements or objectives will help to further define elements or phrases contained in the goals statement, such as what is meant by *fair and reasonable*. Mr. Le said he thinks that an appropriate next step of the Goals Subcommittee would be to develop corollary statements.

Mr. David Avila (Western Dairy Design) asked if there is a relationship between spawning and elevation, and whether spawning is better at higher elevations. Ms. Gretchen Murphey (California Department of Fish and Wildlife) said spawning is dependent on many factors, such as thermal suitability of the habitat and the species of fish. Ms. Murphey said fish spawn close to the dam. Mr. Avila asked if a study has been completed about whether the fish can all spawn below the dam. Ms. Murphey said that the spring-run Chinook population disappeared when the dam was built. Mr. Moore said elevation does not result in big differences to food availability or temperature, therefore elevation does not impact spawning.

Mr. Koepele said if the intent is to build a facility that gets a population over a certain threshold, it is already known that the facility must be at least a certain size and must do certain things. From there, one can determine the cost of the facility, and once the cost is known, a decision can be made. Mr. Koepele said the sequencing makes sense to him. Mr. Koepele asked if the task at hand is to design a facility that gets a population past a certain threshold in terms of contributions to recovery or is the task at hand to build a facility at a fair and reasonable cost, which may or may not contribute to recovery?

Mr. Bill Foster (National Marine Fisheries Service) said the goal should be to develop a viable population that would aid in the recovery of ESA listed species. Once the goal is known, various alternative methods, facilities, and procedures can be considered that would achieve the goal. A cost analysis can be performed for each alternative. From there, the least cost alternative is generally chosen. Mr. Foster said at this point, the Goals Subcommittee has a general goals statement, and cost will come into play at a certain point, but it is not apparent how the goal will be reached and what the alternatives will look like. Mr. Foster said collecting information on other fish passage facilities may help fill in some of the information gaps. Mr. Foster said this group must explore further how the goal can be achieved before it is time to consider cost.

Mr. Koepele asked if the design is driven by the goal to contribute to the recovery of ESA listed salmonids or if the design is driven by cost considerations. Mr. Koepele said cost is definitely part of the decision, but cost should not constrain the study. Mr. Devine said Technical Memorandum No. 1 provides a list of data gaps, such as population sizes and facility performance expectations, which must be filled because this information will influence the facility design. Mr. Le said cost considerations will not constrain the design.

Mr. Le said that instead of completing a stand alone fish passage engineering exercise, the purpose of the Framework is to take a more integrated approach to considering species reintroduction. In addition to fish passage engineering, such an approach would consider the goal of a reintroduction program, the ecological feasibility, and biological constraints, as well as the socioeconomic and regulatory ramifications of reintroduction. Mr. Le said this broader approach to identifying benefits, risks and constraints is consistent with recommendations in Anderson (2014). Mr. Le said the intent of the goals statement is to represent a diversity of interests and the corollary statements would add detail. Mr. Le said all attendees may not arrive at the same decision at the end, but it is important that everyone is working with the same information.

Mr. Chris Shutes (California Sportfishing Protection Alliance) said he does not think the Goals Subcommittee will make progress on whether or not the goals statement should include the phrase *fair and reasonable*. Mr. Shutes said Goals Subcommittee members generally fall into two groups: members who are more concerned about the cost and members who are more concerned about the impacts to fish. Mr. Shutes said what is fair and reasonable to him may not seem fair and reasonable to the person who is footing the bill. Mr. Shutes said he thinks the Goals Subcommittee should add more definition to the goals statement, which is the intent of the corollary statements, and should understand that there is discomfort on all sides because we all have different interests. Mr. Shutes said now that the concerns have been articulated, the group can acknowledge those concerns and move forward.

Ms. Dana Ferreira (Office of U.S. Congressman Jeff Denham) asked how a decision is ultimately made and whether she and the constituents from the 10th District will have a vote in the decision, given that they are the ones who will paying for it. Ms. Ferreira asked if it is fair to say it is unknown if reintroduction would be successful. Mr. Foster said he thinks what must be done first, in addition to drafting the goals statement, is to decide what information is needed and what types of ways have been tried in the past to develop a viable population. Mr. Foster said if a viable population is developed, there will be economic benefits to commercial fishing and recreation. Mr. Foster said once we have information about different types of facilities, then a cost analysis can proceed. Mr. Foster said because projects can vary greatly from one to another, they cannot always be directly compared. However, it is possible to estimate a ball park cost.

Mr. Le said cost considerations are just one component of the Framework. Mr. Le said he thinks corollary statements can be used to help better define elements of the goals statement. Mr. Shutes said while it is unknown what the overall cost for reintroduction might be, and it is also unknown what entities may end up paying for it. Mr. Shutes said it may be that funding becomes available from the federal government, state government and/or non-profit sources.

Mr. Shutes said there are still many biological questions left to be answered, and it is important that individuals remain patient, and not skip ahead to the end of the process. Mr. Larry Byrd (MID) said this timeline has already extended to seven years. Mr. Shutes said although the Don Pedro relicensing has been ongoing for many years, it was not until the La Grange licensing process began that discussions about fish passage began.

An individual said Mr. Foster made several good points and that the first step is to determine what information is needed. There is a cost associated with getting that information and determining what the alternatives are. The individual also said that in his work with the landowners he represents, coordination with the Districts and the county is a priority. Mr. Bill Paris (MID) said the information identification and gathering process has already begun. Mr. Paris said the Districts and NMFS have been conducting several studies in consultation with licensing participants in the upper Tuolumne River about gravel, temperature, and natural barriers to migration, among other topics. The Districts have also researched fish passage facilities at other projects. Mr. Paris said the fish passage research and the upper river studies are intended to provide information to support a study required by FERC to look at fish passage engineering. Mr. Paris said costs to complete these upper river studies are being absorbed by the Districts and NMFS, and to some extent by CCSF. Mr. Foster said the information gathering process is somewhat constrained by what FERC will allow in terms of schedule. Mr. Foster said there is a cost to relicensing, but this is different from the cost of implementing and managing a license. Mr. Paris said FERC ordered the Districts to complete a study of fish passage engineering, and the Framework process began as a means to give context to the engineering study. Mr. Paris said the Districts could have designed a fish passage facility, but it likely would have been too small or too large given that the biological context for the facility was unknown. Mr. Paris said that relates back to using *fair and reasonable* in the goals statement. Something may be fair and unreasonable, or reasonable but unfair, and the Districts want to make sure that as we move through the process, all licensing participants are on the same page.

Mr. Avila said unless the process includes addressing the 90 to 95 percent predation issue, reintroduction will not be feasible. Mr. Foster said predation is an important issue. Mr. Avila said 100 percent recovery may be achievable, but a project will not be viable until predation is addressed. Mr. Avila said there are thousands of trout in the Stanislaus River that are not normally in the river, and they are contributing to predation issues on that river. Mr. Le said predation is one consideration of the biological and ecological component of the Framework. Mr. Foster asked if predation is a line item that will be addressed. Mr. Le said the upper river studies are not looking at predation, but predation in the lower Tuolumne River was studied during the Don Pedro relicensing. Mr. Le said predation is not a line item insomuch as an issue that will affect whether a fish passage project can be successful. Mr. Moore said studies about predation have been completed, but they do not address how to correct the problem. Mr. Moore said changes to regulations may be part of the solution. He also said that predation is an issue in the Tuolumne River, the San Joaquin River, and the Delta.

Mr. Le said the studies being implemented by the Districts are meant to evaluate the baseline conditions. Because predation is part of the baseline condition, it will be considered as part of evaluating the feasibility of reintroduction. Mr. Le said the intent of the Framework process is not to solve the predation problem, but to ensure predation is considered as a factor that constrains whether or not a reintroduction program can be successful. Mr. Devine said the Reservoir Transit Study will look at predation in Don Pedro Reservoir. Test fish were unavailable to complete the study in 2017, so the Districts will look to complete the study in 2018 if necessary. Mr. Foster said the mandate from NMFS is to put terms and conditions forward that will protect the species. Mr. Foster said existing issues like predation do not present favorable conditions, and NMFS' terms and conditions will try to address as many of those types of issues as possible.

Mr. Moore asked if there is wording from the ESA documents that could be used to draft corollary statements. Mr. Le said that the Districts agree that those types of documents may have language relevant to incorporate here as corollary statements. Mr. Moore asked if the documents are available on the licensing website. Mr. Devine said the documents are online and he will provide a link.

Mr. Le said feedback received previously by the Districts indicates that many licensing participants believe the goal should be tied to recovery. The goals statement includes the phrase *contribute to the recovery of ESA listed salmonids*. Mr. Le asked what meeting attendees think is meant by that phrase. Mr. Le asked meeting attendees to share their thoughts on what is meant by a *viable population*.

Mr. Moore said one of the studies the Districts are implementing voluntarily is about socioeconomics. Mr. Moore said he spoke to the study lead early on in the study, but he has not heard anything recently on the status of the study. Mr. Le confirmed the study is ongoing. Mr. Moore recommended that a local person be allowed to participate in the study. Ms. Murphey asked if the study will be discussed in the Updated Study Report (USR). Mr. Le said the USR includes a status update on the study. Mr. Devine said the Districts completed a socioeconomic study for the Don Pedro Project relicensing, the report for which is available online. The study included a tremendous amount of local input. Mr. Le said he will send Mr. Moore a link to the report.

Mr. Byrd asked if *recovery* means the same thing as *reintroduction*. Mr. Foster said *reintroduction* refers to placing fish above a dam into historical habitat whereas *recovery* refers to achieving a sufficient population size so that the species may be removed from the ESA list. Mr. Foster said recovery is best achieved by improving habitat conditions below the dam and getting fish upstream of the dam to areas that were used historically but are now blocked from access. Mr. Foster said part of recovery planning is evaluating the upstream habitat because you do not want to build a bridge to nowhere. It is important to know what conditions exist in the habitat upstream to gauge if reintroduction will be successful.

Ms. Ferreira said that a newspaper article dating back to the 1800s is often cited as evidence of the historical existence of spring-run Chinook in the upper river. Mr. Moore summarized a paper he produced recently for the Framework process about the historical existence of each of the three target species in the Tuolumne River. Meeting attendees discussed the validity of the source materials cited in Mr. Moore's paper. Dr. Ron Yoshiyama (City and County of San Francisco) said while there is no definitive information about the existence of spring-run Chinook in the Tuolumne River, circumstantial evidence suggests spring-run Chinook did exist in the river. Dr. Yoshiyama summarized the evidence. Mr. Byrd and others discussed the appropriateness of implementing studies on spring-run Chinook when it is unknown if the species ever existed in the Tuolumne River.

Ms. Allison Boucher (Tuolumne River Conservancy) requested someone summarize how the Framework process fits into the FERC licensing process. Mr. Paris said as part of the La Grange Project licensing process, the Districts were directed by FERC to complete a set of studies. One study is about fish passage engineering. The Goals Subcommittee is part of the Framework process, which is an effort to provide site-specific context to the engineering design. Ms. Boucher asked if these meetings are an effort to ensure that the engineering study has input from the public. Mr. Paris said that is correct; public input is one facet of the meetings. Mr. Paris said a goal of ensuring public input now is to limit disagreement from licensing participants when the engineering draft study report is out for comment.

Mr. Le asked if meeting attendees are okay with leaving the goals statement as-is for now, and moving forward on developing corollary statements. Mr. Le said the purpose of the list of questions in the document entitled *Tuolumne River Reintroduction Goals Statement and Discussion of Corollary Objectives* is to generate discussion on corollary statements.

Dr. Chuck Hanson (Hanson Environmental, consultant to the Districts) said as part of the NMFS' responsibility for protecting and managing salmonids, the agency undertook a process to develop a recovery plan for listed salmonids. NMFS formed a Technical Recovery Team, a collaborative group of scientists with the goal to give NMFS some guidance on approach, criteria, and other elements that should be embedded in the recovery plan and a recovery effort. The Technical Recovery Team assembled information from reintroduction programs in the Pacific Northwest and added some research from California. This information synthesis culminated in Lindley (2007). NMFS took that guidance and developed a draft of the Recovery Plan. The draft Recovery Plan was circulated for public review and then finalized. The final Recovery Plan describes the characteristics necessary of a habitat and population to contribute to the recovery of a species. Mr. Foster said the NMFS Recovery Plan has two phases; one phase is to stabilize the downstream population and the second phase is to establish a new viable population upstream of the dam. Mr. Foster said every five years, NMFS will evaluate a listed species of interest to see if the species is still in peril or if the species has improved. The hope is that after a number of years, the species can be removed from the ESA list. Mr. Foster said improving fish populations will result in benefits to other species a well.

Dr. Hanson said Lindley (2007) uses numeric criteria to quantify population viability, which is a key component of recovery. Other academic papers about recovery use a population viability assessment, in which a life cycle model of a species is developed to determine the probability that a species will go extinct in 100 years. A probability of less than five percent is desirable. Other academics utilize cohort replacement rate as a benchmark, where the average rate must be greater than one. Dr. Hanson summarized other benchmarks. Dr. Hanson said the Goals Subcommittee can use benchmarks such as these as a bridge to determine what a viable population is and what is needed to contribute to recovery. As we move through this process, the study analyses and results can be weighed against corollary statements that are representative of the reintroduction goal. Developing specific corollary statements now will help clarify how study information will be used later on.

Mr. Foster said the Recovery Plan also mentions various threats and stressors to populations, including the elimination of historical habitat due to dam construction. Dr. Hanson said the construction of dams is one stressor among many, including land use changes and predation. Dr. Hanson said all these conditions must be considered with regards to species recovery.

Mr. Avila asked what section of the Recovery Plan covers 95 percent mortality due to predation. Dr. Hanson said the Recovery Plan includes a series of tables that identify various stressors. The tables are organized geographically. In addition, there are several studies that look at the survival of juvenile salmonids in response to different conditions. Dr. Hanson said 95 percent mortality is what was observed in the San Joaquin River. Dr. Hanson said the NMFS Science Center has also looked at the issue of predation. Advances in technology now allow us to pinpoint where mortality occurs in a river. Dr. Hanson summarized how population dynamics, including hybridization, and environmental conditions have changed over time to result in the current survival numbers. Mr. Avila said hybridization is a natural process that would be very expensive to stop. Dr. Hanson said hybridization does occur naturally, but not at the rates that are currently occurring. Dr. Hanson reviewed factors that may contribute to the high rate of hybridization. Mr. Avila said by preventing hybridization from occurring, it may be that a species is prevented from developing resiliency to current conditions. Mr. Avila recommended that hybridization be allowed to occur naturally.

Dr. Hanson and others discussed fall-run Chinook life history diversity and current sources of data on fall-run Chinook escapement. Mr. Shutes and Ms. Murphey said they will work together to post data that CDFW has on this topic.

Mr. Le said the questions in the *Tuolumne River Reintroduction Goals Statement and Discussion of Corollary Objectives* document are based on the Reintroduction Decision Framework Integrated Decision Tree and are broken out into various sections, consistent with ecological/biological, technical engineering, and socioeconomic and regulatory questions. Mr. Le reviewed some of the questions. Mr. Le said the Districts would like meeting attendees to review the questions and provide input. He said any input would be appreciated and that subcommittee processes needed to make more progress in order to support the Framework within the allowable schedule. Mr. Shutes and Mr. Le discussed how discussing and developing answers to these questions could be used to create corollary statements. Mr. Le said the Districts would like any input or feedback on the list of questions and corollary statements by Friday, February 17, 2017.

Ms. Murphey said debris is an issue that must be addressed when considering a juvenile fish collection facility. Mr. Le said that issue is considered in Technical Memorandum No. 1.

Mr. Allen Zanker (private citizen) said it would be helpful if a public meeting was held to discuss initial solutions to some of the issues discussed, such as river restoration. It would be good to hear from some of the local companies to find out how much it may cost to complete some of this restoration work. Mr. Zanker said his family and company support the restoration effort. His family is from La Grange and they have property in the area. His company sells gravel and sand that may be helpful in completing river restoration and spawning gravel projects. Mr. Zanker said he is very familiar with the area and knows which areas provide the best opportunity for restoration at the lowest cost. Ms. Boucher said regarding river restoration projects, it is preferable to use rock from the local watershed, as fish prefer to use local rock.

The meeting adjourned.

Action Items

1. HDR will provide a link to where ESA documents relevant to drafting corollary statements are available online.

2. HDR will provide a link to the Don Pedro Project relicensing Socioeconomics Study Report.

3. Mr. Shutes and Ms. Murphey will provide CDFW data on fall-run Chinook escapement numbers.

4. Goals Subcommittee members will provide input or feedback on the list of questions in the *Tuolumne River Reintroduction Goals Statement and Discussion of Corollary Objectives* document and input and feedback on corollary statements by Friday, February 17, 2017.

REINTRODUCTION GOALS SUBCOMMITTEE MEETING
THURSDAY, JANUARY 26, 2017
MEETING NOTES

ATTACHMENT A

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Water Temperature/Reintroduction Goals Subcommittees – In-person Meeting

Thursday, January 26, 2017, 1:00 pm to 4:00 pm
Modesto Irrigation District
1231 11th St., Modesto, CA 95354

By Phone - Conference Line: 1-866-583-7984; Passcode: 814-0607

Meeting Objectives:

1. Review and discuss updated water temperature information based upon comments received.
2. Continue discussion of Boughton et al. approach in relation to current Updated Literature Review Summary.
3. Discuss next steps and schedule for WTI selection (Water Temperature Working Document).
4. Review and discuss comments received on draft narrative reintroduction goals statement and finalize statement.
5. Discuss developing objective/corollary statements in support of a reintroduction goals statement.

TIME	TOPIC
1:00 pm – 1:10 pm	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
1:10 pm – 2:30 pm	Water Temperature Subcommittee Topics (All) a. Updated Literature Review Summary – comments received (Districts) b. Boughton approach as applied to Updated Literature Review Summary (Districts) c. Water Temperature Working Document – discussion (All)
2:30 pm – 3:50 pm	Reintroduction Goals Subcommittee Topics (All) a. Additional discussion on current draft narrative reintroduction goals statement – comments received and finalization (All) b. Subcommittee discussion of further development of objective/corollary statements to support narrative goal statement (All)
3:50 pm – 4:00 pm	Next Steps (All) a. Schedule next call and agenda topics b. Action items from this call

PRELIMINARY DRAFT – FOR DISCUSSION PURPOSES ONLY
TUOLUMNE RIVER REINTRODUCTION GOALS STATEMENT AND DISCUSSION OF COROLLARY OBJECTIVES

Per discussions at the December 1, 2016 joint subcommittee meeting, the updated draft Tuolumne River reintroduction goals narrative statement is as follows:

"*Contribute to the recovery of ESA listed salmonids in the Central Valley by establishing viable populations in the Tuolumne River at fair and reasonable cost.*

Specific objectives consistent with the goal statement include the following:"

As discussed by the Reintroduction Goals Subcommittee, the narrative goal statement is intended to be a high level statement that represents the diverse interests of subcommittee participants. The development of additional objective/corollary statements to further define the narrative goal statement may be appropriate to clarify the overarching reintroduction goal statement. Ultimately, the Tuolumne River reintroduction goal statement and associated objectives are intended to guide the Reintroduction Assessment Framework and evaluation of reintroduction feasibility in the Tuolumne River. Below is an initial set of comments and/or questions to facilitate subcommittee discussions toward the development of objective/corollary statements:

"Contribute to the recovery of ESA listed salmonids…"

It has been suggested that goals and objectives for the Tuolumne River reintroduction assessment should be consistent and conform to the NMFS 2014 Recovery Plan for the Central Valley salmonids.

The excerpts provided below are from NMFS 2014 Recovery Plan for background:

- *Recovery of winter-run Chinook salmon, spring-run Chinook salmon, and steelhead across such a vast and altered ecosystem as the Central Valley will require a broadly focused, science-based strategy. The scientific rationale for the strategy in this plan focuses on two key salmonid conservation principles. The first is that functioning, diverse, and interconnected habitats are necessary for a species to be viable. That is, salmon and steelhead recovery cannot be achieved without providing sufficient habitat. The second salmonid conservation principle guiding the recovery strategy is that a species' viability is determined by its spatial structure, diversity, productivity, and abundance (McElhany et al. 2000).* (p 6-2 to 6-3)

- *Population-level criteria are used to determine whether a population is viable or not. A viable population is one with a low extinction risk in the wild over the long-term* (McElhany et al. 2000).

- *The Central Valley Technical Recovery Team (TRT) incorporated the four Viable Salmonid Population (VSP) parameters into [two] assessments of population viability (p 92)… The second set of criteria are simpler and do not require Population Viability Analysis (PVA) modeling results. These simpler extinction risk criteria are <u>the basis of the population-level recovery criteria used in this Recovery Plan, with the low extinction risk levels defining what constitutes a viable population</u>*. (p 93)

- *Census size (N) can be used if direct estimates of effective population size are not available. Census size is estimated as the product of the mean run size and the average generation time.* (p 93)

Questions/Discussion Topics:

1. Should "viable population with low extinction risk" as defined by the Recovery Plan serve as the basis to support development of objective statements to better define success of a reintroduction program?
2. Which is preferred if both sources of information are available --census size or effective population size? Would "census size" concept be similar to the abundance objectives associated with low extinction risk as defined for the Yuba River (assumed an average generation time of 3 years for spring run Chinook salmon resulting in a mean of 833 fish per year)?
3. How are factors outside of the reintroduction area accounted for in the reintroduction objectives? Is the objective to provide access to suitable habitat as compared to abundance of returning spawners?
4. How does one establish a cohort replacement rate (CRR)?
5. How is stock origin considered?
6. How is the influence of hatchery origin fish considered in the definition of low extinction risk?
7. Can the same application of "viable population with low extinction risk" be applied to both spring run Chinook and steelhead? What about fall-run Chinook?
8. How are rainbow trout considered in recovery since they may give rise to steelhead?
9. Confirm Tuolumne River steelhead would be considered a single population.
10. Rainbow trout occur both above and below Don Pedro Dam. It appears that rainbow trout below La Grange with access to the sea do not choose to migrate. Would providing more habitat be expected to result in more migration?
11. How is climate change considered in the evaluation of reintroduction feasibility and recovery?

<u>Cost of Reintroduction (Socioeconomic)</u>

Excerpts identified from the peer-reviewed journal article "Planning Pacific Salmon and Steelhead Reintroductions Aimed at Long-term Viability and Recovery" (Anderson et al. 2014) from NMFS Northwest Fisheries Science Center and colleagues:

- "*…despite considerable cost and effort, reintroduction efforts often fail to establish self-sustaining populations…..*"

- "*….socioeconomic cost-benefit analysis will be crucial for policy decisions regarding large-scale restoration projects.*"

- "*It is also important to remember that reintroduction is only one management option. In some cases, reintroduction may be essential for the conservation of a particular life history type or evolutionary lineage. In other cases, management strategies designed to improve the reproductive success, survival, and productivity of extant populations might offer a better return on the investment dollar than reintroduction.*"

NMFS acknowledges that cost considerations are critical when making decisions as to whether and how to undertake a reintroduction program. When evaluating a river basin or reach of river for possible reintroduction, the Recovery Plan states, "Due to the uncertainty of future budgets, priority will be given to measures that, once implemented, are self-sustaining. In cases in which necessary actions will need maintenance (e.g., reintroductions into habitat upstream of impassible dams), priority will be given to options that need the least intervention in the long term."

Questions/Discussion Topics:

1. What does "fair and reasonable" mean to participants? Are there existing methods or approaches to evaluate thresholds that might define "fair and reasonable"?
2. How are costs considered? What are metrics of economic feasibility?
3. Have other participants implemented cost-benefit approaches for large scale restoration, reintroduction or recovery programs/projects? If so, what?
4. What are elements that would inform cost analysis (e.g., foregone benefits such as water use, hydropower, existing recreation uses [reservoir recreation, angling, whitewater boating, etc.], fish passage infrastructure, other)?
5. What are elements that would inform benefit analysis? (e.g., Increased revenue associated with fishing, changes in tourism (visitor use days), other?)
6. Should consideration of cost-benefit occur by species?

Technical Feasibility of Fish Passage

If reintroduction to the upper Tuolumne River were to occur, both upstream and downstream fish passage structures/programs would likely need to be developed to support this action.

Questions/Discussion Topics:

1. Are objective statements needed to describe the need for a technically feasible alternative for both an upstream and downstream fish passage alternative?

Regulatory Feasibility of Fish Passage

Reintroduction in the Tuolumne River could be influenced by the regulatory context at a broader regional scale given the affected action area may involve public and private lands that are associated with a diverse array of entities (with jurisdictional authority) and/or management plans.

1. How to manage introduction of ESA listed species? Public and priority land uses surrounding the watershed may have additional regulatory obligations based on the status of species introduced? Is "take" a concern or would these populations be considered experimental, non-essential?
2. What are the potential impacts to existing management priorities (BLM, USFS, CDFW, etc.) with ESA listed species introductions (e.g., game fish vs. listed fish, impacts of recreation, etc.)?
3. Are there concerns/limitations with an action in the Wild & Scenic Area (construction of infrastructure, operation and maintenance activities, etc.)? The Clavey Designated Wild and Heritage Trout waters?
4. Does regulatory compliance need to be at best supportive of, and at the very least not inconsistent with, the goals and objectives of existing regulatory requirements in the action area? How do we identify (and address) conflicting state and federal agency goals for species, e.g., Chinook vs. steelhead?

TID/MID Response to Comments on the Reintroduction Goals Statement[1]

Comment No.	Organization / Source	Comment	Response
1.	CSERC (John Buckley) 12/22/16 email	As a participant in the past in settlement discussions and the development of FERC licensing conditions, I believe that wording definitely matters to the success of a process. The updated draft narrative goal statement contains two words that are nebulous, non-measurable, and subjective. The word "reasonable" may at least have some broad consensus in that if measures result in costs that are staggering compared to the expected beneficial outcome, most FERC participants may generally agree that such measures are not "reasonable." But the inclusion of the word "fair" in any goal statement is not appropriate. It is unlikely there will ever be strong, broad agreement from all the participating interests as to how to define "fair" when it comes to the cost of reaching goals or implementing measures. This e-mail communication is simply intended to be helpful, and I can "live with" and accept whatever generalized draft narrative goal statement that the subcommittee selects. But as the FERC process unfolds, any choice to include highly subjective wording that can mean completely different things to different parties will not be helpful to the process.	The word "fair", is not only appropriate, but necessary to include. The idea of its inclusion is precisely because it has a different meaning to different people, and for everyone to hear what it means to different participants. Not every word in a broad "goals statement" has to have a scientific definition. "Fair", according to Webster, means "just" or "according to the rules". So exactly what rules apply here? The Districts look forward to further discussion on this topic. In addition, the subcommittee has discussed the development of more specific objective (corollary) statements that could support this broader goals statement. Development of these specific objective statements would be intended to further clarify elements of the goal statement.

[1] Per discussions at the December 1, 2016 joint subcommittee meeting, an updated draft Tuolumne River reintroduction goals narrative goal statement is as follows: *"Contribute to the recovery of ESA listed salmonids in the Central Valley by establishing viable populations in the Tuolumne River at fair and reasonable cost. Specific objectives consistent with the goal statement include the following:"*

LA GRANGE HYDROELECTRIC PROJECT
FERC NO. 14581

REINTRODUCTION ASSESSMENT FRAMEWORK
PLENARY GROUP MEETING

MAY 18, 2017

FINAL MEETING NOTES AND MATERIALS

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La Grange Hydroelectric Project Licensing (FERC No. 14581)
Reintroduction Assessment Framework
Plenary Group Meeting

Thursday, May 18, 2017
9:00 am to 12:00 pm

Final Meeting Notes

Meeting Attendees		
No.	**Name**	**Organization**
1	Jenna Borovansky	HDR, consultant to the Districts
2	Allison Boucher	Tuolumne River Conservancy
3	David Boucher	Tuolumne River Conservancy
4	Steve Boyd	Turlock Irrigation District
5	Anna Brathwaite	Modesto Irrigation District
6	John Buckley	Central Sierra Environmental Resource Center
7	Larry Byrd	Modesto Irrigation District
8	Jean Castillo*	National Marine Fisheries Service
9	Jesse Deason	HDR, consultant to the Districts
10	John Devine	HDR, consultant to the Districts
11	Peter Drekmeier	Tuolumne River Trust
12	Dana Ferreira	Office of U.S. Congressman Jeff Denham
13	Bill Foster	National Marine Fisheries Service
14	Art Godwin	Turlock Irrigation District
15	Andy Gordus	California Department of Fish and Wildlife
16	Kelsey Gowans	Modesto Irrigation District
17	Chuck Hanson	Hanson Environmental
18	Chase Hildeburn	State Water Resources Control Board
19	Laura Johnson	HDR, consultant to the Districts
20	Jonathan Knapp*	City and County of San Francisco
21	Meg Layhee	Central Sierra Environmental Resource Center
22	Bao Le	HDR, consultant to the Districts
23	Ellen Levin*	City and County of San Francisco
24	Jim McCoy	Don Pedro Recreation Agency
25	Lonnie Moore	Private citizen
26	Gretchen Murphey	California Department of Fish and Wildlife
27	Bill Paris	Modesto Irrigation District
28	Greg Salyer	Modesto Irrigation District
29	Bill Sears*	City and County of San Francisco
30	Chris Shutes	California Sportfishing Protection Alliance
31	Josh Weimer	Turlock Irrigation District
32	Michelle Williams	Modesto Irrigation District
33	Samantha Wookey	Modesto Irrigation District
34	Ron Yoshiyama	City and County of San Francisco
35	Allan Zanker	Private citizen

* Attended by phone.

On May 18, 2017, Turlock Irrigation District and Modesto Irrigation District (collectively, the Districts) hosted the Upper Tuolumne River Fish Reintroduction Assessment Framework (Framework) Plenary Group meeting (Workshop No. 6). This document summarizes discussions during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document provides meeting materials.

Mr. John Devine (HDR, consultant to the Districts) welcomed meeting attendees and reviewed the meeting objectives. Mr. Devine said this meeting has three objectives: (1) present the final results of the Reintroduction Goals Subcommittee (Goals Subcommittee) and the Water Temperature Subcommittee (Temperature Subcommittee) to the Plenary Group; (2) review and discuss the current status of the Districts' voluntary studies; and (3) review and discuss the current status of studies being completed by the National Marine Fisheries Service (NMFS). Mr. Devine asked if there are any comments on the agenda. Ms. Dana Ferreira (Office of U.S. Congressman Jeff Denham) said she needed to leave today's meeting early and requested that NMFS provide their update first.

Mr. Bill Foster (NMFS) said prior to this meeting he emailed the Districts a status update on the NMFS studies (Attachment B). Mr. Foster said in about a month NMFS anticipates that completed "non-public" draft reports for each study will be ready for internal review. Mr. Foster said each report must first undergo internal NMFS review before it can be released to the public. Ms. Ferreira asked when will these reports be available to the public. Mr. Foster said he will let this group know well in advance when the reports may be available for public review.

Ms. Ferreira asked why NMFS is conducting a study on fish passage feasibility, given that the Districts are already completing a study on the same topic (requested by NMFS as part of the La Grange Hydroelectric Project [La Grange Project] FERC licensing process). Mr. Foster said NMFS decided to hire a consultant to collect information on fish passage feasibility. He said NMFS often will complete a fish passage feasibility study as part of a relicensing process. Mr. Foster said he only recently became involved in the La Grange Project licensing process and he believes the NMFS Fish Passage Engineering Study is meant to collect information that has not been collected before.

Ms. Ferreira asked what is the cost of the NMFS Fish Passage Engineering Study. Mr. Foster said he did not know the cost of the study offhand. He said NMFS offices across the nation draw upon one large pool of funds to complete various studies. Mr. Foster said he will talk to his supervisor and provide the cost information. Ms. Ferreira asked if money has already been allocated to the study. Mr. Foster said money has been allocated to the study and the study is underway.

Ms. Ferreira asked who was hired to conduct the NMFS Fish Passage Engineering Study. Mr. Foster said a consulting firm, Anchor QEA (Anchor), is conducting the study. Mr. Foster said the NMFS Science Center is completing the other two NMFS studies. Ms. Ferreira asked if the results of those studies will be shared with the Plenary Group. Mr. Foster said the point of doing the studies is to be able to share the data. When the internal review process is complete, the results can be shared publicly. Ms. Ferreira asked if the Plenary Group will have an opportunity to communicate with the study leads and/or review these various studies before the study reports are finalized. Mr. Foster said he is not sure if that is a possibility, but he will check and report back to the group.

Ms. Jean Castillo (NMFS) said NMFS met with the Districts on March 14, 2017 for a site visit at the La Grange Project and the Don Pedro Project as part of the NMFS Fish Passage Engineering Study. Ms. Castillo said the Districts were generous enough to take NMFS and Anchor staff around to different locations in and around the projects, including to the La Grange powerhouse area and Wards Ferry Bridge. Ms. Castillo said an engineer from HDR also attended the site visit and he and the NMFS and Anchor staff had a very collaborative discussion about different concepts for fish passage in the area. Ms. Castillo said the NMFS engineers and the Districts' engineers seem to be on the same page regarding the range of possibilities for fish passage. She believes that as a result of the site visit, and given that both studies will be taking into account the same site conditions and limiting factors, NMFS staff and HDR's fish passage engineer are on the same page. Ms. Castillo said she thinks the Plenary Group will be pleasantly surprised when the results from both studies are similar. Mr. Devine said Mr. Mike Garello (HDR), who is the study lead for the Districts' Fish Passage Facilities Alternative Assessment, attended the site visit with NMFS and Anchor. Mr. Devine said a lot of discussion took place at the site visit, but he does not think it is accurate to say that similar concepts were agreed to or that the study results will be similar. Mr. Devine said while it is true that each evaluation will be assessing similar site conditions and limiting factors that may exist, no agreement was reached during the site visit on the concepts to be evaluated or the results of HDR's fish passage feasibility evaluations.

Dr. Chuck Hanson (Hanson Environmental, consultant to the Districts) said he recently had a discussion with Mr. Steve Edmondson (NMFS) about the NMFS Fish Passage Engineering Study. During this discussion, Mr. Edmondson said NMFS was planning to prepare a generic guidance document related to fish passage. Dr. Hanson asked if NMFS could clarify as to whether they will be preparing two fish passage engineering documents: one that is specific to the Tuolumne River and one that is generic. Mr. Foster said the NMFS Fish Passage Engineering Study will look into the conceptual feasibility of moving fish and reintroducing them above the Don Pedro Project. Mr. Foster said NMFS previously prepared a "frequently asked questions" document related to fish passage, but that document was prepared separately from this licensing process. Dr. Hanson asked if the scope of the NMFS fish passage feasibility study will include cost estimates for different fish passage concepts. Mr. Foster said he does not know the details of the study scope and he has not seen an outline for the report.

Ms. Ferreira asked if the study report will include design concepts for upstream and downstream passage. Mr. Foster said the purpose of the study is to come up with feasible options, but he does not know to what level of engineering design the concepts will be completed. Ms. Castillo said the study is a general feasibility study and will not go into design details such as the amount of concrete or rebar needed. Ms. Castillo said Anchor is currently waiting on the NMFS Science Center to complete the Estimation of Steelhead and Spring-Run Chinook Salmon Habitat Capacity in the Upper Tuolumne and Upper Merced Rivers Study (Habitat and Carrying Capacity Study), which will include the numbers needed to estimate the project footprint. Anchor is estimating these numbers themselves, but will use the numbers from the NMFS Science Center study to fine-tune and extrapolate the estimates. Mr. Foster said that for the Merced River, NMFS prepared a concept-level fish passage feasibility report for possible passage at each of the dams, and he is expecting that the report for the Tuolumne River will be similar in scope.

Mr. John Buckley (Central Sierra Environmental Resource Center [CSERC]) asked if NMFS can provide a timeframe for when the public will be able to review results from the NMFS studies. Mr. Foster said he does not have a schedule, but once the draft reports are complete, he anticipates NMFS will have a better idea of the schedule for making the reports public. Mr. Foster said at this time, no draft reports have been completed. Ms. Castillo said NMFS is hoping that by the end of June, draft reports for each of the three studies will be ready for internal review. Ms. Castillo said NMFS will try to expedite the internal review process as much as possible and that hopefully in July, NMFS will be able to share results with this group. Ms. Castillo said Anchor is aiming to have a draft report complete by the end of June, but completing that report is dependent on completion of the NMFS Science Center Habitat and Carrying Capacity Study. If that study's draft report is not completed by the end of June, then the Anchor study draft report schedule will extend into July.

Dr. Hanson asked if the NMFS Habitat and Carrying Capacity Study is following a standard protocol or study plan that outlines the habitat criteria to be used or provides details on the study approach. Mr. Foster said the report will likely include information on the study methods, depending on the scope of the contract with the study leads. Mr. Foster said he is unaware of the details of the study and particular standards the study may be following. Dr. Hanson said the reason he asked is that later in this meeting, we will be discussing seasonality and temperature considerations, and the results of the study may be able to inform this process.

Ms. Ferreira asked if the reports are released publicly and if there is disagreement with the study results, is there an appeal process? Mr. Foster said once NMFS releases reports to the public, there is a usually a comment period or a separate independent peer review. However, this process varies from report to report depending on the type of document being released and the budget. Mr. Foster said NMFS is always interested in receiving comments from the public and he will check to see if there will be a public review and comment period for the NMFS studies. Mr. Foster said he is hopeful the study results are helpful to this licensing process and therefore the results of the NMFS studies would be provided to the Plenary Group.

Mr. Devine said when the Districts went through the study planning process for both the FERC-approved and the voluntary studies, draft study plans were prepared that included details on the scope of work (including methodology), cost and schedule. These draft study plans were released for participant review and comment and in general, final study plans integrated these comments where appropriate, or explained why they were not incorporated. Mr. Devine asked if scopes, costs and/or study plans for each of the NMFS studies could be shared with the Plenary Group. Mr. Foster said although he has not seen any study plans, he thinks they likely exist. Mr. Foster said he will find out if scopes, costs and/or study plans exist and if they can be shared with the Plenary Group. Mr. Foster said details about the study methods will probably be included in each report. Dr. Hanson said reports for studies similar to the NMFS Habitat and Carrying Capacity Study usually include one or more appendices that specify the information the study relied upon and the accompanying analyses. Dr. Hanson asked if Mr. Foster anticipates that the NMFS Habitat and Carrying Capacity study report will include similar appendices. Mr. Foster agreed that study reports often include that type of information. Dr. Hanson said having those types of appendices would be very helpful during the public review process.

Ms. Ferreira asked if NMFS will be completing a temperature study for the Tuolumne Study and, if so, what is the schedule for the study report. Mr. Foster said he is only aware of the Fish Passage Engineering Study, Habitat and Carrying Capacity Study, and the *O. mykiss* Genetics Study. Mr. Foster said NMFS has installed temperature loggers that are collecting information and could be used in the future. Mr. Devine said that prior to Mr. Foster's time on the project, Mr. John Wooster (NMFS) provided the Boughton et al. (2015) paper as an indication of how NMFS would likely treat temperature considerations for fish restorations. Mr. Devine said Boughton et al. (2015) is a temperature study done on the Santa Ynez River, and Mr. Wooster said a similar approach would be applied to the Tuolumne River to support estimates of carrying capacity. Mr. Devine asked if that temperature study is still ongoing and if study results will be released to the public. Mr. Foster said he will have to check on that. Mr. Foster said he has read meeting notes from some of the past meetings related to the Framework and Mr. Wooster may have been intending just to share some references that may be relevant, such as the report on the Russian River. Mr. Foster said he did not know of a separate temperature study, but he will find out. Mr. Devine said he thinks Mr. Wooster had mentioned a specific individual, perhaps Dr. Flora Cordoleani, who was developing a separate study related to a spring-run Chinook life cycle model that would be applicable to the Tuolumne River. Mr. Foster said he will find out. Mr. Foster noted that Mr. Wooster had a lot more connection to the NMFS Science Center than he does.

Ms. Ferreira asked where the spring-run Chinook for the Tuolumne restoration will come from. Mr. Foster said information on that topic may be part of the NMFS Fish Passage Engineering Study. Mr. Foster said source stock is usually determined over the course of planning the reintroduction and there are different schools of thought about what stocks should be used to comprise a source population. Mr. Foster said the spring-run Chinook source population may be comprised of spring-run Chinook or, if spring-run Chinook is unavailable, fall-run Chinook. Mr. Foster said determining the source population is a very important part of a fish passage program and is often the subject of a separate study. Mr. Bao Le (HDR) asked if discussions are currently underway at NMFS to determine the source population for spring-run Chinook. Mr. Foster said the NMFS Recovery Plan discusses the topic of developing a source population.

Dr. Hanson said in the San Joaquin reintroduction process, participants had a series of conversations very early in the process about broodstock selection and the number of fish that needed to be reintroduced. Dr. Hanson said it was important that these discussions were held early in the process because the results of those discussions resulted in a change of restoration strategy. Originally, the participants intended to use spring-run Chinook from several different sources (wild fish from Butte, Battle, Mill and Deer creeks and the Feather River Hatchery) and let the environmental conditions in the San Joaquin sort out which broodstock was best. Dr. Hanson said this approach was met with pushback from stakeholders who did not want wild fish from other rivers used as broodstock elsewhere. Dr. Hanson said ultimately, only fish from the Feather River Hatchery were used as broodstock. Dr. Hanson reiterated that giving some thought to broodstock early in the process is critical. Mr. Foster said he agreed with Dr. Hanson and that once a fish passage program is designed, part of the implementation process is developing information such as source of broodstock and adapting the approach and original assumptions as the implementation progresses. Ms. Ferreira asked if adapting a fish passage program once implementation has begun will result in additional program costs. Mr. Foster said it is important that a fish passage program be cost-effective, but he does not know what that cost would be to make changes once implementation has begun. Ms. Ferreira said she is concerned that costs may escalate quickly if a fish passage program is designed and implemented without knowing first what the source population may be or if there is even an appropriate source population to use. Mr. Foster said cost is factored into that decision because cost-effectiveness is an important factor, but cost is not the only factor that must be considered.

Mr. Devine said one of the goals of today's meeting is to report the findings of the Goals Subcommittee and the Temperature Subcommittee to the Plenary Group. Both Subcommittees were formed to help the Plenary Group. Many individuals from the Plenary Group volunteered their time to participate in one or both of the Subcommittees. Both Subcommittees now have final results to report to this Plenary Group.

Mr. Devine said the Goals Subcommittee was formed in January 2016. The Goals Subcommittee has had five meetings and each meeting was well attended. At these meetings, the Goals Subcommittee worked on developing a statement to define the goal of the reintroduction program for the Tuolumne River. At the December 1, 2016, Goals Subcommittee meeting, attendees reviewed a draft Goal Statement that was previously drafted and circulated by the Districts. Attendees discussed revisions to the statement as well as the use of corollary statements or objectives to provide detail about or clarify the Goal Statement. The Districts revised the Goal Statement per discussions at the December 1 meeting and circulated a new draft for review, asking that Goals Subcommittee members provide feedback on the statement as well as corollary statements. The only feedback received was from Mr. Buckley, who said he thought the language *"fair and reasonable"* is subjective and hard to define. The idea of providing corollary statements to attach to the Goal Statement was discussed and agreed to. The Districts also prepared a response to Mr. Buckley's comment and this response was circulated to the Goals Subcommittee, as was a request to provide any corollary statements to be added to the primary Goal Statement. No feedback or corollary statements were received. The final Goal Statement, without corollary statements, was forwarded to the Plenary Group prior to today's meeting (Attachment A). Mr. Devine thanked the members of the Goals Subcommittee for their participation and asked the Plenary Group to provide feedback on the Goal Statement.

Mr. Peter Drekmeier (Tuolumne River Trust) asked if the Goals Subcommittee had discussed the fall-run Chinook salmon doubling goal. Mr. Devine said he did not remember any specific discussion of the doubling goal. Mr. Devine said the doubling goal applies only to fall-run Chinook and this Framework process is focused on steelhead and spring-run Chinook. Mr. Le said the Goal Statement was focused on defining *"recovery of ESA listed salmonids"* and that fall-run Chinook do not meet this criterion. Mr. Buckley said he thinks the final Goal Statement is broad and lacks clarity. Mr. Buckley said reintroduction is clearly a controversial topic and it is unlikely there will be broad agreement. Mr. Buckley asked if the Districts think it is sufficient to have a broad statement that everyone can live with or if there is value in having a statement with more specificity. Mr. Devine said the Goal Statement is meant to be a general statement. Mr. Devine said his sense is that the Goals Subcommittee members think it is okay to have a general statement and that it is also fine for individuals to have different interpretations of the statement. Mr. Devine added that individuals are welcome to share any disagreement with the statement and those opinions will be documented in the record.

Mr. Chris Shutes (California Sportfishing Protection Alliance) said he thinks it will be easier to add corollary or objective statements once the results from the voluntary studies are available. Mr. Shutes said having data on the character and capacity of the habitat will make it easier to draft numeric objectives and specific actions or activities and have a more informed discussion. Mr. Le reminded the Plenary Group that the purpose of the Goals Subcommittee was to develop a reintroduction Goal Statement in parallel with, but independent of, the studies and their results so that the Goal Statement would not be biased by the study results. This approach would ensure that the Framework's primary objective, which is to objectively assess the feasibility of reintroduction in the Tuolumne River, would be met. Mr. Devine said the Goal Statement reflects a variety of interests and the intent of the Framework process has always been to first develop a Goal Statement and then to review the results of the studies within the context of those goals. Mr. Devine asked if there are any other comments on the Goal Statement. There were none.

Ms. Ferreira said the Goals Subcommittee has spent many hours discussing the statement and part of those discussions were about how individuals may have different perspectives on the phrase *"fair and reasonable cost."* Mr. Devine said part of the interest in developing corollary statements was to provide clarity on different phrases in the Goal Statement. Mr. Devine said that since no subcommittee participants submitted corollary statements, the part of the Goal Statement about corollary statements can be removed. Mr. Devine asked if everyone is okay with removing the sentence about corollary statements. Mr. Lonnie Moore (private citizen) said corollary statements could be added later as they become important to the Goal Statement and that removing the language that introduces the corollaries would seem to shut down the possibility of adding corollaries in the future. Mr. Shutes agreed corollary statements could be added at a later time. Mr. Devine said one objective of the Goals Subcommittee was to develop these corollary statements. Over the course of several Goals Subcommittee meetings, the Districts requested feedback and input to support corollary statement development. No corollary statements came out of those activities or were provided by any subcommittee participant. The Goals Subcommittee has now reported its results to the Plenary Group. Mr. Devine said he considers the work of the Goals Subcommittee to be complete.

Mr. Moore said he thinks it is important that members of the Plenary Group be able to add corollary statements in the future. Mr. Devine stated that this collaborative process is informal and the Plenary Group is welcome to do that in the future. Ms. Ferreira said she thinks enough time has already been spent discussing the Goal Statement and corollary statements and she suggests that the group vote on not allowing corollary statements to be added in the future. Meeting attendees discussed how the informal Framework process allows for all opinions to be documented in the meeting notes.

Meeting attendees agreed to remove the last part of the Goal Statement about corollary statements and to accept that the remaining language is the final Goal Statement. No meeting attendees were opposed.

Meeting attendees took a 10-minute break.

Mr. Devine said the goal of the Temperature Subcommittee was to develop general temperature indices or guidelines for assessing reintroduction with regards to thermal suitability. The Temperature Subcommittee first met on April 13, 2016 and has had a series of conference calls and meetings, led primarily by Mr. Paul Bratovich (HDR). Over that period of time, the Temperature Subcommittee produced a literature review (using Water Temperature Considerations for the Yuba River Basin – Anadromous Salmonid Reintroduction Evaluations (Bratovich et al. 2012) as a starting point) to help inform the development of potentially suitable temperatures for reintroduction. The subject of thermal suitability includes various terms such as *upper optimal*, *upper tolerable*, *lethal*, etc. and part of the Temperature Subcommittee's work included reviewing the definition of each term to ensure the clarity of each term. On November 29, 2016, the Districts circulated to subcommittee members a blank Water Temperature Index (WTI) table, the goal of which was to generate discussion on recommended values for each of the thermal indices. No feedback was received from any member so the Districts recirculated the table on January 24, 2017. Mr. Shutes provided comments on the spring-run Chinook lifestage periodicity table. Other than Mr. Shutes' feedback, no other comments were received. In the absence of other feedback, the Districts populated the table based on information collected from the literature review, much of which came from the Yuba Salmon Forum. Mr. Devine said the Districts circulated the table with the suggested temperature indices to the Temperature Subcommittee for review and no further feedback was received. Mr. Devine said today the Temperature Subcommittee is presenting this table of final WTIs to the Plenary Group for acceptance.

Mr. Devine reviewed the table's content and what the shading represents. The dark gray boxes indicate periods of time when, based on the cited literature, there is peak activity during that life stage. The light gray indicates shoulder periods where, based on the information available, presence exists but peak activity is not expected.

Mr. Drekmeier said the table is helpful and recommended adding a key or legend to indicate what the shading represents. He added that it was interesting that some lifestages, such as rearing, do not have any periods of peak activity. Mr. Shutes agreed that adding a key would be helpful. Mr. Le said much of the table was populated using information from the Yuba Salmon Forum. Given that neither spring-run Chinook nor steelhead currently exist in the upper Tuolumne River, fish periodicities largely originated from information provided in the NMFS Recovery Plan and the Districts' Salmonid Population Information Integration and Synthesis Study Report (W&AR-05 from the Don Pedro Hydroelectric Project). The Districts' technical team provided additional refinements to periodicities based upon site-specific data, information from nearby watersheds, and professional judgment.

Ms. Alison Boucher (Tuolumne River Conservancy) said it might be necessary to use a third color in the WTI table, in addition to the dark gray and light gray. Juvenile rearing for steelhead is an example of a lifestage that could use a third color. This lifestage has light gray boxes throughout the year, and it could be that there is a time of peak activity that is missing from this table. Mr. Le said the duration and timing of the lifestage, and when peak activity occurs, is based on, and limited by, the information available. For example, the literature on fry rearing for steelhead states that this lifestage occurs from February through mid-July. There is currently no information in the literature indicating relatively greater fry rearing activity occurring at any time during that time frame to justify adding dark gray shading (peak period). As such, the information indicates only that fry rearing exists from February through mid-July. The white boxes indicate the period of time when, based on the literature, no fry rearing is observed. Ms. Boucher said she proposes that the entire period for steelhead fry rearing be changed to dark gray because if there is no specific time of peak activity it means that the all the months within the period are of equal importance. Ms. Boucher said she is concerned that when it comes to managing flows on the river, often the last few weeks of a lifestage period are removed from temperature management. Ms. Boucher said based on the table, there is nothing to differentiate an actual shoulder period from a period when peak activity may occur.

Mr. Buckley suggested that Ms. Boucher's concerns could be addressed by adding an asterisk to all lifestages that have only light gray boxes. Mr. Shutes agreed and said an asterisk could be added for each lifestage depending on whether or not a period of peak activity can be identified in the literature. Mr. Devine agreed it would be helpful to add footnotes. Mr. Devine said that for any lifestages that are all light gray, he would be hesitant to change them to all dark gray because there is no data available to suggest that each month in the period is a peak period. Mr. Devine said asterisks would be added and Ms. Boucher said that would be sufficient to address her concerns.

Mr. Larry Byrd (Modesto Irrigation District) asked if the data in the table is based on studies. Mr. Le said in developing the lifestage periodicities, the technical team first reviewed the NMFS Recovery Plan and the Districts' Salmonid Population Information Integration and Synthesis Study Report. The periodicities developed from this base of information were refined based on site-specific information available for the Tuolumne River and other nearby watersheds. Mr. Byrd said it makes sense that the table would use data from other rivers, given that steelhead do not exist in the Tuolumne River.

Mr. Foster suggested adding the definition of MWAT somewhere in the table. Mr. Devine said MWAT is defined in the literature review and the Districts will add that definition to the table.

The Plenary Group voted to adopt the WTI table and the literature review. No individuals were opposed to adopting these two documents.

Ms. Jenna Borovansky (HDR) presented an overview of the Regulatory Context for Potential Anadromous Salmonid Reintroduction into the Upper Tuolumne River Basin Study (Regulatory Study) including the goals and objectives, methods, and study status.

Mr. Foster asked if the study report will note which management plans are considered comprehensive plans under the Federal Power Act. Ms. Borovansky said the list of management plans compiled for the study does not currently include whether or not the plan is on FERC's list of comprehensive plans, but it would be a good idea to include this information.

Mr. Buckley asked if the study report will just be a list of potentially applicable plans or if the study report will state which plans are a barrier to reintroduction. Mr. Buckley said if the study report will include a description of which plans are a barrier to reintroduction, it would be helpful if the study report could be issued soon so that licensing participants can provide feedback on what some of the plans are aiming to accomplish. Ms. Borovansky said the study report is intended only to identify which plans, based on such factors as the plan's goals and objectives and geographic area, may be relevant for consideration in implementing a reintroduction program. Which plans may act as hurdles for a reintroduction program is somewhat speculative given that the details of a fish passage action are unknown at this time. Ms. Borovansky said once the report is released, licensing participants will have an opportunity to provide comments on particular facets of a plan or plans that may have been missed.

Ms. Gretchen Murphey (California Department of Fish and Wildlife) asked when the Districts expect to release a draft report. Ms. Borovansky said work on the report is underway and the Districts are aiming to have a draft report finished in time to include it in the La Grange Project Final License Application (FLA), which will be filed with FERC in September. Ms. Borovansky said feedback on specific plans is welcome now, so that it may be incorporated into the study report.

Ms. Borovansky presented an overview of the Socioeconomic Scoping Study including the goals and objectives, methods, and study status. Ms. Borovansky said similar to the Regulatory Study, the Districts are aiming to complete a draft study report in time to include it in the FLA.

Mr. Foster said a FERC report from 1995 noted that projects on the Tuolumne River have the potential to have cumulative effects on the Delta. Mr. Foster noted that the scope of the Socioeconomic Scoping Study extends only to the lower Tuolumne River. Mr. Foster said given the amount of data that would need to be processed and analyzed if the scope extended to the Delta, he understood why the scope only extended to the lower Tuolumne River. Ms. Borovansky said when the Districts initially proposed the study, the study scope only included the upper Tuolumne River. Based on feedback from licensing participants, the scope was extended to the lower Tuolumne River. Ms. Borovansky said Mr. Foster's point about the extent of cumulative effects is a good one. Mr. Foster said for ESA consulting purposes, the scope may extend beyond the Tuolumne River. Mr. Devine said FERC defined the scope of cumulative effects in the scoping documents for both the Don Pedro Project and the La Grange Project, and the scope of cumulative effects extends beyond the Tuolumne River.

Mr. Lonnie Moore (public citizen) asked if the Socioeconomic Scoping Study is on hold until there is an actual proposal for fish passage. Mr. Devine said the study is meant to provide background information on what socioeconomic resources could be benefitted or adversely affected by a reintroduction program. Mr. Devine said the purpose of conducting the study was to collect information that would help inform this collaborative process. Mr. Le said the study is meant only to scope or catalogue what socioeconomic resources might be relevant, and not to describe how those resources may be affected.

Mr. Le gave a status update on the five voluntary studies not covered by Ms. Borovansky. Mr. Le said that study reports for these studies are on the same schedule as the Regulatory Study and the Socioeconomic Scoping Study (drafts by September 2017). Mr. Le said the SED review and response process pulled much of the technical team away from the study work for six months and only recently were they able to reengage in the studies and begin working on them again.

Mr. Le presented an overview of the Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study including the goals and objectives, methods, and study status.

Mr. Buckley said the current high flows in the river have likely reshaped many of the river segments that were documented in the study. Mr. Buckley asked if there is a way to include these recent flow conditions in this study. Mr. Le said given that the fieldwork was completed in 2016, it is unknown what impacts the recent high flow conditions may be having in the study area. Mr. Le said there are no plans to perform additional fieldwork. However, Mr. Le noted that even though there has been a lot of precipitation, he did not know how this precipitation translated into high flows in the study area given that flows in the study area are managed. Furthermore, Mr. Le noted that the initial desktop mapping of spawning gravels used 2007 imagery and that the field review completed in 2016 noted that there were no major differences in spawning gravel distribution between these two periods of time. Mr. Devine noted that 2011 was also a very wet year.

Ms. Boucher noted the presentation refers to *steelhead* and asked if the study makes a distinction between steelhead and resident *O. mykiss*. Mr. Le said that all the voluntary studies make a distinction between steelhead and resident *O. mykiss* and in all the studies, steelhead are referenced. Ms. Boucher asked if a footnote could be added to the presentation to clarify this. Mr. Le said a footnote will be added.

Mr. Le presented an overview of the Upper Tuolumne River Habitat Mapping Assessment including the goals and objectives, methods, and study status. There were no questions or comments.

Mr. Le presented an overview of the Upper Tuolumne River Macroinvertebrate Assessment including the goals and objectives, methods, and study status. Ms. Meg Layhee (CSERC) asked if each site was sampled once. Mr. Le confirmed that each site was sampled once. Mr. Shutes asked how many sites were sampled. Mr. Le said seven sites were sampled.

Mr. Le presented an overview of the Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study including the goals and objectives, methods, and study status. Mr. Drekmeier asked if the study team was coordinating with Mr. Bill Sears (City and County of San Francisco) regarding releases from O'Shaughnessy Dam. Mr. Drekmeier said he and others have been working on a draft management plan for the reach and he suggested that the Districts get in touch with Mr. Sears to get a copy of this document. Mr. Drekmeier noted that the management plan includes changes to the current flow regime, which may result in impacts to temperatures in the reach. Mr. Le said the scope of the study is to evaluate current flow conditions, though he is interested to review the plan and will follow up with Mr. Sears to get a copy. *[Note: Following the meeting, Mr. Drekmeier said given that the scope of the study only includes current conditions, it was unnecessary for the study leads to review the draft management plan.]*

Mr. Le presented an overview of the Upper Tuolumne River Instream Flow Study including the goals and objectives, methods, and study status. Mr. Shutes asked what flows occurred during the fieldwork and how different flows may have impacted the fieldwork. Mr. Le said different flows were needed in order to calibrate the model. The flows ranged from about 200 cfs or so to peaking flows of over 1,000 cfs.

Mr. Devine thanked everyone for attending the meeting and thanked the Temperature Subcommittee and Goals Subcommittee members for their participation. Mr. Devine thanked NMFS for providing an update on their studies.

Meeting adjourned.

<u>Action Items</u>

1. Mr. Foster will keep the Plenary Group informed of the schedule for public release of the NMFS study reports.

2. Mr. Foster will find out the cost of the NMFS Fish Passage Engineering Study.

3. Mr. Foster will check to see if there will be a public review and comment period for the NMFS studies.

4. Mr. Foster will find out if scopes, costs, and/or study plans exist for the NMFS studies and if they can be shared with the Plenary Group.

5. Mr. Foster said he will find out if the NMFS Science Center is completing a temperature study of the Tuolumne River, (e.g., similar to Boughton et al. [2015]).

6. The Districts will revise the WTI table to add the definition of MWAT and to clarify what the light gray and dark gray boxes indicate. (complete) *(Note: See Attachment C to for the updated version of the WTI table.)*

7. The Districts will ensure that the Regulatory Study Report indicates which management plans are on FERC's list of comprehensive plans.

8. The Districts will add a footnote to the Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study PowerPoint presentation cover slide to indicate that *steelhead* refers only to steelhead, and not resident *O. mykiss*. (complete) *(Note: See Attachment C for the updated version of this PowerPoint.)*

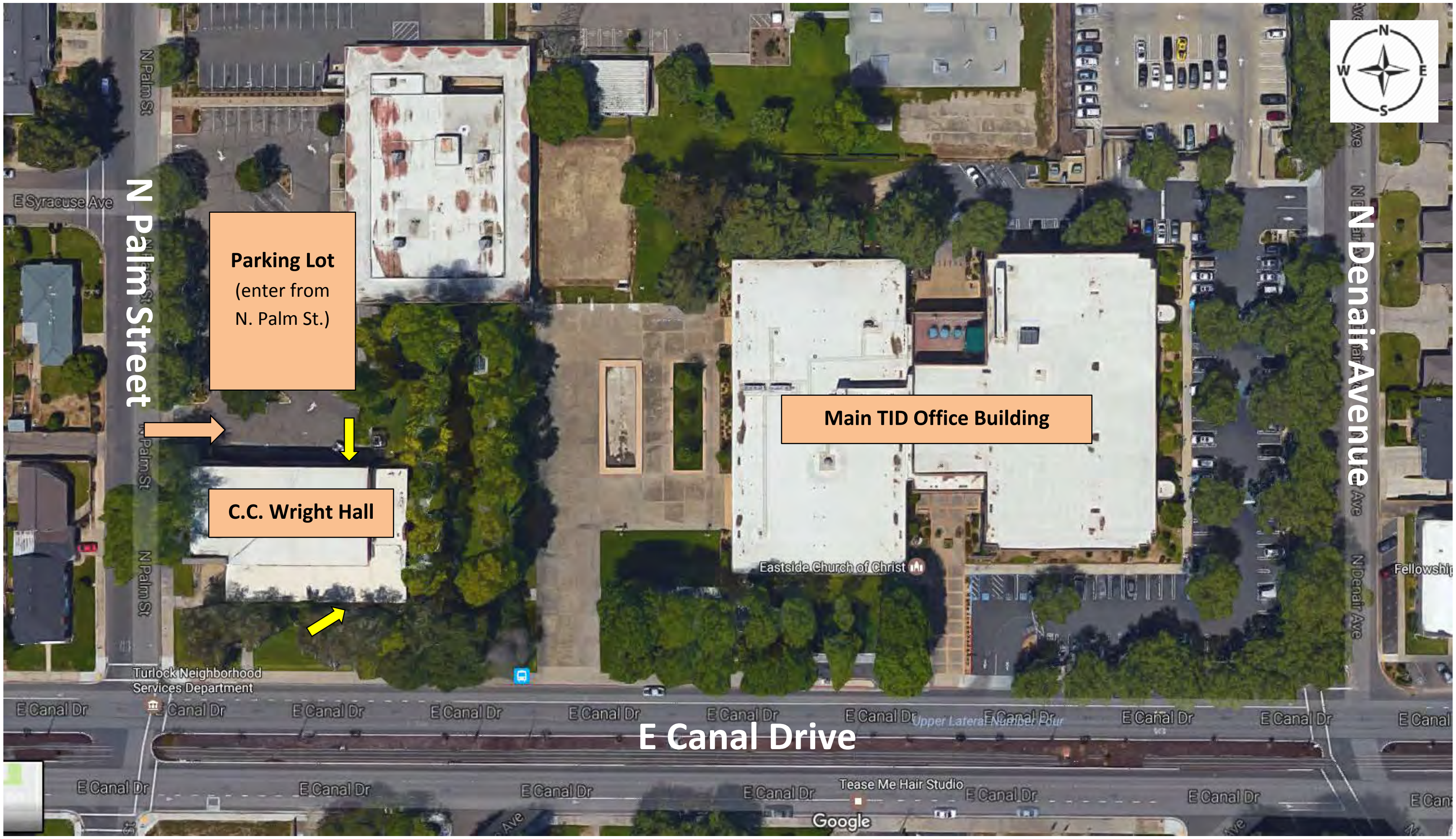
LA GRANGE HYDROELECTRIC PROJECT

REINTRODUCTION ASSESSMENT FRAMEWORK
MAY 18, 2017 PLENARY GROUP MEETING

ATTACHMENT A

MEETING MATERIALS

C.C. Wright Hall, 247 E Canal Drive, Turlock CA



The parking lot north of C.C. Wright Hall is free and open to the public. Individuals may enter C.C. Wright Hall using either the north entrance or the main entrance located off of E Canal Drive.

La Grange Hydroelectric Project
Reintroduction Assessment Framework
Plenary Group Meeting

Thursday, May 18, 2017
9:00 am to 12:00 pm

Turlock Irrigation District's C.C. Wright Hall
247 E. Canal Drive, Turlock, CA
Conference Line: 1-866-583-7984; Passcode: 814-0607
Skype Meeting https://meet.hdrinc.com/jenna.borovansky/3D64F0F5

Meeting Objectives

1. Present the results of the Reintroduction Goals Subcommittee and the Water Temperature Subcommittee.
2. Review and discuss the current status of the Districts' voluntary studies.
3. Review and discuss the current status of NMFS' studies.

TIME	TOPIC
9:00 am – 9:15 am	Introduction of Participants (All) Review Agenda and Meeting Objectives (Districts)
9:15 am – 10:00 am	Status of the Reintroduction Goals Subcommittee and the Water Temperature Subcommittee
10:00 am to 11:00 am	Status update of Districts' ongoing voluntary studies 1. Regulatory Context for Potential Anadromous Salmonid Reintroduction into the Upper Tuolumne River Basin 2. Socioeconomic Scoping Study 3. Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study 4. Upper Tuolumne River Habitat Mapping Assessment 5. Upper Tuolumne River Macroinvertebrate Assessment 6. Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study 7. Upper Tuolumne River Instream Flow Study
11:00 am to 11:45 am	Status of NMFS' ongoing Tuolumne River studies 1. Estimation of Steelhead and Spring-Run Chinook Salmon Habitat Capacity in the Upper Tuolumne and Upper Merced Rivers 2. Genetic Evaluation of *O. mykiss* Populations in the Upper Tuolumne and Merced Watersheds 3. Fish Passage Engineering Study
11:45 am to 12:00 pm	Next Steps (All)

Goal Statement

"Contribute to the recovery of ESA listed salmonids in the Central Valley by establishing viable populations in the Tuolumne River at fair and reasonable cost.

Specific objectives consistent with the goal statement include the following:……"

UPPER TUOLUMNE RIVER REINTRODUCTION ASSESSMENT FRAMEWORK
WATER TEMPERATURE SUBCOMMITTEE

LIFESTAGE-SPECIFIC WATER TEMPERATURE BIOLOGICAL EFFECTS AND INDEX TEMPERATURE VALUES

Literature Review Summary

INTRODUCTION

The La Grange Hydroelectric Project (La Grange Project), owned and operated by the Turlock Irrigation District and Modesto Irrigation District (TID/MID, or the Districts), is currently undergoing the Federal Energy Regulatory Commission (FERC) Integrated Licensing Process (ILP). As part of this process, the Districts are implementing a FERC-approved Fish Passage Facilities Alternatives Assessment which consists of developing general design criteria and design considerations applicable to upstream and downstream fish passage facilities at the La Grange Project. Design criteria and considerations include items such as: site-specific physical and operational parameters; applicable regulatory requirements; National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and California Department of Fish and Wildlife (CDFW) biological and engineering design criteria; site-specific biological/habitat information relevant to the sizing and configuration of facilities; and any other information gaps that may affect siting, sizing, general design parameters, capital cost, and operating requirements of potential fish passage facilities.

To make certain that detailed, site-specific information is available to support and adequately inform decisions regarding fish reintroduction and fish passage, TID, MID, and licensing participants came to a consensus on the need for and utility of an Upper Tuolumne River Reintroduction Assessment Framework (Framework). The Framework is intended to provide a comprehensive, collaborative, and transparent approach for evaluating the full range of potential issues associated with the future reintroduction of anadromous salmonids to the upper Tuolumne River. In addition to considering aspects of the technical feasibility of building and operating fish passage facilities, the Framework considers the interrelated issues of ecological feasibility, biological constraints, economics, regulatory implications, and other considerations of reintroduction. Elements of the Framework are interconnected, with fish passage construction and operational requirements needing to properly reflect biological constraints, ecological considerations, and economic cost-benefit assessments.

Water temperature considerations are a primary component of assessing any potential anadromous salmonid reintroduction effort. In support of the Framework, the Districts and licensing participants established a Water Temperature Subcommittee to begin investigating water temperature considerations pertinent to anadromous salmonid reintroduction opportunities in the accessible reaches of the Tuolumne River upstream of Don Pedro Reservoir (upper Tuolumne River). On September 15, 2016, the Districts hosted the first conference call for the Water Temperature Subcommittee (draft meeting notes from this call were distributed on October 3 for a 30-day comment period). On the conference call, attendees discussed the need for a comprehensive literature review of regional and site-specific information to inform the selection of water temperature index (WTI) values to be used in an evaluation of the water temperature-related reintroduction potential in the reaches of the upper Tuolumne River. Meeting attendees agreed that the literature review performed for the Yuba Salmon Forum (Appendix A; Bratovich *et al.* 2012) to support the anadromous salmonid reintroduction assessment in this watershed coupled with site-specific temperature studies or data for the Tuolumne River, if available, would be a good basis for this effort. The following represents an updated literature review summary that is being provided to the Water Temperature Subcommittee to support selection of water temperature index values for the Framework.

The WTI values presented herein represent a gradation of potential biological effects from optimal to lethal water temperatures for each lifestage. Literature on salmonid water temperature requirements generally reports water temperature thresholds using various descriptive terms including "optimal", "preferred", "suitable", "suboptimal", "tolerable", "stressful – chronic and acute", "sublethal", "incipient lethal", and "lethal". Water temperature effects on salmonids are often discussed in terms of "lethal" and "sublethal" effects, and depend on the both the magnitude and the duration of exposure (Sullivan *et al.* 2000), as well as acclimation water temperature. Acute, chronic, and optimal growth zones are displayed in Figure 1.

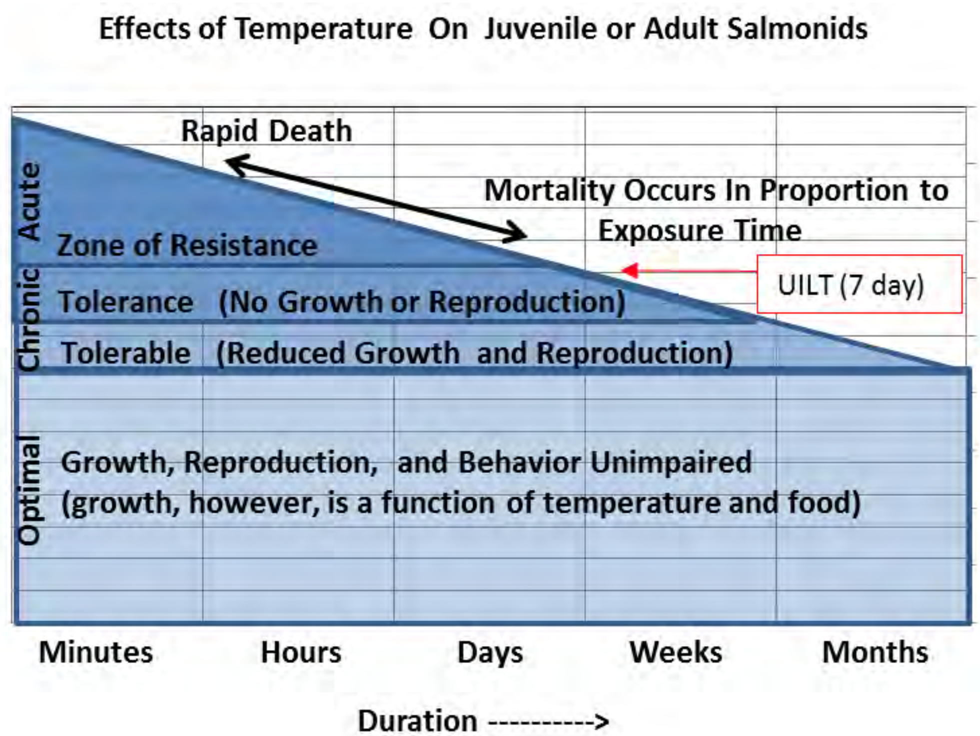


Figure 1. Illustration of acute, chronic, and optimal temperature zones (adapted from Sullivan et al. 2000).

STEELHEAD LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

Adult Immigration and Holding

Water temperatures can control the timing of adult spawning migrations and can affect the viability of eggs in holding females. Yuba County Water Agency (YCWA) *et al.* (2007) suggests that few studies have been published examining the effects of water temperature on either steelhead immigration or steelhead holding, and none of the available studies were recent (Bruin and Waldsdorf 1975; McCullough *et al.* 2001). The available studies suggest that adverse effects occur to immigrating and holding steelhead at water temperatures exceeding the mid-50°F range, and that immigration will be delayed if water temperatures approach approximately 70°F (Table 1). WTI values of 52°F, 56°F, 61°F, 64°F, 65°F, 68°F and 70°F were identified because they provide a gradation of potential water temperature effects, and the available literature provided the strongest support for these values.

Because of the paucity of literature pertaining to steelhead adult immigration and holding, an evenly spaced range of WTI values could not be achieved. 52°F was identified as a WTI value because it has been referred to as a "recommended" (Reclamation 2003), "preferred" (McEwan and Jackson 1996; NMFS 2000; NMFS 2002), and "optimum" (Reclamation 1997a) water temperature for steelhead adult immigration. Increasing levels of thermal stress to this lifestage may reportedly occur above the 52°F WTI value. 56°F was identified as a WTI value because 56°F represents a water temperature above which adverse effects to migratory and holding steelhead begin to arise (Bruin and Waldsdorf 1975; Leitritz and Lewis 1980; McCullough *et al.* 2001; Smith *et al.* 1983). 50-59°F is referred to as the "preferred" range of water temperatures for California summer steelhead holding (Moyle *et al.* 1995). Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter-run steelhead (USFWS 1995a). A water temperature of 64°F (7DADM) was identified as the value for steelhead adult lifestage for the San Joaquin River (CALFED 2009) and as the Upper Optimum Value for steelhead adult migration (maximum weekly average temperature; MWAT) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" migration (EPA 2003b). 65°F was identified as a WTI value because steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Additionally, over 93% of steelhead detections occurred in the 65.3-71.6°F range, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006) and/or may modify migration timing due to holding in coldwater refugia (High *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). A water temperature of 68°F was found to drop egg fertility in vivo to 5% after 4.5 days (McCullough *et al*. 2001). Additionally, empirical adult *O. mykiss* population data from the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon rivers were collected in 2007-2009 were plotted against temperature (Figure 4 of Bratovich *et al*. 2012). The data show a population density break at about 68°F. Although smaller population densities occurred at higher temperatures, the largest population densities occurred at temperatures near 68.0°F or less. 70°F was identified as the highest WTI value because the literature suggests that water temperatures near and above 70.0°F may result in a thermal barrier to adult steelhead migrating upstream (McCullough *et al.* 2001) and are water temperatures referred to as "stressful" to upstream migrating steelhead in the Columbia River (Lantz 1971 as cited in Beschta *et al.* 1987). Further, Coutant (1972) found that the upper incipient lethal temperature (UILT) for adult steelhead was 69.8°F and temperatures between 73-75°F are described as "lethal" to holding adult steelhead in Moyle (2002).

As part of the Framework, TID and MID, in collaboration with stakeholders developed a table of WTI values from select salmon and steelhead programs in the Central Valley (Temperature Criteria Matrix; presented at the September 15, 2016 Water Temperature Subcommittee conference call). The table was developed to support the Framework's Water Temperature Subcommittee whose purpose is to establish a technical basis to evaluate water temperature regimes for target anadromous salmonid reintroduction into the Tuolumne River upstream of Don Pedro Reservoir. For steelhead adult immigration, the Temperature Criteria Matrix identified 64°F for the San Joaquin (CALFED 2009) and 64°F (Upper Optimum Value) and

68°F (Upper Tolerable Value) for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). For steelhead adult holding, the Temperature Criteria Matrix identified 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value), MWAT, for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Table 1. Steelhead Adult Immigration and Holding WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F (11.1°C)	Preferred range for adult steelhead immigration of 46.0°F to 52.0°F (NMFS 2000; NMFS 2001a; SWRCB 2003). Optimum range for adult steelhead immigration of 46.0°F to 52.1°F[1] (Reclamation 1997a). Recommended adult steelhead immigration temperature range of 46.0°F to 52.0°F (Reclamation 2003).
56°F (13.3°C)	To produce rainbow trout eggs of good quality, brood fish must be held at water temperatures not exceeding 56.0°F (Leitritz and Lewis 1980). Rainbow trout brood fish must be held at water temperatures not exceeding 56°F for a period of 2 to 6 months before spawning to produce eggs of good quality (Bruin and Waldsdorf 1975). Holding migratory fish at constant water temperatures above 55.4°F to 60.1°F may impede spawning success (McCullough *et al.* 2001).
61°F (16.1°C)	Water temperatures greater than 61°F may result in "chronic high stress" of holding Central Valley winter- run steelhead (USFWS 1995a). Preferred range of water temperature for holding California summer steelhead occurs between 50-59°F (Moyle 1995). A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for steelhead adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
64°F (17.8°C)	Steelhead (and fall-run Chinook salmon) encounter potentially stressful temperatures between 64.4-73.4°F (Richter and Kolmes 2005). Over 93% of steelhead detections occurred in the 65.3-71.6°F, although this may be above the temperature for optimal immigration (Salinger and Anderson 2006). A water temperature of 64°F was identified as the value for steelhead adult lifestage, 7DADM, for the San Joaquin River (CALFED 2009) and as the Upper Optimum Value for steelhead adult migration, MWAT, for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" migration (EPA 2003b).
65°F (18.3°C)	A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
68°F (20°C)	A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). A water temperature of 68°F was found to drop egg fertility in vivo to 5% after 4.5 days (McCullough *et al.* 2001).
70°F (21.1°C)	Migration barriers have frequently been reported for pacific salmonids when water temperatures reach 69.8°F to 71.6°F (McCullough *et al.* 2001). Snake River adult steelhead immigration was blocked when water temperatures reached 69.8 (McCullough *et al.* 2001). The UILT for adult steelhead was determined to be 69.8°F (Coutant 1972).

Spawning and Embryo Incubation

Relatively few studies have been published directly addressing the effects of water temperature on steelhead spawning and embryo incubation (Redding and Schreck 1979;

[1] Similar to Bratovich *et al*. 2012, rounded whole integers were identified for index values to avoid unwarranted specificity.

Rombough 1988). Because anadromous steelhead and non-anadromous rainbow trout are genetically and physiologically similar, studies on non-anadromous rainbow trout also were considered in the development of WTI values for steelhead spawning and embryo incubation (Moyle 2002; McEwan 2001). From the available literature, water temperatures in the low 50°F range appear to support high embryo survival, with substantial mortality to steelhead eggs reportedly occurring at water temperatures in the high 50°F range and above (Table 2). Water temperatures in the 45-50°F range have been referred to as the "optimum" for spawning steelhead (FERC 1993).

WTI values of 46°F, 52°F, 54°F, 55°F, 57°F, 59°F and 60°F were identified for two reasons. First, the available literature provided the strongest support for WTI values at or near these integers. Second, the index values reflect a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead spawning and embryo incubation. Some literature suggests water temperatures ≤ 50°F are when steelhead spawn (Orcutt *et al.* 1968) and/or are optimal for steelhead spawning and embryo survival (FERC 1993; Myrick and Cech 2001; Timoshina 1972) and temperatures between 39-52°F are "preferred" by spawning steelhead (IEP Steelhead Project Work Team (no date); McEwan and Jackson 1996). Orcutt *et al.* (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F. A larger body of literature suggests optimal conditions occur at water temperatures ≤ 52°F (Humpesch 1985; NMFS 2000; NMFS 2001a; NMFS 2002; Reclamation 1997b; SWRCB 2003; USFWS 1995b). Further, water temperatures between 48-52°F were referred to as "optimal" (FERC 1993; McEwan and Jackson 1996; NMFS 2000) and "preferred" (Bell 1986) for steelhead embryo incubation. Therefore, 52°F was identified as the lowest WTI value. Increasing levels of thermal stress to the steelhead spawning and embryo incubation lifestage may reportedly occur above the 52°F WTI value.

54°F was identified as the next index value, because although most of the studies conducted at or near 54.0°F report high survival and normal development (Kamler and Kato 1983; Redding and Schreck 1979; Rombough 1988), some evidence suggests that symptoms of thermal stress arise at or near 54.0°F (Humpesch 1985; Timoshina 1972). Thus, water temperatures near 54°F may represent an inflection point between properly functioning water temperature conditions, and conditions that cause negative effects to steelhead spawning and embryo incubation. Further, water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning and egg incubation (EPA 2003b). For steelhead spawning and embryo incubation in the Yuba River, the Framework Temperature Criteria Matrix identified 54°F and 57°F for Upper Optimum and Upper Tolerable values, respectively (Bratovich *et al.* 2012). 57°F was identified as an index value because embryonic mortality increases sharply and development becomes retarded at incubation temperatures greater than or equal to 57°F. Velsen (1987) provided a compilation of data on rainbow trout and steelhead embryo mortality to 50% hatch under incubation temperatures ranging from 33.8°F to 60.8°F that demonstrated a two-fold increase in mortality for embryos incubated at 57.2°F, compared to embryos incubated at 53.6°F.

In a laboratory study using gametes from Big Qualicum River, Vancouver Island, steelhead mortality increased to 15% at a constant temperature of 59.0°F, compared to less than 4% mortality at constant temperatures of 42.8°F, 48.2°F, and 53.6°F (Rombough 1988). Also, alevins hatching at 59°F were considerably smaller and appeared less well developed than those incubated at the lower temperature treatments. From fertilization to 50% hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56% survival when incubated at 59.0°F (Kwain 1975).

As part of the Don Pedro Hydroelectric Project FERC relicensing process, the Districts conducted an *O. mykiss* Population Study (TID/MID 2014) for the Lower Tuolumne River below La Grange Diversion Dam. The goal of the study is to provide a quantitative population model to investigate the relative influences of various factors on the lifestage-specific production of *O. mykiss* in the Tuolumne River including water temperature effects on population response for specific in-river lifestages. The study noted that although no literature information could be identified regarding upper temperature limits for spawning initiation, maximum temperature limits for spawning are assumed to be on the order of 15°C (59°F) inferred from egg mortality thresholds for resident *O. mykiss* (Velsen 1987) as well as steelhead (Rombough 1988). Similarly, for egg incubation, the model allowed for a broad range of flow and water temperature conditions using the completed model, an initial acute mortality threshold of 15°C (59°F) was included based upon a literature review by Myrick and Cech (2001).

From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). Myrick and Cech (2001) similarly described water temperatures >59°F as "lethal" to incubating steelhead embryos, although FERC (1993) suggested that water temperatures exceeding 68°F were "stressful" to spawning steelhead and "lethal" when greater than 72°F.

Table 2. Steelhead Spawning and Embryo Incubation WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
46°F (7.8°C)	Orcutt *et al*. (1968) reported that steelhead spawning in late spring in the Clearwater and Salmon Rivers, Idaho, occurred at temperatures between 35.6 and 46.4°F.
52°F (11.1°C)	Rainbow trout from Mattighofen (Austria) had highest egg survival at 52.0°F compared to 45.0°F, 59.4°F, and 66.0°F (Humpesch 1985). Water temperatures from 48.0°F to 52.0°F are suitable for steelhead incubation and emergence in the American River and Clear Creek (NMFS 2000; NMFS 2001a; NMFS 2002a). Optimum water temperature range of 46.0°F to 52.0°F for steelhead spawning in the Central Valley (USFWS 1995b). Optimum water temperature range of 46.0°F to 52.1°F for steelhead spawning and 48.0°F to 52.1°F for steelhead egg incubation (Reclamation 1997a). Upper limit of preferred water temperature of 52.0°F for steelhead spawning and egg incubation (SWRCB 2003).

Index Value	Supporting Literature
54°F (12.2°C)	Big Qualicum River steelhead eggs had 96.6% survival to hatch at 53.6°F (Rombough 1988). Highest survival from fertilization to hatch for *Salmo gairdneri* incubated at 53.6°F (Kamler and Kato 1983). Emergent fry were larger when North Santiam River (Oregon) winter steelhead eggs were incubated at 53.6°F than at 60.8°F (Redding and Schreck 1979). The upper optimal water temperature regime based on constant or acclimation water temperatures necessary to achieve full protection of steelhead is 51.8°F to 53.6°F (EPA 2001). From fertilization to hatch, rainbow trout eggs and larvae had 47.3% mortality (Timoshina 1972). Survival of rainbow trout eggs declined at water temperatures between 52.0 and 59.4°F (Humpesch 1985). The optimal constant incubation water temperature for steelhead occurs below 53.6°F (McCullough *et al.* 2001). A water temperature of 54°F (MWAT) was identified as the Upper Optimum Value for steelhead spawning and embryo incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
55°F (12.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning and egg incubation (EPA 2003b). Water temperatures greater than 55°F were referred to as "stressful" for incubating steelhead embryos (FERC 1993).
57°F (13.9°C)	From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987). A sharp decrease in survival was observed for rainbow trout embryos incubated above 57.2°F (Kamler and Kato 1983). A water temperature of 57°F (MWAT) was identified as the Upper Tolerable Value for steelhead spawning and embryo incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
59°F (15°C)	Based on egg mortality thresholds for steelhead, maximum temperature limits for spawning are assumed to be 59°F (Rombaugh 1988 as cited in TID/MID 2014). A water temperature of 59°F was identified as the initial acute mortality threshold for steelhead egg incubation (Myrick and Cech 2001 as cited in TID/MID 2014). From fertilization to 50% hatch, rainbow trout eggs from Ontario Provincial Normendale Hatchery had 56% survival when incubated at 59.0°F (Kwain 1975).
60°F (15.6°C)	Water temperatures >59°F are described as "lethal" to incubating steelhead embryos (Myrick and Cech 2001), From fertilization to 50% hatch, Big Qualicum River steelhead had 93% mortality at 60.8°F, 7.7% mortality at 57.2°F, and 1% mortality at 47.3°F and 39.2°F (Velsen 1987).

Juvenile Rearing & Downstream Movement

Water temperature index values were developed to evaluate the combined steelhead rearing (fry and juvenile) and juvenile downstream movement lifestages. Some steelhead may rear in freshwater for up to three years before emigrating as yearling+ smolts, whereas other individuals move downstream shortly after emergence as post- emergent fry, or rear in the river for several months and move downstream as juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals continue to rear and grow in downstream areas and undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are assessed in this Technical Memorandum using the fry and juvenile rearing WTI values.

The growth, survival, and successful smoltification of juvenile steelhead are controlled largely by water temperature. The duration of freshwater residence for juvenile steelhead is long relative to that of Chinook salmon, making the juvenile lifestage of steelhead more susceptible to the influences of water temperature, particularly during the over-summer rearing period.

Central Valley juvenile steelhead have high growth rates at water temperatures in the mid-60°F range, but reportedly require lower water temperatures to successfully undergo the transformation to the smolt stage.

WTI values of 61°F, 63°F, 64°F, 65°F, 68°F, 72°F, 75°F, and 77°F were identified to represent a gradation of potential water temperature effects ranging between optimal to lethal conditions for steelhead juvenile rearing (Table 3). A water temperature of 61°F (7DADM) was identified as the value for steelhead juvenile rearing for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 61°F (7DADM) for "salmon and trout" core juvenile rearing. The WTI value of 63°F was identified because Myrick and Cech (2001) describe 63°F as the "preferred" water temperature for wild juvenile steelhead, whereas "preferred" water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" juvenile rearing (EPA 2003b). 65°F was also identified as a WTI value because NMFS (2000; 2002a) reported 65°F as the upper limit preferred for growth and development of Sacramento and American River juvenile steelhead. Also, 65°F was found to be within the optimum water temperature range for juvenile growth (i.e., 59-66°F) (Myrick and Cech 2001), and supported high growth of Nimbus strain juvenile steelhead (Cech and Myrick 1999). Increasing levels of thermal stress to this life stage may reportedly occur above the 65°F WTI value.

Kaya *et al.* (1977) reported that the upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F. Cherry *et al.* (1977) observed an upper preference water temperature near 68.0°F for juvenile rainbow trout, duplicating the upper preferred limit for juvenile steelhead observed in Cech and Myrick (1999) and FERC (1993). Growth for 200 mm juvenile *O. mykiss* versus temperature for three food levels (percent of maximum consumption = 30%, 50%, and 70%) was evaluated. The average empirically derived percent of maximum consumption in the Middle Fork American Fork River was 50% (Hanson *et al.* 1997). Positive growth only occurs up to approximately 68°F. Because of the literature describing 68°F as both an upper preferred and an avoidance limit for juvenile *O. mykiss*, and because of the empirical fish population data and bioenergetics growth data, 68°F was identified as an upper tolerable WTI value.

A WTI value of 72°F was identified because symptoms of thermal stress in juvenile steelhead have been reported to arise at water temperatures approaching 72°F. For example, physiological stress to juvenile steelhead in Northern California streams was demonstrated by increased gill flare rates, decreased foraging activity, and increased agonistic activity as stream temperatures rose above 71.6°F (Nielsen *et al.* 1994). Also, 72°F was identified as a WTI value because 71.6°F has been reported as an upper avoidance water temperature (Kaya *et al.* 1977) and an upper thermal tolerance water temperature (Ebersole *et al.* 2001) for juvenile rainbow trout. The WTI value of 75°F was identified because NMFS and EPA report that direct mortality to rearing juvenile steelhead results when stream temperatures reach 75°F (EPA 2002; NMFS 2001b). Water temperatures >77°F have been referred to as "lethal" to juvenile steelhead (FERC 1993; Myrick and Cech 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al.* 2000; McCullough 2001).

A swim tunnel study conducted on the Lower Tuolumne River (Verhille et al. 2016) generated high quality field data on the physiological performance of Tuolumne River *O. mykiss* acutely exposed to a temperature range of 13 to 25°C (55.4°F to 77°F). The data indicated that wild juvenile *O. mykiss* represents an exception to the expected based on the 7DADM criterion for juvenile rearing set out by EPA (2003b) for Pacific Northwest *O. mykiss*. The study recommended that a conservative upper aerobic performance limit of 71.6°F, instead of 64.4°F (EPA), be considered in re-determining a 7DADM for this population.

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified the UILT for *O. mykiss* juveniles has been estimated at 22.8–25.9ºC (73–79°F) (Threader and Houston 1983). In the model, an initial mortality threshold of 25°C (77°F) daily average temperature was identified for *O. mykiss* juveniles. Note also that both fry rearing and resident adult rearing lifestages of *O. mykiss* also had UILT values of 77°F to support the model.

For steelhead juvenile rearing, the Temperature Criteria Matrix identified 65°F for the Lower American River (Water Forum 2007); 61°F for the San Joaquin (CALFED 2009); and 65°F (Upper Optimum Value) and 68°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich *et al.* 2012).

Table 3. Steelhead Juvenile Rearing WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
61°F (16.1°C)	A water temperature of 61°F (7DADM) was identified as the value for steelhead juvenile rearing for the San Joaquin River (CALFED 2009).
63°F (17.2°C)	Preferred water temperature for wild juvenile steelhead is reportedly 63°F, whereas preferred water temperatures for juvenile hatchery steelhead reportedly range between 64-66°F. Myrick and Cech (2001)
64°F (17.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" juvenile rearing (EPA 2003b).
65°F (18.3°C)	Upper limit of 65°F preferred for growth and development of Sacramento River and American River juvenile steelhead (NMFS 2002a). Nimbus juvenile steelhead growth showed an increasing trend with water temperature to 66.2°F, irrespective of ration level or rearing temperature (Cech and Myrick 1999). The final preferred water temperature for rainbow fingerlings was between 66.2 and 68°F (Cherry *et al.* 1977). Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). A water temperature of 65°F (daily average temperature) was identified as the value for steelhead juvenile rearing for the Lower American River (Water Forum 2007). A water temperature of 65°F (MWAT) was identified as the Upper Optimum Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Index Value	Supporting Literature
68°F (20°C)	Nimbus juvenile steelhead preferred water temperatures between 62.6°F and 68.0°F (Cech and Myrick 1999). The final preferred water temperature for rainbow trout fingerlings was between 66.2°F and 68°F (Cherry *et al.* 1977). Rainbow trout fingerlings preferred or identified water temperatures in the 62.6°F to 68.0°F range (McCauley and Pond 1971). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al*. 1977). FERC (1993) referred to 68°F as "stressful" to juvenile steelhead. Empirical fish population and water temperature data in the North Yuba, Middle Yuba, South Yuba, Middle Fork American, and Rubicon Rivers (Figure 4 of Bratovich *et al.* 2012) indicate a sharp reduction in O. *mykiss* population densities when temperatures exceed 68°F for greater than one week. Bioenergetics modeling of growth based on consumption (P value = 0.5) in the Middle Fork American River watershed (adjacent watershed) indicates that growth likely does not occur above 68°F (Figure 5 of Bratovich *et al.* 2012). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for steelhead juvenile rearing for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
72°F (22.2°C)	Increased physiological stress, increased agonistic activity, and a decrease in forage activity in juvenile steelhead occur after ambient stream temperatures exceed 71.6°F (Nielsen *et al.* 1994). The upper avoidance water temperature for juvenile rainbow trout was measured at 68°F to 71.6°F (Kaya *et al.* 1977). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6°F to 79.9°F (Ebersole *et al.* 2001). A swim tunnel study conducted on the Lower Tuolumne recommended a conservative upper aerobic performance limit of 71.6°F for *O. mykiss* juvenile rearing (Verhille et al. 2016).
75°F (23.9°C)	The maximum weekly average water temperature for survival of juvenile and adult rainbow trout is 75.2°F (EPA 2002). Rearing steelhead juveniles have an upper lethal limit of 75.0°F (NMFS 2001a). Estimates of upper thermal tolerance or avoidance limits for juvenile rainbow trout (at maximum ration) ranged from 71.6 to 79.9°F (Ebersole *et al.* 2001). The UILT for juvenile rainbow trout, based on numerous studies, is between 75-79°F (Sullivan *et al*. 2000; McCullough 2001).
77°F (25°C)	In the model associated with the Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014), an initial mortality threshold of 77°F daily average temperature was identified for *O. mykiss* juveniles.

Smolt Emigration

Laboratory data suggest that smoltification, and therefore successful emigration of steelhead smolts, is directly controlled by water temperature (Adams *et al.* 1975) (Table 4). WTI values of 52°F and 55°F were identified to evaluate the steelhead smolt emigration lifestage, because most literature on water temperature effects on steelhead smolting suggest that water temperatures less than 52°F (Adams *et al.*1975; Myrick and Cech 2001; Rich 1987a) or less than 55°F (EPA 2003a; McCullough *et al.* 2001; Wedemeyer *et al.* 1980; Zaugg and Wagner 1973) are required for successful smoltification to occur. Adams *et al.* (1973) tested the effect of water temperature (43.7°F, 50.0°F, 59.0°F or 68.0°F) on the increase of gill microsomal Na^+-, K^+-stimulated ATPase activity associated with parr-smolt transformation in steelhead and found a two-fold increase in Na^+-, K^+-ATPase at 43.7 and 50.0°F, but no increase at 59.0°F or 68.0°F. In a subsequent study, the highest water temperature where a parr-smolt transformation occurred was at 52.3°F (Adams *et al.* 1975). The results of Adams *et al.* (1975) were reviewed in Myrick and Cech (2001) and Rich (1987b), which both recommended that water temperatures below 52.3°F are required to successfully complete the parr-smolt transformation. Further, Myrick and Cech (2001) suggest that water temperatures between 43-50°F are the "physiologically optimal" temperatures required during the parr-smolt transformation and necessary to maximize saltwater survival. The 52°F WTI value identified for the steelhead smolt emigration lifestage is the index value generally reported in the literature as the upper limit of the water temperature range that provides successful smolt transformation thermal conditions. Increasing levels of thermal stress to this lifestage may reportedly occur above the 52°F WTI value.

Zaugg and Wagner (1973) examined the influence of water temperature on gill ATPase activity related to parr-smolt transformation and migration in steelhead. They found ATPase activity was decreased and migration reduced when juveniles were exposed to water temperatures of 55.4°F or greater. In a technical document prepared by the EPA to provide temperature water quality standards for the protection of Northwest native salmon and trout, water temperatures greater than 54.5°F were identified as an impairment to smoltification for juvenile steelhead (EPA 2003b). Water temperatures are considered "unsuitable" for steelhead smolts at >59°F (Myrick and Cech 2001) and "lethal" at 77°F (FERC 1993).

For steelhead smolt emigration, the Temperature Criteria Matrix identified 57°F for the San Joaquin (CALFED 2009) and 52°F (Upper Optimum Value) and 55°F (Upper Tolerable Value) for the Yuba River Basin (Bratovich et al. 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 57°F (7DADM) for steelhead smoltification.

The Lower Tuolumne River *O. mykiss* Population Study (TID/MID 2014) identified an initial UILT mortality threshold of 77°F daily average temperature for *O. mykiss* smolts on the basis of literature reviews by Myrick and Cech (2001).

Table 4. Steelhead Smolt Emigration WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
52°F (11.1°C)	Steelhead successfully smolt at water temperatures in the 43.7°F to 52.3°F range (Myrick and Cech 2001). Steelhead undergo the smolt transformation when reared in water temperatures below 52.3°F, but not at higher water temperatures (Adams *et al.* 1975). Optimum water temperature range for successful smoltification in young steelhead is 44.0°F to 52.3°F (Rich 1987a). A water temperature of 52°F (MWAT) was identified as the Upper Optimum Value for steelhead smolt emigration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
55°F (12.8°C)	ATPase activity was decreased and migration reduced for steelhead at water temperatures greater than or equal to 55.4°F (Zaugg and Wagner 1973). Water temperatures should be below 55.4°F at least 60 days prior to release of hatchery steelhead to prevent premature smolting and desmoltification (Wedemeyer *et al.* 1980). In winter steelhead, a temperature of 54.1°F is nearly the upper limit for smolting (McCullough *et al.* 2001; Zaugg and Wagner 1973). Water temperatures less than or equal to 54.5°F are suitable for emigrating juvenile steelhead (EPA 2003b). Water temperatures greater than 55°F prevent increases in ATPase activity in steelhead juveniles (Hoar 1988). Water temperatures greater than 56°F do not permit smoltification in summer steelhead (Zaugg *et al.* 1972). A water temperature of 55°F (MWAT) was identified as the Upper Tolerable Value for steelhead smolt emigration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
57°F (13.9°C)	A water temperature of 57°F (7DADM) was identified as the value for steelhead smolt emigration for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 57°F (7DADM) for steelhead smoltification (EPA 2003b).

Index Value	Supporting Literature
59°F (15°C)	Yearling steelhead held at 43.7°F and transferred to 59°F had a substantial reduction in gill ATPase activity, indicating that physiological changes associated with smoltification were reversed (Wedemeyer *et al.* 1980).
77°F (25°C)	A water temperature of 77°F (daily average temperature) was identified as UILT mortality threshold for *O. mykiss* smolts (Myrick and Cech 2001 as cited in TID/MID 2014).

CHINOOK SALMON LIFESTAGE-SPECIFIC WATER TEMPERATURE INDEX VALUES

It has been suggested that separate water temperatures standards should be developed for each run-type of Chinook salmon. For example, McCullough (1999) states that spring-run Chinook salmon immigrate in spring and spawn in 3rd to 5th order streams and, therefore, face different migration and adult holding temperature regimes than do summer- or fall-run Chinook salmon, which spawn in streams of 5th order or greater . However:(1) there is a general paucity of literature specific to each lifestage of each run-type; (2) there is an insufficient amount of data available in the literature suggesting that Chinook salmon run-types respond to water temperatures differently; (3) the WTI values derived from all the literature pertaining to Chinook salmon for a particular lifestage will be sufficiently protective of that lifestage for each run-type; and (4) all run- types overlap in timing of adult immigration and holding and in some cases are not easily distinguished (Healey 1991). Information distinctly applicable to spring-run or fall-run Chinook salmon is identified where run-specific information is available.

Adult Immigration and Holding

The adult immigration and staging lifestages for fall-run Chinook salmon are evaluated together, because they are believed to not spend significant amounts of time after immigrating and prior to spawning. The adult immigration and holding lifestages are evaluated separately for spring-run Chinook salmon, because of the potential extended duration of holding after immigrating and prior to spawning.

The WTI values reflect a gradation of potential water temperature effects that range between those reported as "optimal" to those reported as "lethal" for adult Chinook salmon during upstream spawning migrations and holding. The WTI values identified for the Chinook salmon adult immigration and holding lifestage are 60°F, 61°F, 64°F, 65°F, 68°F and 70°F (Table 5). Although 56°F is referenced in the literature frequently as the upper "optimal" water temperature limit for upstream migration and holding, the references are not foundational studies and often are inappropriate citations. For example, Boles *et al.* (1988), Marine (1992), and NMFS (1997b) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for adult Chinook salmon immigration. However, Hinze (1959) is a study examining the effects of water temperature on incubating Chinook salmon eggs in the American River Basin. Further, water temperatures between 38-56°F are considered to represent the "observed range" for upstream migrating spring-run Chinook salmon (Bell 1986).

The lowest WTI value identified was 60°F because in a previous NMFS biological opinion for the proposed operation of the Central Valley Project (CVP) and State Water Project

(SWP), 59°F to 60°F is reported as…"*The upper limit of the optimal temperature range for adults holding while eggs are maturing*" (NMFS 2000). Also, NMFS (1997b) states…"*Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F*". Oregon Department of Environmental Quality (ODEQ; 1995) reports that "*…many of the diseases that commonly affect Chinook become highly infectious and virulent above 60°F*." Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b).

Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon. EPA (2003a) chose a holding value of 61°F (7DADM) based on laboratory data various assumptions regarding diel temperature fluctuations. The 61°F WTI value identified for the Chinook salmon adult immigration and holding lifestage is the index value generally reported in the literature as the upper limit of the optimal range, and is within the reported acceptable range. Increasing levels of thermal stress to this lifestage may reportedly occur above the 61°F WTI value.

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards (EPA 2003b) identifies 64°F (7DADM) for "salmon and trout" adult migration. A water temperature of 64°F (MWAT) was identified as the Upper Optimum Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al*. 2012).

An index value of 65°F was identified because Berman (1990) suggests effects of thermal stress to pre-spawning adults are evident at water temperatures near 65°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults that ranged from 63.5°F to 66.2°F. During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6 of Bratovich *et al.* 2012). Tracy McReynolds (pers. comm. October 2011) suggested that an upper tolerable holding temperature of 65°F was reasonable. A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

An index value of 68°F was identified because the Butte Creek data and the literature suggests that thermal stress at water temperatures greater than 68°F is pronounced, and severe adverse effects to immigrating and holding pre-spawning adults, including mortality, can be expected (Berman 1990; Marine 1997; NMFS 1997b; Ward *et al.* 2004).

Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68°F (Marine 1992). Water temperatures of 68°F resulted in nearly 100% mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Water temperatures between 70-77°F are reported as the range of maximum temperatures for holding pool conditions used by spring-run Chinook salmon in the Sacramento-San Joaquin system (Moyle *et al*. 1995). Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al*. 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).

For spring-run Chinook salmon adult immigration, the Framework Temperature Criteria Matrix identified 64°F (Upper Optimum Value) and 68°F (Upper Tolerable Value), MWAT, for the Yuba River Basin (Bratovich *et al*. 2012). For spring-run Chinook salmon adult holding, the Framework Temperature Criteria Matrix identified 61°F (Upper Optimum Value) and 65°F (Upper Tolerable Value), MWAT, for the Yuba River Basin (Bratovich *et al.* 2012).

Table 5. Chinook Salmon Adult Immigration and Holding WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F (15.6°C)	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59°F to 60°F (NMFS 1997b). Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NMFS 2000). Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60°F (ODEQ 1995). Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995b).
61°F (16.1°C)	A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). Ward and Kier (1999) designated temperatures <60.8°F as an "optimum" water temperature threshold for holding Battle Creek spring-run Chinook salmon.
64°F (17.8°C)	A water temperature of 64°F (MWAT) was identified as the Upper Optimum Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM) for "salmon and trout" adult migration (EPA 2003b).
65°F (18.3°C)	Acceptable range for adults migrating upstream is from 57°F to 67°F (NMFS 1997b). Disease risk becomes high at water temperatures above 64.4°F (EPA 2003b). Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5°F to 66.2°F (Berman 1990). During each of the years when Chinook salmon temperature mortality was not observed at Butte Creek (2001, 2004-2007), on average, daily temperature did not exceed 65.8°F for more than 7 days (Figure 6 of Bratovich *et al.* 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult holding for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Index Value	Supporting Literature
68°F (20°C)	Acceptable water temperatures for adults migrating upstream range from 57°F to 67°F (NMFS 1997b). For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992). Water temperatures of 68°F resulted in nearly 100% mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963). Adult Chinook salmon migration rates through the lower Columbia River were slowed significantly when water temperatures exceeded 68°F (Goniea *et al.* 2006). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook adult migration for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
70°F (21.1°C)	Migration blockage occurs for Chinook salmon at temperatures from 70-71+°F (McCollough 1999; McCullough *et al.* 2001; EPA 2003b). Strange (2010) found that the mean average body temperature during the first week of Chinook salmon migration on the Klamath River was 71.4°F. The UILT for Chinook salmon jacks is 69.8-71.6°F (McCullough 1999).

Spawning and Embryo Incubation

The adult spawning and embryo (i.e., eggs and alevins) incubation lifestages share one set of WTI values because spawning and embryonic survival and development typically are considered concurrently in the literature on the effects of water temperature. Spawning and incubation evaluations are conducted separately due to differences in their temporal distributions.

The WTI values identified for the Chinook salmon spawning and embryo incubation lifestages are 55°F, 56°F, 58°F, 60°F, and 62°F (Table 6). Anomalously, FERC (1993) refers to 50°F as the "optimum" water temperature for spawning and incubating Chinook salmon. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning, egg incubation, and fry emergence (EPA 2003b). A water temperature of 55°F (7DADM) was identified as the value for Chinook incubation for the San Joaquin River fall-run Chinook salmon (CALFED 2009).

Additionally, for the adult spawning lifestage, FERC (1993) reports "stressful" and "lethal" water temperatures occurring at >60°F and >70°F, respectively, whereas for incubating Chinook salmon embryos, water temperatures are considered to be "stressful" at <56°F or "lethal" at >60°F. Much literature suggests that water temperatures must be less than or equal to 56°F for maximum survival of Chinook salmon embryos (i.e., eggs and alevins) during spawning and incubation. NMFS (1993b) reported that optimum water temperatures for egg development are between 43°F and 56°F. Similarly, Myrick and Cech (2001) reported the highest egg survival rates occur between water temperatures of 39-54°F. Reclamation (unpublished work) reports that water temperatures less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs. Bell (1986) recommends water temperatures ranging between 42-57°F for spawning Chinook salmon, and water temperatures between 41-58°F for incubating embryos. USFWS (1995a) reported a water temperature range of 41°F to 56°F for maximum survival of eggs and yolk-sac larvae in the Central Valley of California. The preferred water temperature range for Chinook salmon egg incubation in the Sacramento River was suggested as 42°F to 56°F (NMFS 1997a). Alevin mortality is reportedly significantly higher when Chinook salmon embryos are incubated at water temperatures above 56°F (USFWS 1999). NMFS (2002a) reported 56°F as the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River. The 56°F WTI value identified for the Chinook salmon spawning and embryo incubation lifestage is the index value generally reported in the literature as the upper limit of the optimal range for egg development and the upper limit of the range reported to provide maximum survival of eggs and yolk-sac larvae in the Central Valley of California. Increasing levels of thermal stress to this lifestage may reportedly occur above the 56°F WTI value.

High survival of Chinook salmon embryos also has been suggested to occur at incubation temperatures at or near 58°F. For example, (Reclamation Unpublished Work) reported that the natural rate of mortality for alevins occurs at 58°F or less. Combs (1957) concluded constant incubation temperatures between 42.5°F and 57.5°F resulted in normal development of Chinook salmon eggs, and NMFS (2002a) suggests 53°F to 58°F is the preferred water temperature range for Chinook salmon eggs and fry. The model associated with the Chinook Salmon Population Model Study (TID/MID 2013), established an initial acute egg/alevin mortality threshold of 58°F. A water temperature of 58°F (MWAT) was identified as the Upper Tolerable Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).

Johnson (1953) found consistently higher Chinook salmon egg losses resulted at water temperatures above 60°F than at lower temperatures. In order to protect late incubating Chinook salmon embryos and newly emerged fry NMFS (1993a) determined that a water temperature criterion of less than or equal to 60°F be maintained in the Sacramento River from Keswick Dam to Bend Bridge from October 1 to October 31. Seymour (1956) provides evidence that 100% mortality occurs to late incubating Chinook salmon embryos when held at a constant water temperature greater than or equal to 60°F. For Chinook salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957), however, found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F/month). The Chinook Salmon Population Model (TID/MID 2013) established an initial estimate of 60.4°F as the upper limit for initiation of spawning (Groves and Chandler 1999); also interpreted as the temperature at which spawning habitat will be considered usable by spawners.

The literature largely agrees that 100% mortality will result to Chinook salmon embryos incubated at water temperatures greater than or equal to about 62°F (Hinze 1959; Myrick and Cech 2003; Seymour 1956; USFWS 1999). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Geist *et al.* (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

For Chinook salmon spawning and incubation, the Framework Temperature Criteria Matrix identified 60°F or less (as early in October as possible) and 56°F or less (as early in November as possible) as water temperature targets for lower American River fall-run Chinook salmon (Water Forum 2007); 64°F (spawning) and 55°F (incubation) for San Joaquin fall-run Chinook salmon (CALFED 2009); 56°F for Shasta River winter and spring-run Chinook salmon (SWRCB 2016); and 56°F (Upper Optimum Value) and 58°F (Upper Tolerable Value) in the Yuba River Basin (Bratovich *et al*. 2012).

Table 6. Chinook Salmon Spawning and Embryo Incubation WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
55°F (12.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 55°F (7DADM) for "salmon and trout" spawning, egg incubation, and fry emergence (EPA 2003b). A water temperature of 55°F (7DADM) was identified as the value for Chinook incubation for the San Joaquin River fall-run Chinook salmon (CALFED 2009).
56°F (13.3°C)	Less than 56°F results in a natural rate of mortality for fertilized Chinook salmon eggs (Reclamation Unpublished Work). Optimum water temperatures for egg development are between 43°F and 56°F (NMFS 1993b). Upper value of the water temperature range (i.e., 41°F to 56°F) suggested for maximum survival of eggs and yolk-sac larvae in the Central Valley of California (USFWS 1995b). Upper value of the range (i.e., 42°F to 56°F) given for the preferred water temperature for Chinook salmon egg incubation in the Sacramento River (NMFS 1997a). Incubation temperatures above 56°F result in significantly higher alevin mortality (USFWS 1999). 56°F is the upper limit of suitable water temperatures for spring-run Chinook salmon spawning in the Sacramento River (NMFS 2002a). Water temperatures averaged 56.5°F during the week of fall-run Chinook salmon spawning initiation on the Snake River (Groves and Chandler 1999). A water temperature of 56°F or less (daily average temperature), as early in November as possible, was identified as the value for fall-run Chinook salmon spawning and incubation for the lower American River (Water Forum 2007). A water temperature of 56°F (daily average temperature) was identified as the value for Chinook spawning and incubation for the Shasta River winter- and spring-run Chinook (SWRCB 2016). A water temperature of 56°F (MWAT) was identified as the Upper Optimum Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
58°F (14.4°C)	Upper value of the range given for preferred water temperatures (i.e., 53°F to 58°F) for eggs and fry (NMFS 2002a). Constant egg incubation temperatures between 42.5°F and 57.5°F resulted in normal development (Combs and Burrows 1957). The natural rate of mortality for alevins occurs at 58°F or less (Reclamation Unpublished Work). The model associated with the Chinook Salmon Population Model Study, established an initial acute egg/alevin mortality threshold of 58°F (TID/MID 2013). A water temperature of 58°F (MWAT) was identified as the Upper Tolerable Value for Chinook spawning and incubation for the Yuba Reintroduction Assessment (Bratovich *et al.* 2012).
60°F (15.6°C)	100% mortality can occur to late incubating Chinook salmon embryos (yolk-sac stage) if temperatures are 60°F or greater (Seymour 1956). An October 1 to October 31 water temperature criterion of less than or equal to 60°F in the Sacramento River from Keswick Dam to Bend Bridge has been determined for protection of late incubating larvae and newly emerged fry (NMFS 1993b). Mean weekly water temperature at first observed Chinook salmon spawning in the Columbia River was 59.5°F (Dauble and Watson 1997). Consistently higher egg losses resulted at water temperatures above 60°F than at lower temperatures (Johnson and Brice 1953). For Chinook Salmon eggs incubated at constant temperatures, mortality increases rapidly at temperatures greater than about 59-60°F (see data plots in Myrick and Cech 2001). Olsen and Foster (1957) found high survival of Chinook salmon eggs and fry (89.6%) when incubation temperatures started at 60.9°F and declined naturally for the Columbia River (about 7°F/month). A water temperature of 60°F or less (daily average temperature), as early in October as possible, was identified as a target value for Chinook spawning and incubation for the lower American River fall-run Chinook (Water Forum 2007). The model associated with the Chinook Salmon Population Model Study (TID/MID 2013), established an initial estimate of 60.4°F as the upper limit for initiation of spawning (Groves and Chandler 1999).

Index Value	Supporting Literature
62°F (16.7°C)	100% mortality of fertilized Chinook salmon eggs after 12 days at 62°F (Reclamation Unpublished Work). Incubation temperatures of 62ºF to 64°F appear to be the physiological limit for embryo development resulting in 80 to 100% mortality prior to emergence (USFWS 1999). 100% loss of eggs incubated at water temperatures above 62°F (Hinze 1959). 100% mortality occurs during yolk-sac stage when embryos are incubated at 62.5°F (Seymour 1956). Approximately 80% or greater mortality of eggs incubated at constant temperatures of 63°F or greater (see data plots in Myrick and Cech 2001). Geist *et al*. (2006) found low Chinook salmon incubation survival (1.7%) for naturally declining temperatures (0.36°F/day) when temperatures started at 62.6°F.

Juvenile Rearing and Downstream Movement

WTI values were developed to evaluate the Chinook salmon rearing (fry and juvenile) and juvenile downstream movement lifestages. Some Chinook salmon juveniles, both fall-run and spring-run, move downstream shortly after emergence as post- emergent fry, or rear in the river for several months and move downstream as YOY juveniles without exhibiting the ontogenetic characteristics of smolts. Presumably, these individuals undergo the smoltification process prior to entry into saline environments. Thus, fry and juvenile rearing occur concurrently with post-emergent fry and juvenile downstream movement and are presented in this Technical Memorandum using the fry and juvenile rearing WTI values.

The WTI values of 60°F, 61°F, 64°F, 65°F, 68°F, 70°F, 73°F, 75°F, and 77°F were identified for the Chinook salmon juvenile rearing and downstream movement lifestage. The lowest index value of 60°F was identified because regulatory documents as well as several source studies, including ones conducted on Central Valley Chinook salmon fry and juveniles, report 60°F as an optimal water temperature for growth (Banks *et al.* 1971; Brett *et al.* 1982; Marine 1997; NMFS 1997b; NMFS 2000; NMFS 2001a; NMFS 2002; Rich 1987b) (Table 7). Water temperatures below 60°F also have been reported as providing conditions optimal for fry and fingerling growth, but were not identified as index values, because the studies were conducted on fish from outside of the Central Valley (Brett 1952; Seymour 1956). Studies conducted using local fish may be particularly important because *Oncorhynchus* species show considerable variation in morphology, behavior, and physiology along latitudinal gradients (Myrick 1998; Taylor 1990b; Taylor 1990a). More specifically, it has been suggested that salmonid populations in the Central Valley prefer higher water temperatures than those from more northern latitudes (Myrick and Cech 2000).

The 60°F WTI value identified for the Chinook salmon juvenile rearing and downstream movement lifestage is the index value generally reported in the literature as the upper limit of the optimal range for fry and juvenile growth and the upper limit of the preferred range for growth and development of spring-run Chinook salmon fry and fingerlings. NMFS (2002a) identified 60°F as the “preferred” water temperature for juvenile spring-run Chinook salmon in the Central Valley. Increasing levels of thermal stress to this lifestage may reportedly occur above the 60°F WTI value.

A water temperature of 61°F (7DADM) was identified as the value for Chinook juvenile rearing for the San Joaquin River (CALFED 2009). A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 61°F (7DADM; early year) for salmon juvenile rearing (EPA 2003b).

EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM; late year) for salmon juvenile rearing (EPA 2003b). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64°F are considered not ″properly functioning" by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by *C. columnaris* are high at temperatures greater than or equal to 64°F (EPA 2001). Optimal range for Chinook salmon survival and growth from 53°F to 64°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001).

The index value of 65°F was identified because it represents an intermediate value between 64°F and 66.2°F, at which both adverse and beneficial effects to juvenile salmonids have been reported to occur. For example, at temperatures approaching and beyond 65°F, sub-lethal effects associated with increased incidence of disease reportedly become severe for juvenile Chinook salmon (EPA 2003a; Johnson and Brice 1953; Ordal and Pacha 1963; Rich 1987a). Conversely, numerous studies report that temperatures between 64.0°F and 66.2°F provide conditions ranging from suitable to optimal for juvenile Chinook salmon growth (Brett *et al.* 1982; Cech and Myrick 1999; Clarke and Shelbourn 1985; EPA 2003a; Myrick and Cech 2001; NMFS 2002; USFWS 1995b). Maximum growth of juvenile fall-run Chinook salmon has been reported to occur in the American River at water temperatures between 56-59°F (Rich 1987b) and in Nimbus Hatchery spring-run Chinook salmon at 66°F (Cech and Myrick 1999). Bioenergetics modeling of growth based on consumption for 100 mm juvenile Chinook salmon in the Middle Fork American River watershed indicates that growth likely does not occur above about 65°F (Figure 5 of Bratovich *et al*. 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook salmon (Bratovich *et al.* 2012).

A WTI value of 68°F was identified because, at water temperatures above 68°F, sub-lethal effects become severe such as reductions in appetite and growth of juveniles (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).

Chronic stress associated with water temperature can be expected when conditions reach the index value of 70°F. For example, growth becomes drastically reduced at temperatures close to 70.0°F and has been reported to be completely prohibited at 70.5°F (Brett *et al.* 1982; Marine 1997). No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett *et al.* 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck *et al.* 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ± 1.8°F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).

A WTI value of 73.4°F was identified because, in a laboratory study of juvenile fall-run Chinook salmon from the Mokelumne River Hatchery, in testing across a range of environmentally relevant acute temperature changes (from 53.6°F to 78.8°F), routine metabolic rate (RMR) and maximal metabolic rate (MMR) increased with acute warming, but aerobic capacity was unaffected by test temperatures up to 73.4°F in both acclimation groups of 59°F and 62.2°F (Poletto et al. 2017).

75°F was identified as a WTI value because high levels of direct mortality to juvenile Chinook salmon reportedly result at this water temperature (Cech and Myrick 1999; Hanson 1991; Myrick and Cech 2001; Rich 1987b). Other studies have suggested higher upper lethal water temperature levels (Brett 1952; Orsi 1971), but 75°F was identified because it was derived from experiments using Central Valley Chinook salmon and it is a more rigorous index value representing a more protective upper lethal water temperature level. Furthermore, the lethal level determined in Rich (1987b) was derived using slow rates of water temperature change and, thus, is ecologically relevant. The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan *et al.* 2000; McCullough *et al.* 2001; Myrick and Cech 2001). Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952; Orsi 1971), the Chinook Salmon Population Model (TID/MID 2013) identified an initial UILT mortality threshold of 77°F for Chinook salmon juveniles as a daily average water temperature. Note that the model also identified this same value for fry mortality.

Table 7. Chinook Salmon Juvenile Rearing and Downstream Movement WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F (15.6°C)	Optimum water temperature for Chinook salmon fry growth is between 55°F and 60°F (Seymour 1956). Water temperature range that produced optimum growth in juvenile Chinook salmon was between 54°F and 60°F (Rich 1987b). Water temperature criterion of less than or equal to 60°F for the protection of Sacramento River winter-run Chinook salmon from Keswick Dam to Bend Bridge (NMFS 1993b). Upper optimal water temperature limit of 61°F for Sacramento River fall-run Chinook salmon juvenile rearing (Marine 1997; Marine and Cech 2004). Upper water temperature limit of 60°F preferred for growth and development of spring-run Chinook salmon fry and fingerlings (NMFS 2000; NMFS 2002a). To protect salmon fry and juvenile Chinook salmon in the upper Sacramento River, daily average water temperatures should not exceed 60°F after September 30 (NMFS 1997b). A water temperature of 60°F appeared closest to the optimum for growth of fingerlings (Banks et al. 1971). Optimum growth of Nechako River Chinook salmon juveniles would occur at 59°F at a feeding level that is 60% of that required to satiate them (Brett et al. 1982). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F

Index Value	Supporting Literature
	and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
61°F (16.1°C)	A water temperature of 61°F (7DADM) was identified as the value for Chinook juvenile rearing for the San Joaquin River (CALFED 2009). A water temperature of 61°F (MWAT) was identified as the Upper Optimum Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich et al. 2012). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 61°F (7DADM; early year) for salmon juvenile rearing (EPA 2003b).
64°F (17.8°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 64°F (7DADM; late year) for salmon juvenile rearing (EPA 2003b). Recommended summer maximum water temperature of 64.4°F for migration and non-core rearing (EPA 2003b). Water temperatures greater than 64°F are considered not ″properly functioning" by NMFS in Amendment 14 to the Pacific Coast Salmon Plan (NMFS 1995). Fatal infection rates caused by C. columnaris are high at temperatures greater than or equal to 64°F (EPA 2001). Optimal range for Chinook salmon survival and growth from 53°F to 64°F (USFWS 1995b). Survival of Central Valley juvenile Chinook salmon declines at temperatures greater than 64.4°F (Myrick and Cech 2001).
65°F (18.3°C)	Water temperatures between 45°F to 65°F are preferred for growth and development of fry and juvenile spring-run Chinook salmon in the Feather River (NMFS 2002a). Disease mortalities diminish at water temperatures below 65°F (Ordal and Pacha 1963). Fingerling Chinook salmon reared in water greater than 65°F contracted C. columnaris and exhibited high mortality (Johnson and Brice 1953). Water temperatures greater than 64.9°F identified as being stressful in the Columbia River Ecosystem (Independent Scientific Group 1996). Juvenile Chinook salmon have an optimum temperature for growth that appears to occur at about 66.2°F (Brett et al. 1982). Juvenile Chinook salmon reached a growth maximum at 66.2°F (Cech and Myrick 1999). Increased incidence of disease, reduced appetite, and reduced growth rates at 66.2 ± 1.4 °F (Rich 1987b). Bioenergetics modeling of growth based on consumption for 100 mm juvenile Chinook salmon in the Middle Fork American River watershed indicates that growth likely does not occur above about 65°F (Figure 5 of Bratovich et al. 2012). A water temperature of 65°F (MWAT) was identified as the Upper Tolerable Value for Chinook juvenile rearing for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook salmon (Bratovich et al. 2012).
68°F (20°C)	Sacramento River juvenile Chinook salmon reared at water temperatures greater than or equal to 68°F suffer reductions in appetite and growth (Marine 1997; Marine and Cech 2004). Significant reductions in growth rates may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck et al. 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997).
70°F (21.1°C)	No growth at all would occur for Nechako River juvenile Chinook salmon at 70.5°F (Brett et al. 1982; Zedonis and Newcomb 1997). Juvenile spring-run Chinook salmon were not found in areas having mean weekly water temperatures between 67.1°F and 71.6°F (Burck et al. 1980; Zedonis and Newcomb 1997). Results from a study on wild spring-run Chinook salmon in the John Day River system indicate that juvenile fish were not found in areas having mean weekly water temperatures between 67.1°F and 72.9°F (McCullough 1999; Zedonis and Newcomb 1997). Increased incidence of disease, hyperactivity, reduced appetite, and reduced growth rates at 69.8 ± 1.8 °F (Rich 1987b). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly

Index Value	Supporting Literature
	decreased growth rates and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004).
73°F (23°C)	In a laboratory study of juvenile fall-run Chinook salmon from the Mokelumne River Hatchery, RMR and MMR increased with acute warming, but aerobic capacity was unaffected by test temperatures up to 23°C in both acclimation groups of 59°F and 62.2°F (Poletto et al. 2017).
75°F (23.9°C)	For juvenile Chinook salmon in the lower American River fed maximum rations under laboratory conditions, 75.2°F was determined to be 100% lethal due to hyperactivity and disease (Rich 1987b; Zedonis and Newcomb 1997). Lethal temperature threshold for fall-run juvenile Chinook salmon between 74.3°F and 76.1°F (McCullough 1999). In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F (Marine 1997; Marine and Cech 2004). The juvenile Chinook Salmon UILT based on numerous studies is 75-77°F (Sullivan et al. 2000; McCullough et al. 2001; Myrick and Cech 2001).
77°F (25°C)	The model associated with the Chinook Salmon Population Model Study, established an initial UILT mortality threshold of 77°F (daily average temperatures) for Chinook salmon fry and juveniles (Brett 1952 and Orsi 1971, as cited in TID/MID 2013).

Smolt Emigration

Juvenile Chinook salmon that exhibit extended rearing in a riverine environment are assumed to undergo the smoltification process and volitionally emigrate from the river as smolts. WTI values of 57°F, 59°F, 63°F, 68°F 72°F, and 77°F were identified for the Chinook salmon smolt emigration lifestage (Table 8).

A water temperature of 57°F (7DADM) was identified as the value for Chinook smolt migration for the San Joaquin River (CALFED 2009). EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 59°F (7DADM; late year) for salmon smolts (EPA 2003b).

A WTI value of 63°F was identified because water temperatures at or below this value allow for successful transformation to the smolt stage, and water temperatures above this value may result in impaired smoltification indices, inhibition of smolt development, and decreased survival and successful smoltification of juvenile Chinook salmon. Laboratory experiments suggest that water temperatures at or below 62.6°F provide conditions that allow for successful transformation to the smolt stage (Clarke and Shelbourn 1985; Marine 1997; Zedonis and Newcomb 1997). 62.6°F was rounded and used to support an index value of 63°F. A water temperature of 63°F (MWAT) was identified as the Upper Optimum Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).

Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989). A WTI value of 68°F was identified because water temperatures above 68°F prohibit successful smoltification (Marine 1997; Rich 1987a; Zedonis and Newcomb 1997). Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook smolt migration for the Yuba Reintroduction Assessment for spring-run Chinook salmon (Bratovich *et al*. 2012).

Support for an index value of 72°F is provided from a study conducted by (Baker *et al.* 1995) in which a statistical model is presented that treats survival of Chinook salmon smolts fitted with coded wire tags in the Sacramento River as a logistic function of water temperature. Using data obtained from mark-recapture surveys, the statistical model suggests a 95% confidence interval for the upper incipient lethal water temperature for Chinook salmon smolts as 71.5°F to 75.4°F. In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F. Furthermore, fish reared between 63°F and 68°F did not have significantly different growth rates compared to those reared at 55°F and 61°F (Marine 1997; Marine and Cech 2004). Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).

Based upon information reviewed for Chinook salmon juvenile mortality (Brett 1952), the Chinook Salmon Population Model (TID/MID 2013) identified an initial mortality threshold of 77°F for Chinook salmon smolts as a daily average water temperature.

Table 8. Chinook Salmon Smolt Emigration WTI Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
57°F (13.9°C)	A water temperature of 57°F (7DADM) was identified as the value for Chinook smolt migration for the San Joaquin River (CALFED 2009).
59°F (15°C)	EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards identifies 59°F (7DADM; late year) for salmon smolts (EPA 2003b).
63°F (17.2°C)	Acceleration and inhibition of Sacramento River Chinook salmon smolt development reportedly may occur at water temperatures above 63°F (Marine 1997; Marine and Cech 2004). Laboratory evidence suggest that survival and smoltification become compromised at water temperatures above 62.6°F (Zedonis and Newcomb 1997). Juvenile Chinook salmon growth was highest at 62.6°F (Clarke and Shelbourn 1985). A water temperature of 63°F (MWAT) was identified as the Upper Optimum Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).

Index Value	Supporting Literature
68°F (20°C)	Significant inhibition of gill sodium ATPase activity and associated reductions of hyposmoregulatory capacity, and significant reductions in growth rates, may occur when chronic elevated temperatures exceed 68°F (Marine 1997; Marine and Cech 2004). Water temperatures supporting smoltification of fall-run Chinook salmon range between 50°F to 68°F, the colder temperatures represent more optimal conditions (50°F to 62.6°F), and the warmer conditions (62.6°F to 68°F) represent marginal conditions (Zedonis and Newcomb 1997). A water temperature of 68°F (MWAT) was identified as the Upper Tolerable Value for Chinook smolt migration for the Yuba Reintroduction Assessment for both fall- and spring-run Chinook (Bratovich *et al.* 2012).
72°F (22.2°C)	In a laboratory study, juvenile fall-run Chinook salmon from the Sacramento River reared in water temperatures between 70°F and 75°F experienced significantly decreased growth rates, impaired smoltification indices, and increased predation vulnerability compared with juveniles reared between 55°F and 61°F. Furthermore, fish reared between 63°F and 68°F did not have significantly different growth rates compared to those reared at 55°F and 61°F (Marine 1997; Marine and Cech 2004). Indirect evidence from tagging studies suggests that the survival of fall-run Chinook salmon smolts decreases with increasing water temperatures between 59°F and 75°F in the Sacramento-San Joaquin Delta (Kjelson and Brandes 1989).
77°F (25°C)	The model associated with the Chinook Salmon Population Model Study, established an initial mortality threshold of 77°F (daily average temperatures) for Chinook salmon smolts (Brett 1952 as cited in TID/MID 2013).

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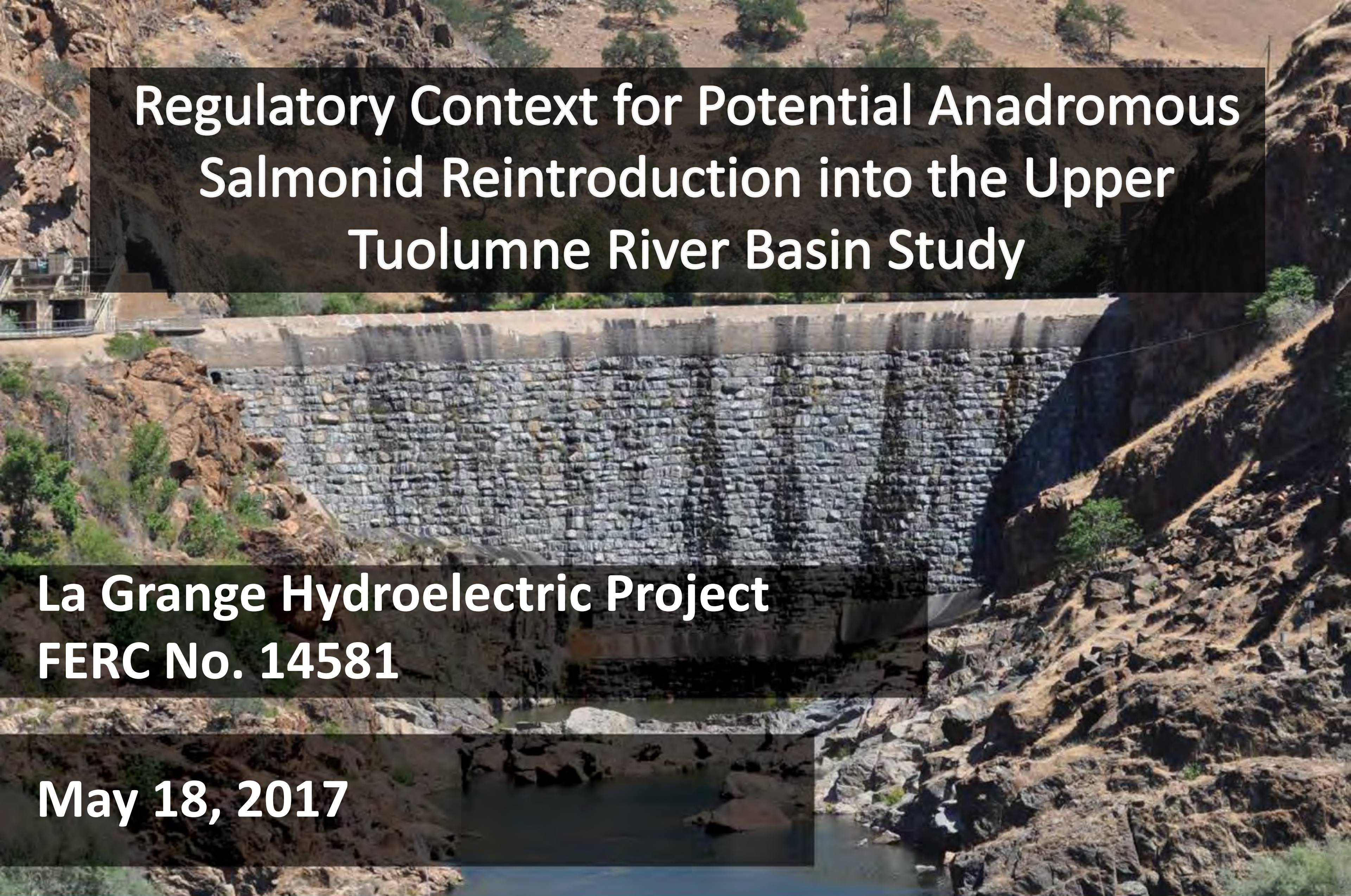
	UOWTI (MWAT)	UTWTI (MWAT)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spring-run Chinook Salmon														
Adult Upstream Migration	64	68												
Adult Holding	61	65												
Adult Spawning	56	58												
Embryo Incubation and Emergence	56	58												
Fry Rearing	65	68												
Juvenile Rearing and Downstream Movement	65	68												
Smolt Outmigration	63	68												
Steelhead														
Adult Upstream Migration	64	68												
Holding	61	65												
Adult Spawning	54	57												
Embryo Incubation and Emergence	54	57												
Fry Rearing	68	72												
Juvenile Rearing and Downstream Movement	68	72												
Smolt Outmigration	55	57												

UOWTI = Upper Optimum Water Temperature Index
UTWTI = Upper Tolerance Water Temperature Index

May 2017



Regulatory Context for Potential Anadromous Salmonid Reintroduction into the Upper Tuolumne River Basin Study

La Grange Hydroelectric Project
FERC No. 14581

May 18, 2017

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Regulatory Context for Potential Reintroduction Study Goals and Objectives

- Identify applicable existing legal precedent, regulatory guidance and resource management plans in the study area
- Identify additional regulatory guidance and rules that may apply to or affect the reintroduction of fall-run and spring-run Chinook and/or steelhead
- Identify federal, state, and local regulatory issues associated with a potential fish passage/reintroduction program

Regulatory Context for Potential Reintroduction Study Area

- Entire Tuolumne River basin, including Don Pedro Reservoir and the mainstem Tuolumne River
- Associated tributaries (North Fork Tuolumne River, Clavey River, Cherry Creek, etc.) and surrounding public and private land

Regulatory Context for Potential Reintroduction Study Methodology

- Step 1: identify and assemble relevant documents for the study area, including plans provided by state and federal agencies
- Step 2: review the resource management documents and create a comprehensive summary of planning goals and regulations relevant to potential reintroduction of Chinook and/or steelhead or fish passage in the basin

Regulatory Context for Potential Reintroduction

Documents Reviewed for Potential Applicability

- California Water Action Plan 2016 Update (State of California [California Natural Resources Agency (CNRA), CDFA, and California Environmental Protection Agency (CalEPA)] 2016)
- Sierra Nevada Watershed Improvement Program Regional Strategy DRAFT (Sierra Nevada Conservancy and USFS 2016)
- Stanislaus Urban County and City of Turlock Regional Consolidated Plan Fiscal Years 2015-2020 (Stanislaus County 2015)
- Stanislaus County General Plan (Stanislaus County 2015)
- Sierra Nevada Forest and Community Initiative (SNFCI) Action Plan (Sierra Nevada Conservancy 2014)
- California State Wildlife Action Plan 2015 Update (CDFW 2015)
- The State of the Sierra Nevada's Forests (Sierra Nevada Conservancy 2014)
- Tuolumne Wild and Scenic River Comprehensive Management Plan Record of Decision and supporting documents (National Park Service [NPS] 2014)
- Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead (NMFS 2014)
- Watershed Condition Framework (USFS 2011)
- Stanislaus National Forest Plan Direction (USFS 2010)
- Sierra Resource Management Plan (BLM 2008)
- City of Waterford General Plan Update Vision 2025 (City of Waterford 2006)
- Sierra Nevada Forest Plan and Amendments (USFS 2004, 2013)
- 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)
- City of Ceres General Plan (City of Ceres 1997)
- Tuolumne County General Plan, Policy Document (Tuolumne County 1996)
- Steelhead Restoration and Management Plan for California (California Department of Fish and Game 1996)
- Restoring Central Valley Streams: A Plan for Action (CDF&G 1993)
- Tuolumne Wild and Scenic River Management Plan (USFS 1988)
- Final Red Hills Management Plan and Environmental Assessment (BLM 1985)
- Yosemite National Park, General Management Plan (Visitor Use/Park Operations/Development) (NPS 1980)

Regulatory Context for Potential Reintroduction Study Update

- Relevant plans and policies identified (continued):
  - Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead (NMFS 2014)
  - California State Wildlife Action Plan 2015 Update (CDFW September 2015)
  - Tuolumne Wild and Scenic River Comprehensive Management Plan Record of Decision and supporting documents (NPS 2014)
  - Sierra Nevada Forest Plan and Amendments (USFS 2004, 2013)
  - Stanislaus National Forest, Forest Plan Direction (USFS 2010)

Regulatory Context for Potential Reintroduction Study Update

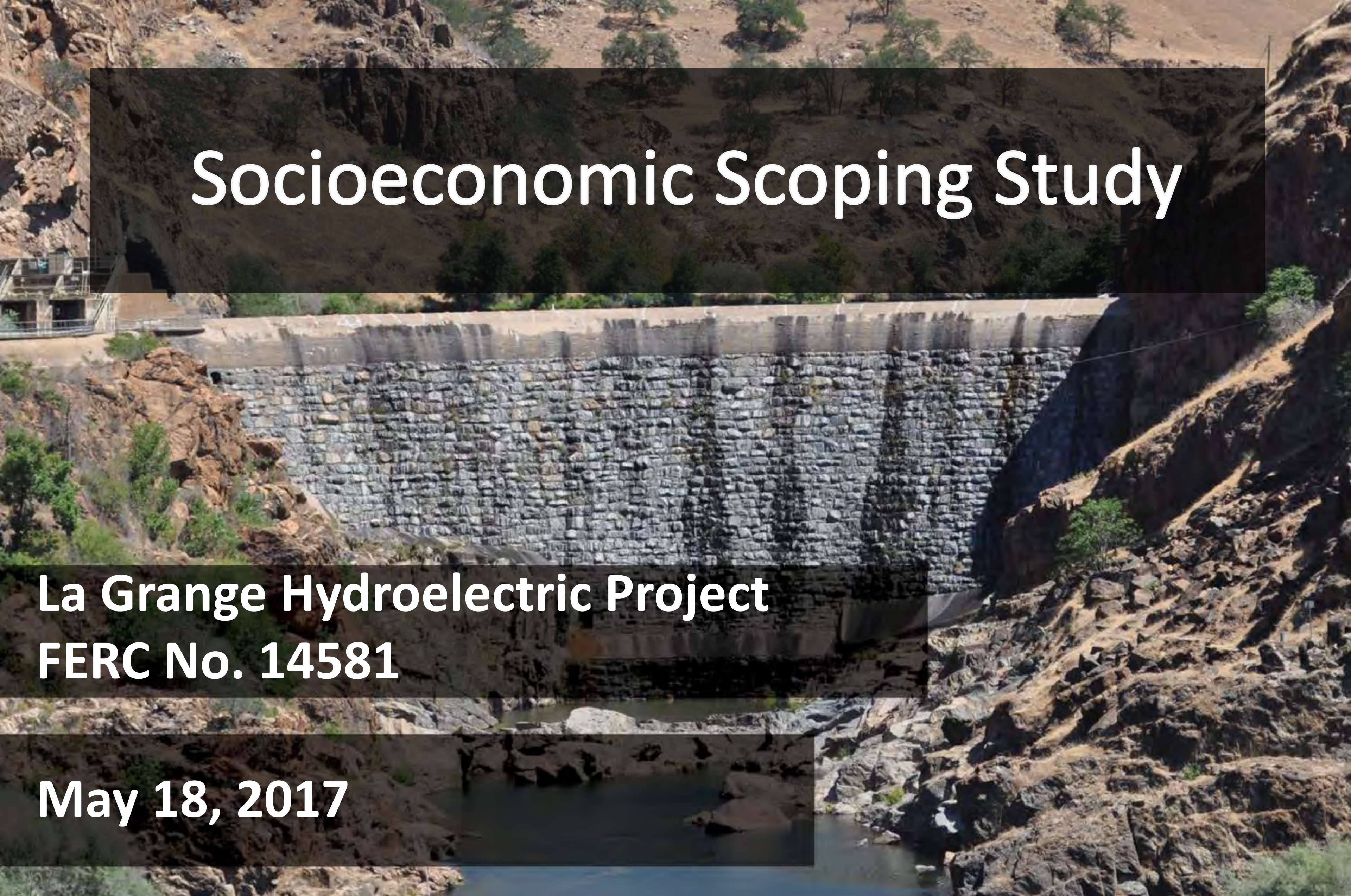
- Relevant plans and policies identified (continued):
  - Sierra Resource Management Plan and Record of Decision (BLM 2008)
  - Final Restoration Plan for the Anadromous Fish Restoration Program: A Plan to Increase Natural Production of Anadromous Fish in the Central Valley of California (USFWS 2001)
  - Steelhead Restoration and Management Plan for California (CDF&G and Sport Fish Restoration 1996)
  - National Forest Management Act (1976)

Regulatory Context for Potential Reintroduction Study Status

- Data has been collected and compiled
- Report preparation is ongoing

Questions?

Socioeconomic Scoping Study



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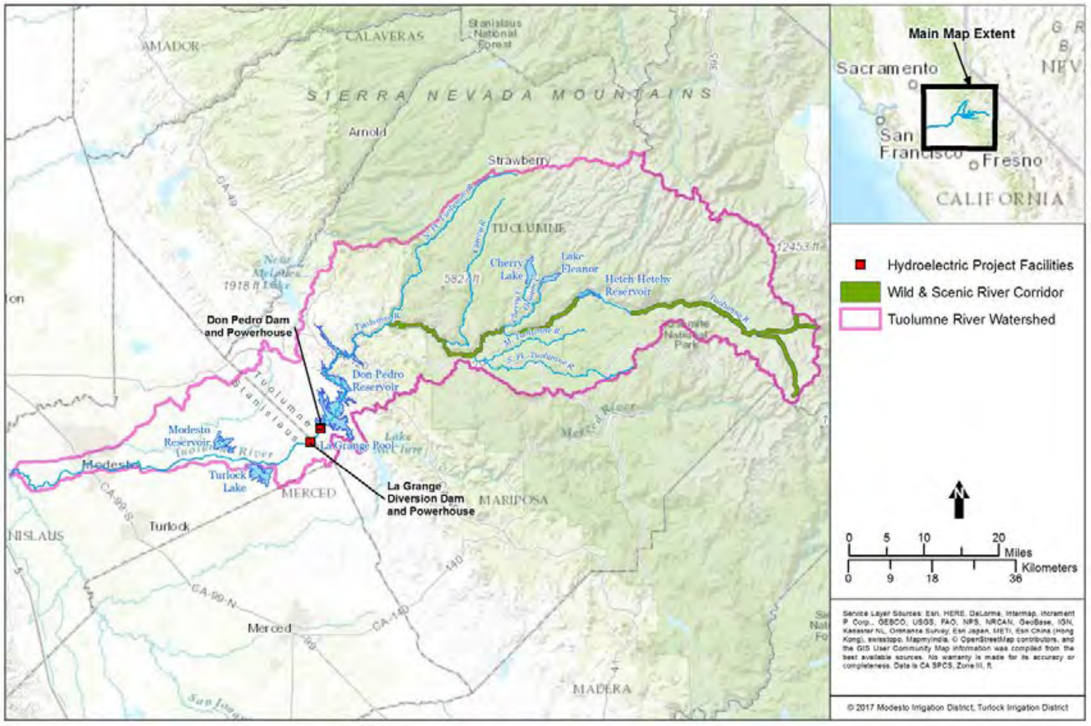
Socioeconomic Scoping Study
Study Goals

- Develop a comprehensive description of the human environment, activities, and current uses of the resources and facilities in the study area
- Assess the potential positive and negative impacts to socioeconomic resources as a result of constructing and/or operating fish passage facilities and the introduction of anadromous fish

Socioeconomic Scoping Study
Study Area

The study area included the Tuolumne River basin including the Upper Tuolumne River, as well as Don Pedro Reservoir and the mainstem Tuolumne River to its confluence with the San Joaquin River



Socioeconomic Scoping Study
Study Update

- Economic activities directly or indirectly related to activities in the Upper Tuolumne River basin, including Don Pedro Reservoir:
  - Power generation
  - Retail businesses
  - Timber harvest
  - Agricultural use
  - Municipal and Industrial use
  - Recreational use (e.g., camping, fishing, hiking, rafting, boating, swimming)
  - Flood control

Socioeconomic Study
Study Update

Economic activities directly or indirectly related to activities in the Tuolumne River basin:

- Agricultural irrigation
- Municipal and Industrial water supply
- Recreational activities
  - Whitewater rafting within the National Wild and Scenic River corridor
  - Don Pedro Reservoir activities and amenities, including marinas, houseboat and other motorized watercraft use, developed and remote camping access, and reservoir fishing
  - Lower Tuolumne River basin activities, including fishing, swimming, camping, and boating
- Hydropower generation in the Upper Tuolumne River basin, Don Pedro Reservoir, and the Lower Tuolumne River basin
- Flood control measures within the Lower Tuolumne River basin
- Potential changes in land use, including private timber practices, farming and ranching, rural residential development, and urban development

Socioeconomic Scoping Study
Study Status

- Literature review is continuing, data has been collected and compiled
- Report preparation is ongoing

Questions?

Upper Tuolumne River Voluntary Studies Progress Update

La Grange Hydroelectric Project
FERC No. 14581

May 18, 2017

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Upper Tuolumne River Voluntary Studies Progress Update

- Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
- Upper Tuolumne River Habitat Mapping Assessment
- Upper Tuolumne River Macroinvertebrate Assessment
- Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
- Upper Tuolumne River Instream Flow Study

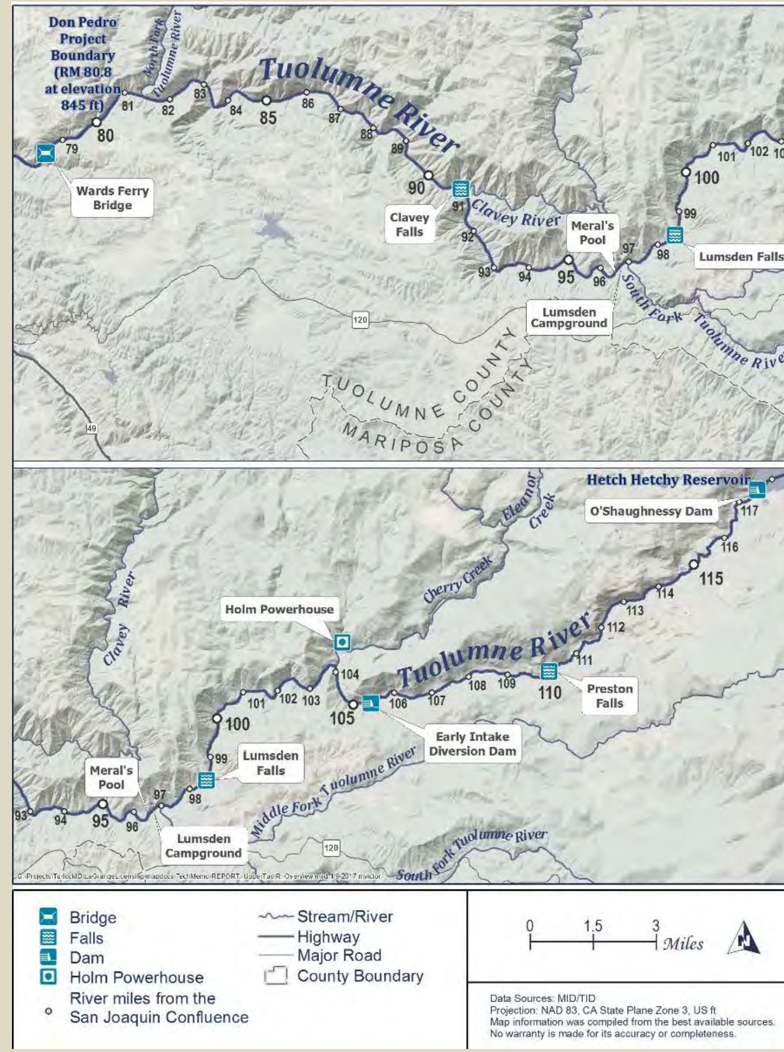
Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Study Goals and Objectives

- Map the distribution of potentially suitable spawning gravel available for Chinook salmon and steelhead in the upper Tuolumne River.
- Quantify the amount of suitable spawning gravel by species and geomorphic reach.
- Assess the quality of potentially suitable spawning gravel based on particle characteristics (i.e., size, sorting, angularity, and embeddedness), gravel depth, and permeability.

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study

Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Spawning Gravel Mapping Methodology

- Spawning gravel initially desktop mapped within modeled ~2,000 cfs inundation area using 2007 air photos provided by Towill Surveying and GIS Services, Inc.
- ~130 cfs inundation empirically defined from water edge in 2007 air photos.
- Field reconnaissance to calibrate and validate desktop mapping.
- Detailed field delineation of gravel patches from Cherry Creek to Don Pedro Reservoir:
  - Mapping: two-person crew using support of two whitewater rafts from July 18-24, 2016.
  - Field tiles: desktop mapping, 2007 air photo, river stationing, and 2,000 cfs inundation.
  - Patch descriptions: surface texture, grain size (D_{50}, D_{84} and D_{16}), quality (substrate depth, particle sorting, angularity, and embeddedness), and geomorphic feature type.
  - Overall gravel quality rating from 1 (poor) to 10 (good) assigned to each patch and later classified by category; good (7–10), fair (4–6), and poor (1–3).

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Permeability Methodology

- Based on spawning gravel mapping results, gravel permeability sampling strategy developed to characterize conditions influencing Chinook salmon and steelhead egg incubation and survival-to-emergence.
- Permeability sampled in select spawning gravel patches from pool tail, point bar, medial bar, and lateral bar geomorphic units with Gr dominant facies, Co or finer subdominant facies, and $D_{84} \leq 128$ mm.
- Survival-to-emergence will be estimated using published empirical relationships.

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Permeability Methodology

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Study Status

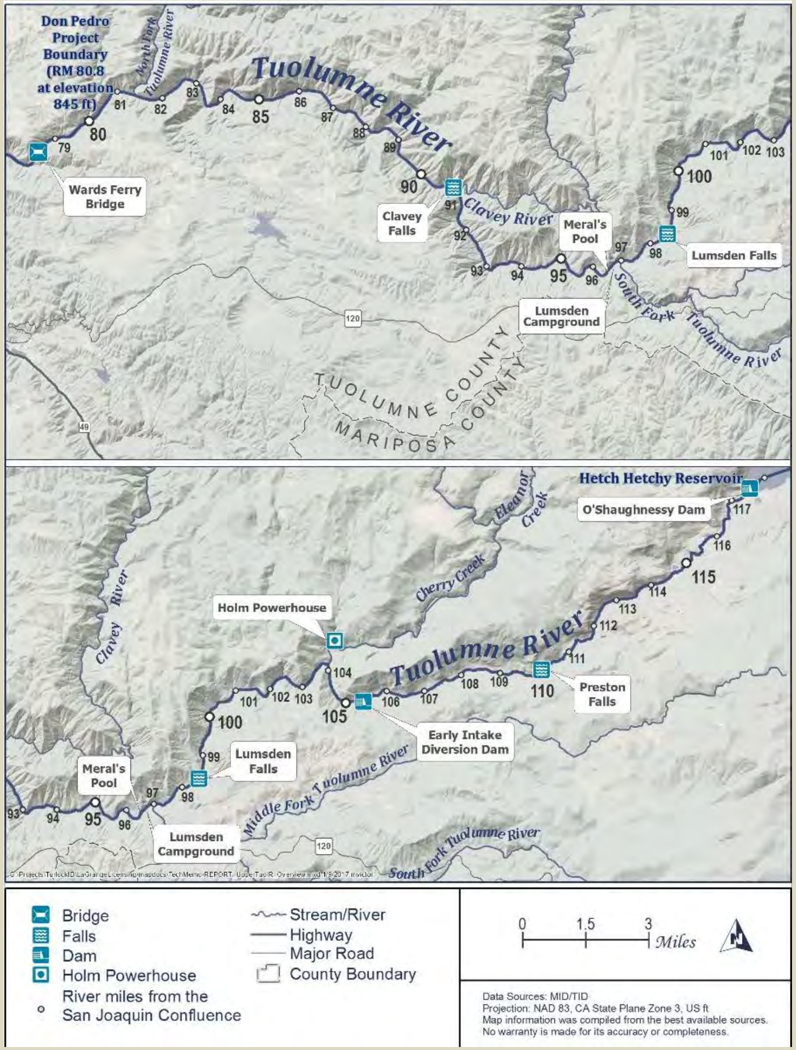
- Data compilation and QC is in process.
- Data analysis and study report development is anticipated to occur this summer.

Upper Tuolumne River Habitat Mapping Assessment Study Goals and Objectives

- Document the number, size, and distribution of mesohabitat units in the upper Tuolumne River.
- Collect detailed data on habitat attributes in representative reaches of the upper Tuolumne River.
- Document potential pool habitat for over-summering adult Chinook salmon.

Upper Tuolumne River Habitat Mapping Assessment Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Habitat Mapping Assessment Study Methodology

Objective 1: Documenting mesohabitat units from Early Intake (RM 105) to upstream limit of Don Pedro (RM 80.8).

- Conducted in the field and remotely using standardized methodologies.
- Field:
  - Mesohabitat collected during daily high flow period (~1200 cfs) by raft (July 17 – July 31, 2016).
  - Early Intake to Merals Pool: Georeferenced GoPro video (July 28 – 31, 2016).
  - Merals Pool to Don Pedro Project Boundary: Mapbook and GPS used to complete reconnaissance level effort from 2015 (July 17 – 23, 2016).
- Remote:
  - Post-processing field data to determine habitat lengths and consolidate notes into GIS database.

Upper Tuolumne River Habitat Mapping Assessment Study Methodology

Objective 2: Collecting detailed habitat data in representative reaches.

- CDFW Level III habitat typing methodology.
  - Unit measurements, bankfull width, pool tail crest depth, large woody debris counts, canopy, shelter value and substrate characteristics at every habitat unit.
- Collected during the daily "baseflow" period (~300 cfs).

Upper Tuolumne River Habitat Mapping Assessment Study Methodology

Objective 3: Documenting potential pool holding habitat for over-summering adult Chinook salmon.

- Early Intake to Merals Pool:
  - Pool surface area estimated based on 2007 aerial imagery.
  - Depth was visually estimated .
- Merals Pool to Wards Ferry:
  - Pool surface dimensions were measured using laser rangefinder.
  - Depth data collected using stadia rod or digital depth sounder.

Upper Tuolumne River Habitat Mapping Assessment Study Status

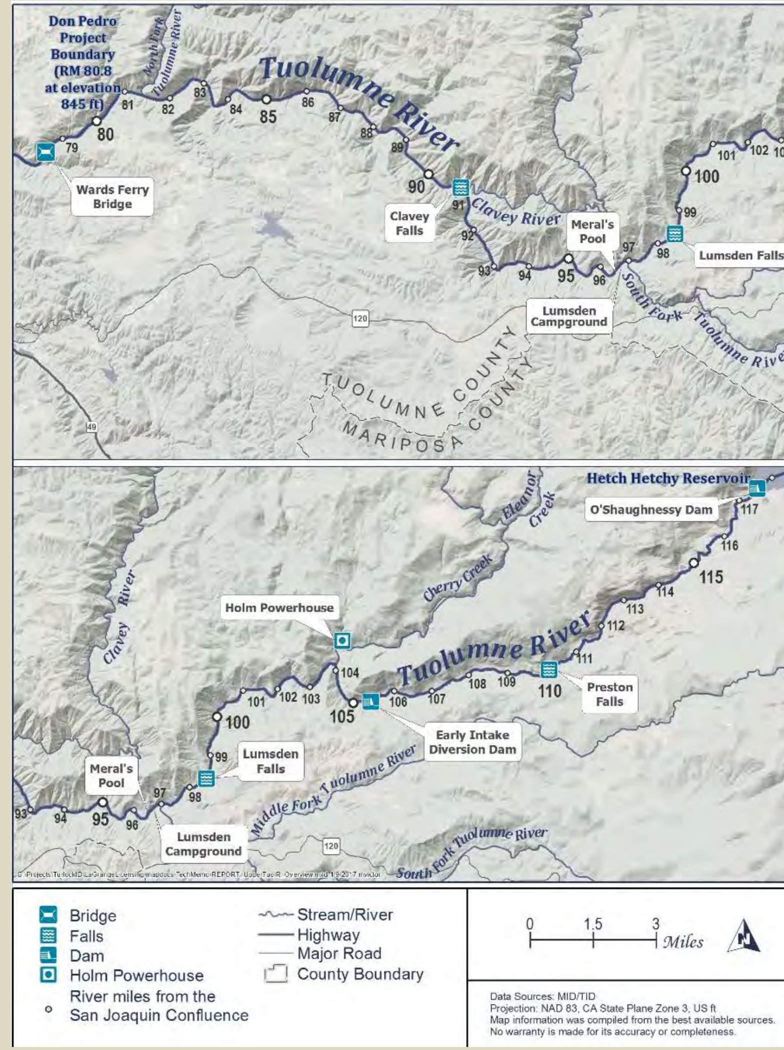
- Data compilation and QC is in process.
- Data analysis and study report development is anticipated to occur this summer.

Upper Tuolumne River Macroinvertebrate Assessment Study Goals and Objectives

- Objectives:
  - (1) Salmonid prey: Determine whether macroinvertebrate drift is consistent with other similar streams currently supporting salmonid populations; and
  - (2) Bioassessment: Use benthic macroinvertebrate (BMI) data to assess aquatic ecosystem health and compare with similar streams and data sets.

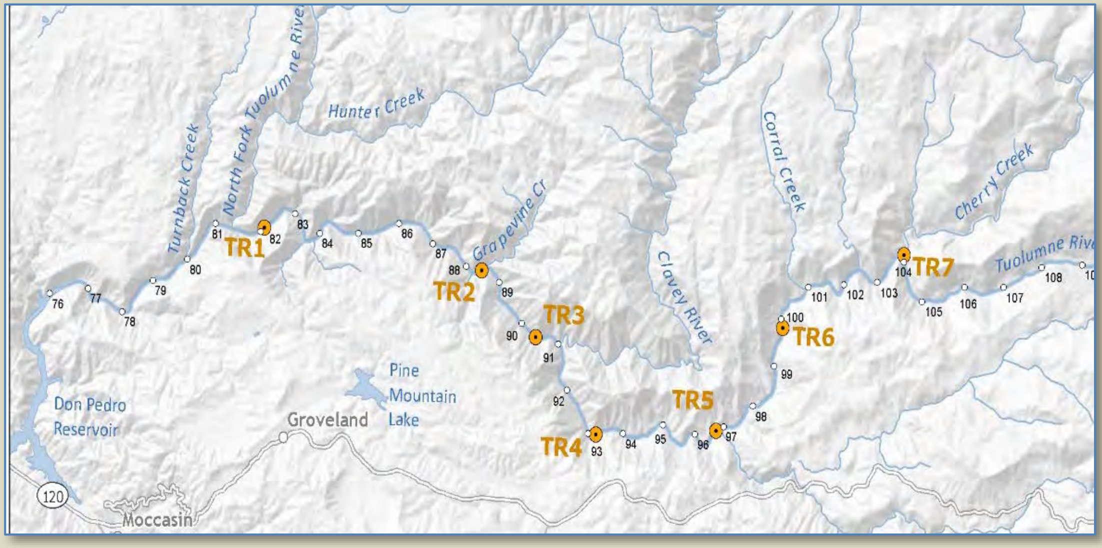
Upper Tuolumne River Macroinvertebrate Assessment Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project Boundary (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Macroinvertebrate Assessment Study Methodology

- Raft-based macroinvertebrate sampling was conducted during summer (July) and fall (October) of 2016.
  - Drift sampling and benthic sampling.
- 7 mainstem sites sampled between N.F. Tuolumne River and Cherry Creek.
- Sampled in riffle and run habitats.
- Physical habitat characteristics, including water velocity and basic water quality parameters were measured at the time of sampling at each site.



Upper Tuolumne River Macroinvertebrate Assessment Study Methodology

- Followed standard protocols for benthic (kick net) and drift sampling.
- Benthic: Modified SWAMP TRC method; 8 subsamples and 1 composited sample per site.
- Drift: 1 nearshore and 1 thalweg drift net per site; nets set for ~3 hrs in evening.
- Laboratory and office: sort, ID, count, density (drift), biomass (drift), bioassessment metrics and indices (benthic).

Upper Tuolumne River Macroinvertebrate Assessment Study Status

- Data compilation and QC is in process.
- Data analysis and study report development is anticipated to occur this summer.

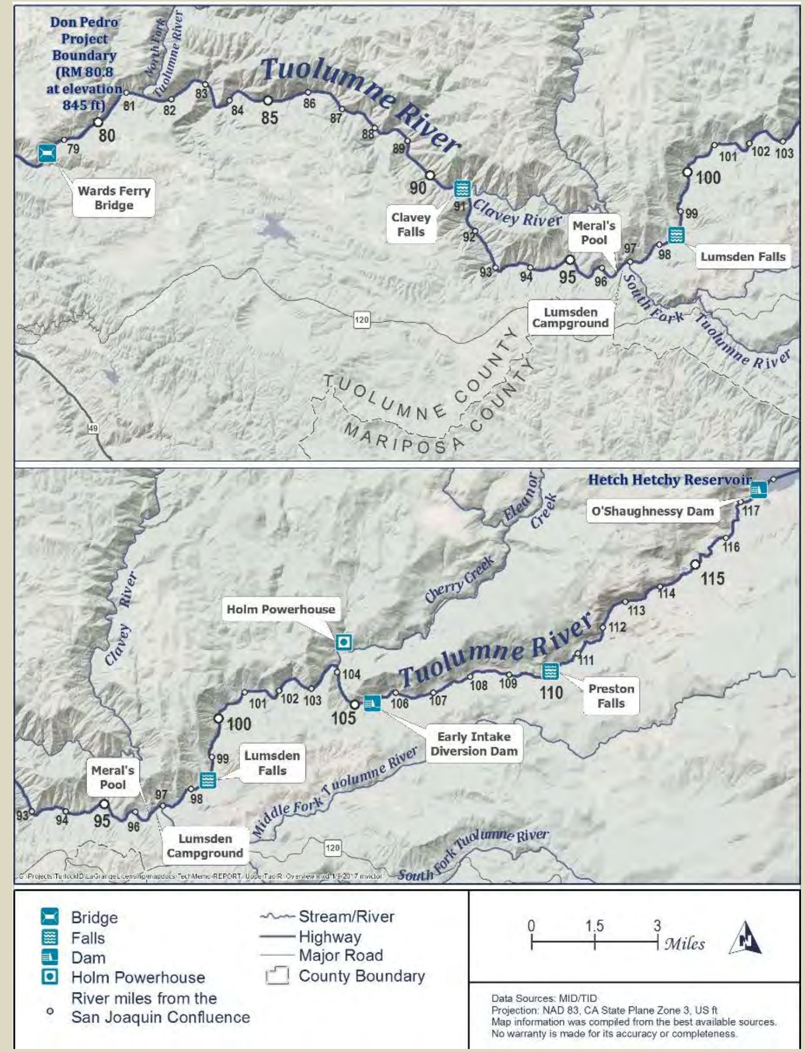
Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Study Goals and Objectives

- Use existing data to characterize the thermal regimes of the upper Tuolumne River and tributaries.
- Install water temperature and/or stage data loggers to obtain additional information at locations for which existing data are inadequate.
- Develop and test a computer model to simulate existing thermal conditions in the Tuolumne River from below Early Intake to above Don Pedro Project Boundary.

Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study

Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project Boundary (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Study Methodology

1. Identify, synthesize and interpret existing data (temperature, flow, meteorological, etc.).
2. Install additional water temperature and stage data loggers as needed.
3. Water temperature and stage data collection and review.
4. Water temperature modeling
   – Model Selection
   – Data Development
   – Model Implementation
   – Model Calibration
   – Model Application

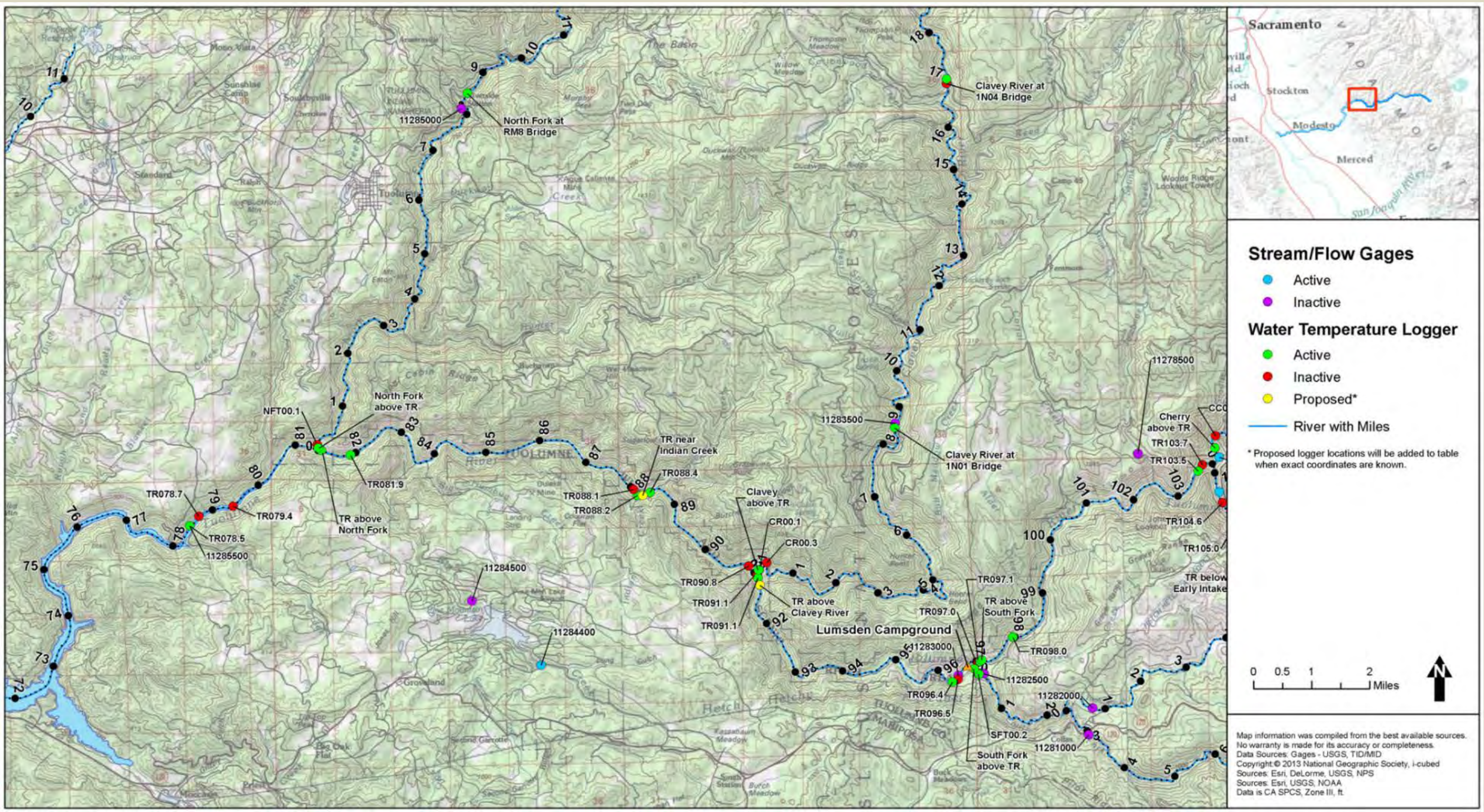
Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Methods: Monitoring

1. Water temperature
2. Stage and velocity
3. Cooperative effort (USGS, NMFS, others)

River Mile	Agency	Land Owner	Site_Locations	2015												2016											
				J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
CC00.5	TID/MID	USFS	Cherry Ck. bel. Dion Holm Powerhouse																								
CC02.0	TID/MID	USFS	Cherry Ck. ab. Dion Holm Powerhouse																								
SFT00.1	TID/MID	USFS*	SF Tuolumne R. ab. Tuolumne R.																								
CR00.1	TID/MID	USFS*	Clavey R. ab. Tuolumne R.																								
CR08.4	TID/MID	USFS	Clavey R. at 1N01 Bridge																								
CR16.9	TID/MID	USFS	Clavey R. at 1N04 Bridge																								
NF00.1	TID/MID	BLM*	NF Tuolumne R. ab. Tuolumne R.																								
NF08.4	TID/MID	USFS	NF Tuolumne R, near 1N01 Bridge																								
TR81.3	TID/MID	USFS*	Tuolumne R. ab. NF Tuolumne R.																								
TR091.1	TID/MID	USFS*	Tuolumne R. ab. Clavey R.																								
TR097.0	TID/MID	USFS*	Tuolumne R. ab. SF Tuolumne R.																								
TR105.2	TID/MID	USFS	Tuolumne R. bel. Early Intake																								

*managed under Wild and Scenic River designation

Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Methods: Monitoring



Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study

Methods: Model Development

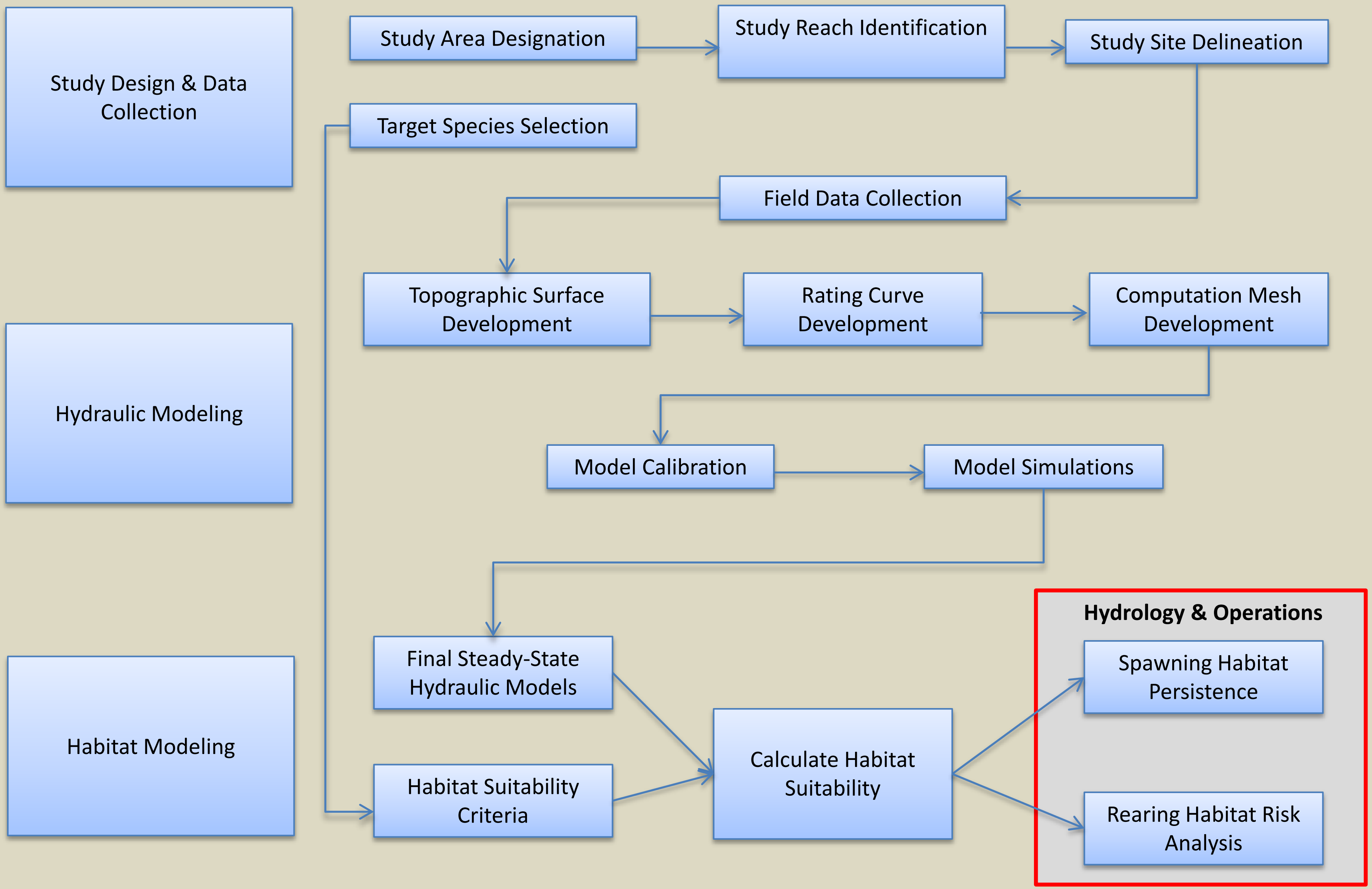
- Domain
  - Early Intake to above Don Pedro
- Model resolution
  - 15 minute time steps
  - 25 meter (82 ft) spatial resolution
- Period of Simulation: 1/1/2008 to 9/30/2016
- Data
  - Geometry
  - Flow
  - Water Temperature
  - Meteorology

Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Study Status

- Water temperature model development, calibration, and validation are underway.
- Water temperature modeling and study report development is anticipated to occur this summer.

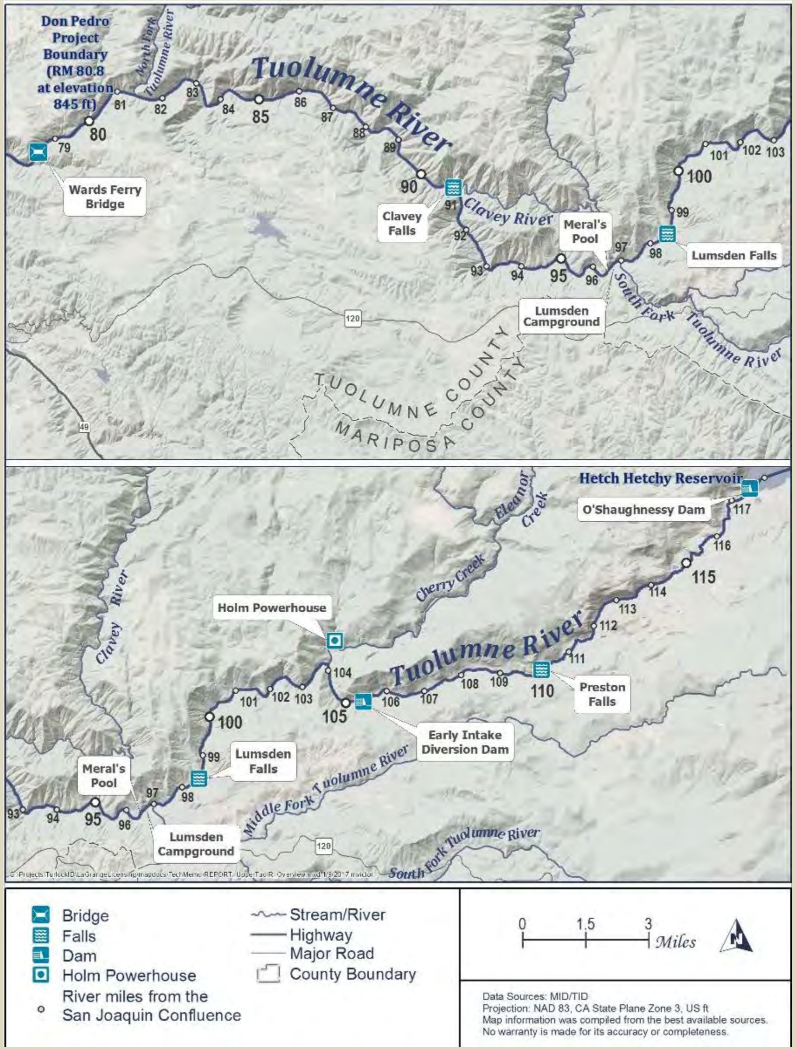
Upper Tuolumne River Instream Flow Study
Study Goals and Objectives

- Model existing aquatic habitat for spring-run Chinook salmon and steelhead.
- Evaluate the existing aquatic habitat over a representative range of observed water years and City and County of San Francisco's operations.
- Provide quantifiable metrics of aquatic habitat suitability in the context of potential reintroduction.


Study Design & Data Collection
Study Area Designation
Study Reach Identification
Study Site Delineation
Target Species Selection
Field Data Collection
Hydraulic Modeling
Topographic Surface Development
Rating Curve Development
Computation Mesh Development
Model Calibration
Model Simulations
Habitat Modeling
Final Steady-State Hydraulic Models
Habitat Suitability Criteria
Calculate Habitat Suitability
Hydrology & Operations
Spawning Habitat Persistence
Rearing Habitat Risk Analysis

Upper Tuolumne River Instream Flow Study
Study Area

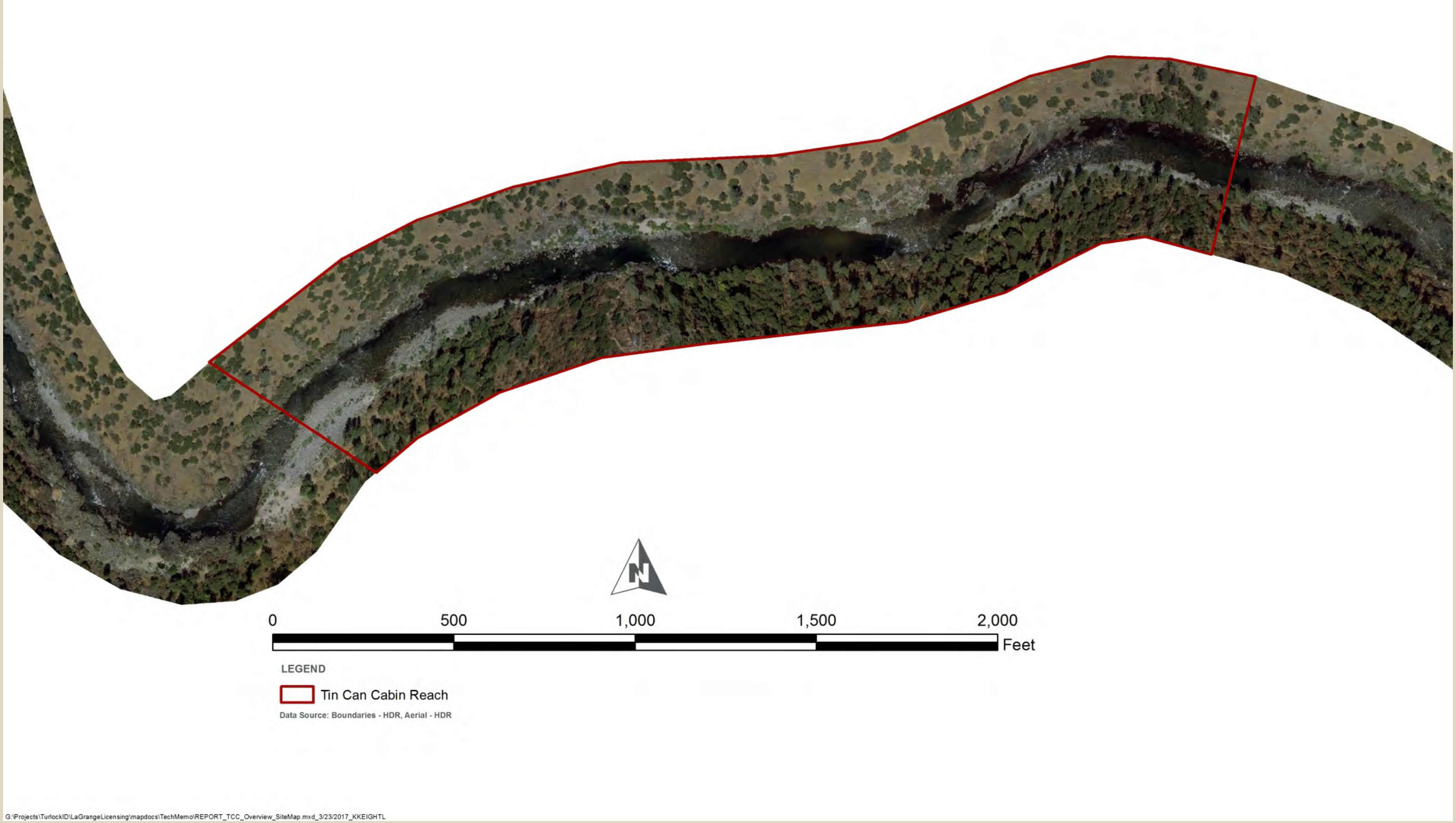
- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project Boundary (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Instream Flow Study
Study Sites

- Tin Can Cabin ~ 2,678 ft (0.5 miles, RM 93.2-93.8)
  - 12 habitat units
- Wheelbarrow ~ 3,801 ft (0.72 miles, RM 87.0-87.7)
  - 11 habitat units
- Mohican ~ 3,040 ft (0.57 miles, RM 81.7-82.2)
  - 12 habitat units

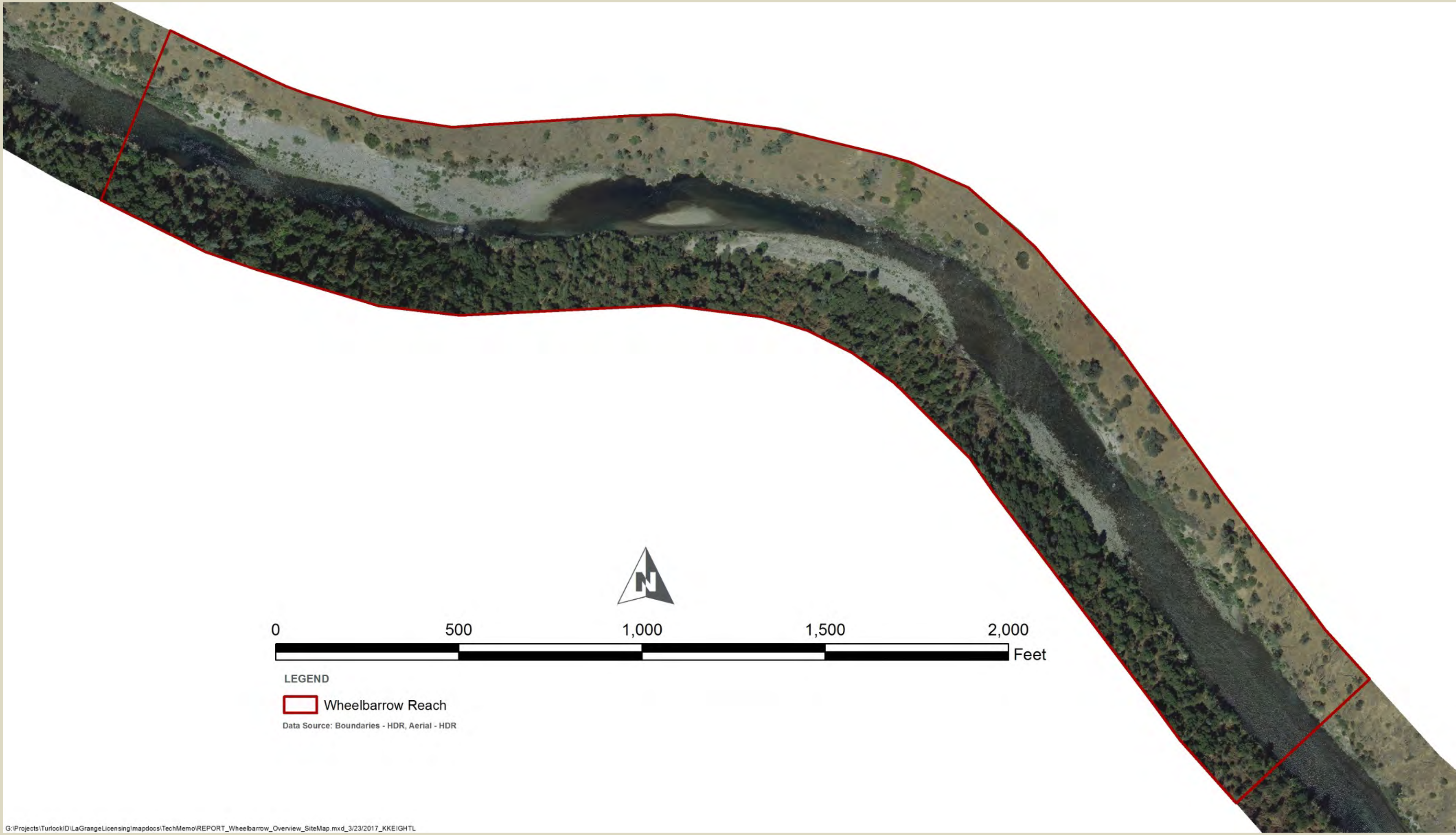
Upper Tuolumne River Instream Flow Study
Study Site: Tin Can Cabin



Upper Tuolumne River Instream Flow Study
Study Site: Tin Can Cabin



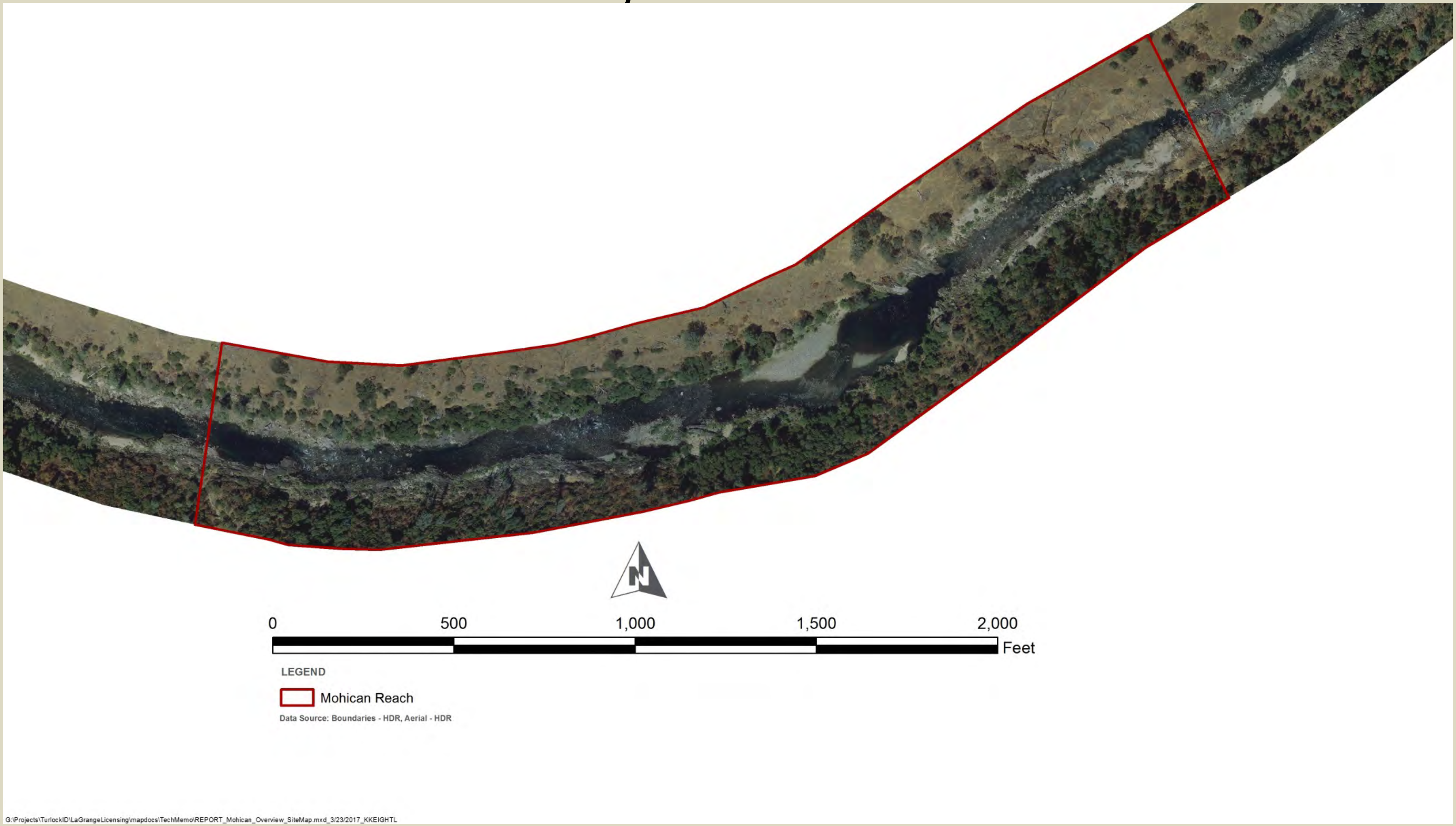

Upper Tuolumne River Instream Flow Study
Study Site: Wheelbarrow



Upper Tuolumne River Instream Flow Study
Study Site: Wheelbarrow

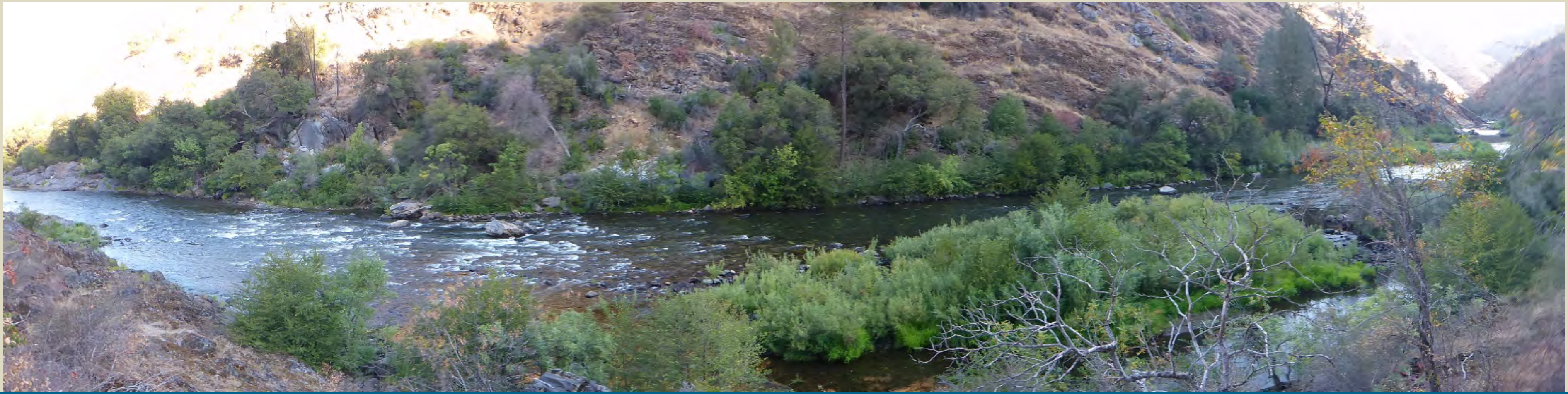



Upper Tuolumne River Instream Flow Study
Study Site: Mohican



Upper Tuolumne River Instream Flow Study
Study Site: Mohican



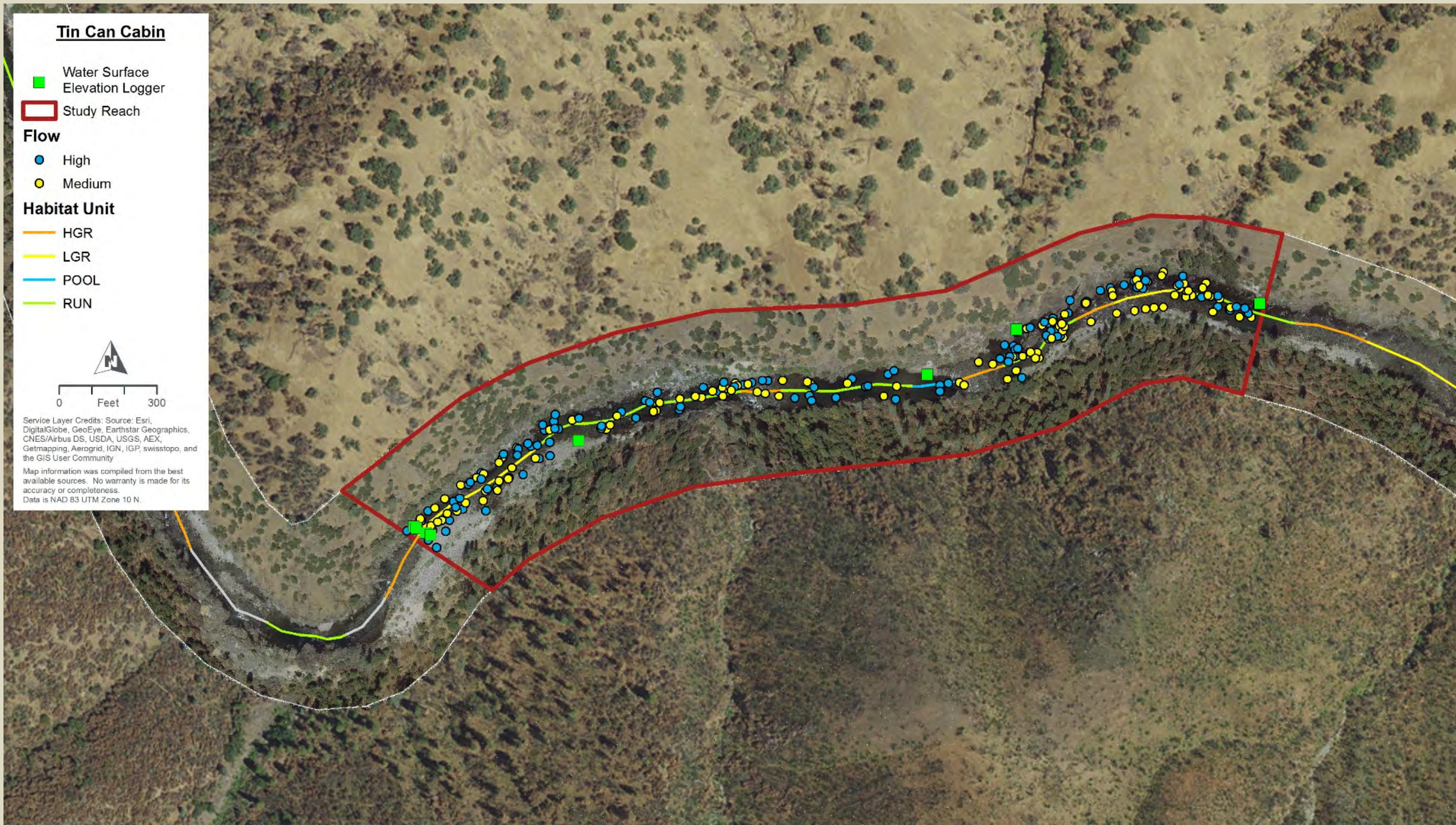



- Field Data Collection
  - Methods
    - RTK GPS Survey
    - Total Station Survey
    - Single beam bathymetry
    - Acoustic Doppler Current profiler (ADCP)
    - Flow meter
    - Stage recorders – (Level Loggers)

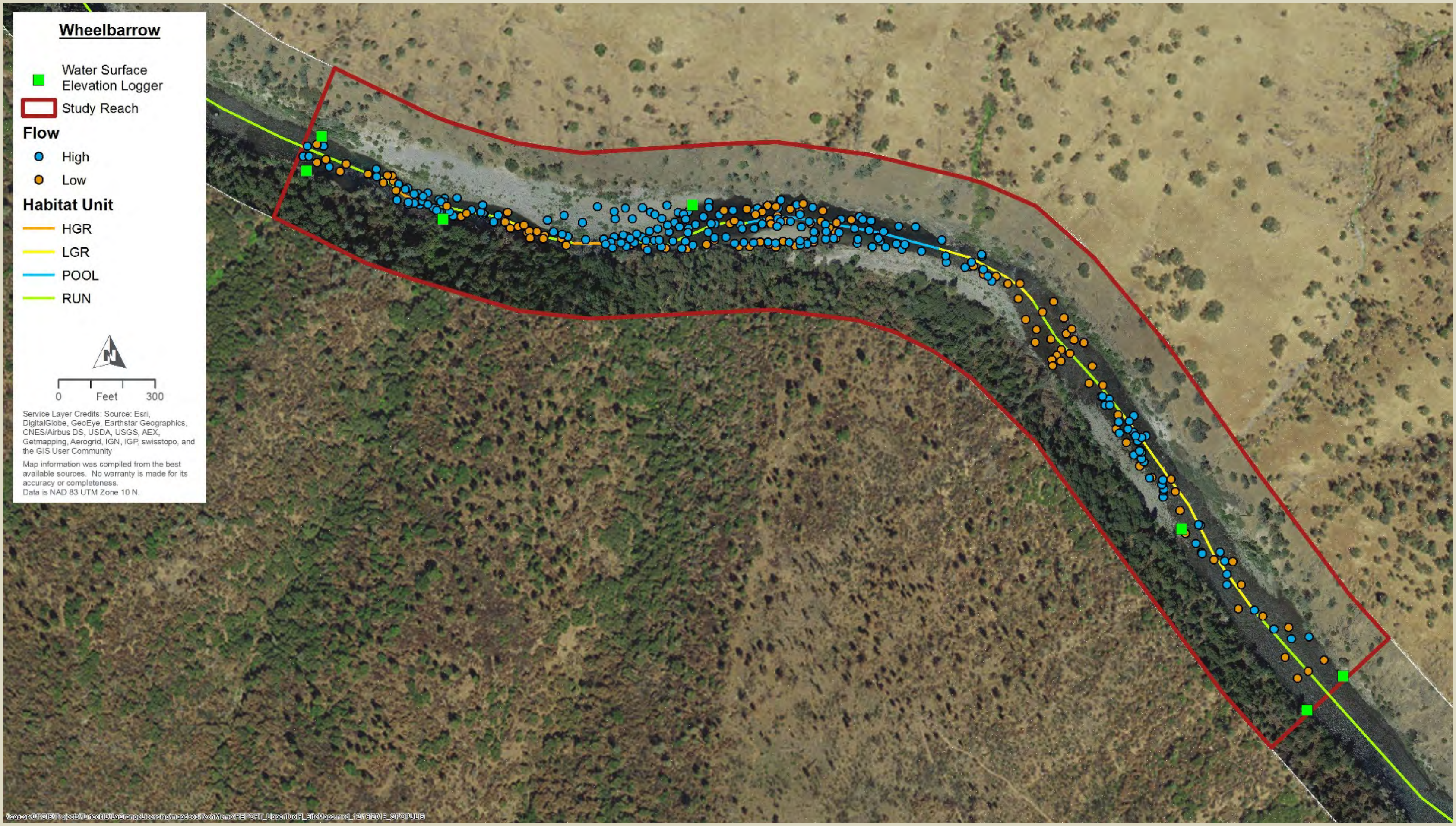
Upper Tuolumne River Instream Flow Study
Field Data Collection

Upper Tuolumne River Instream Flow Study
Field Data Collection

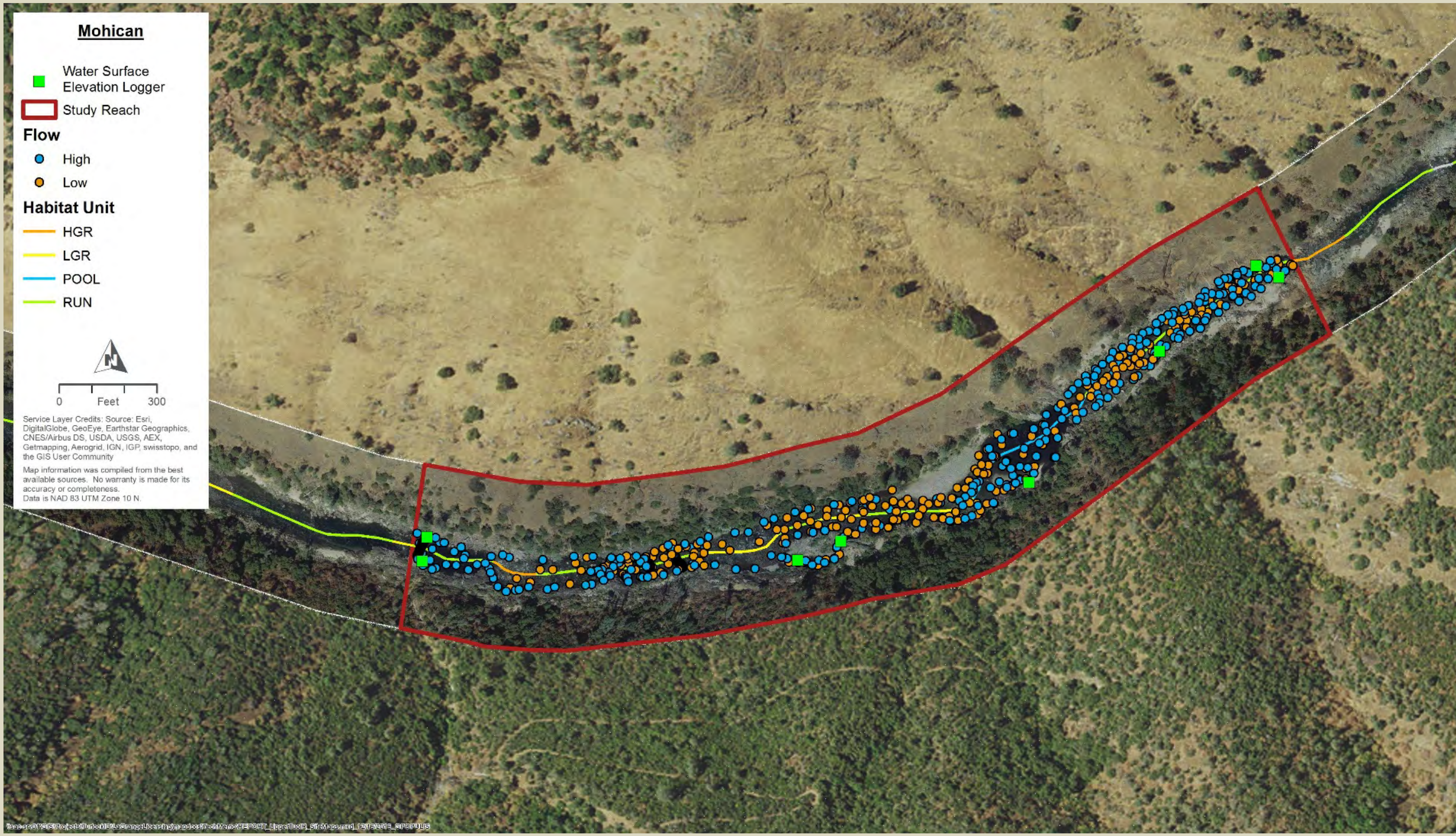
Upper Tuolumne River Instream Flow Study
Example of Observed Data: Tin Can Cabin



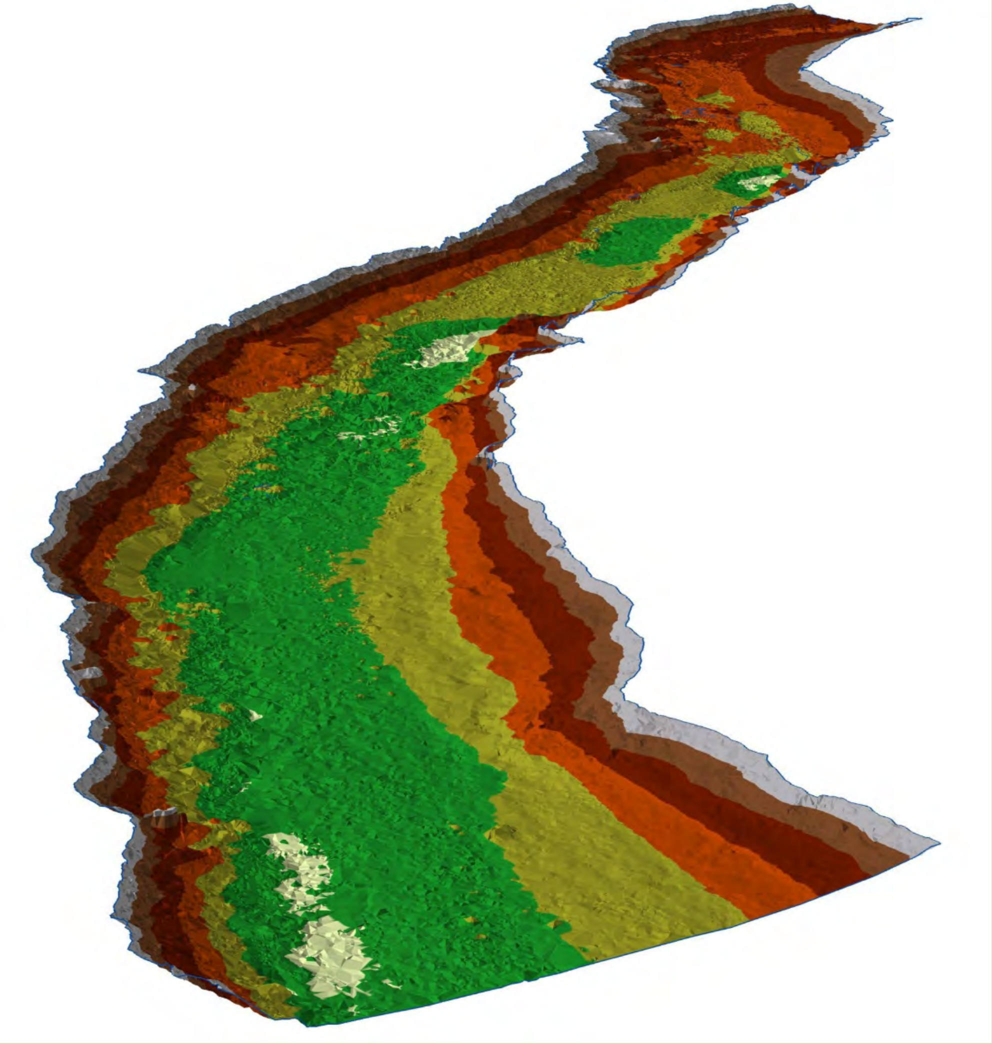
Upper Tuolumne River Instream Flow Study
Example of Observed Data: Wheelbarrow



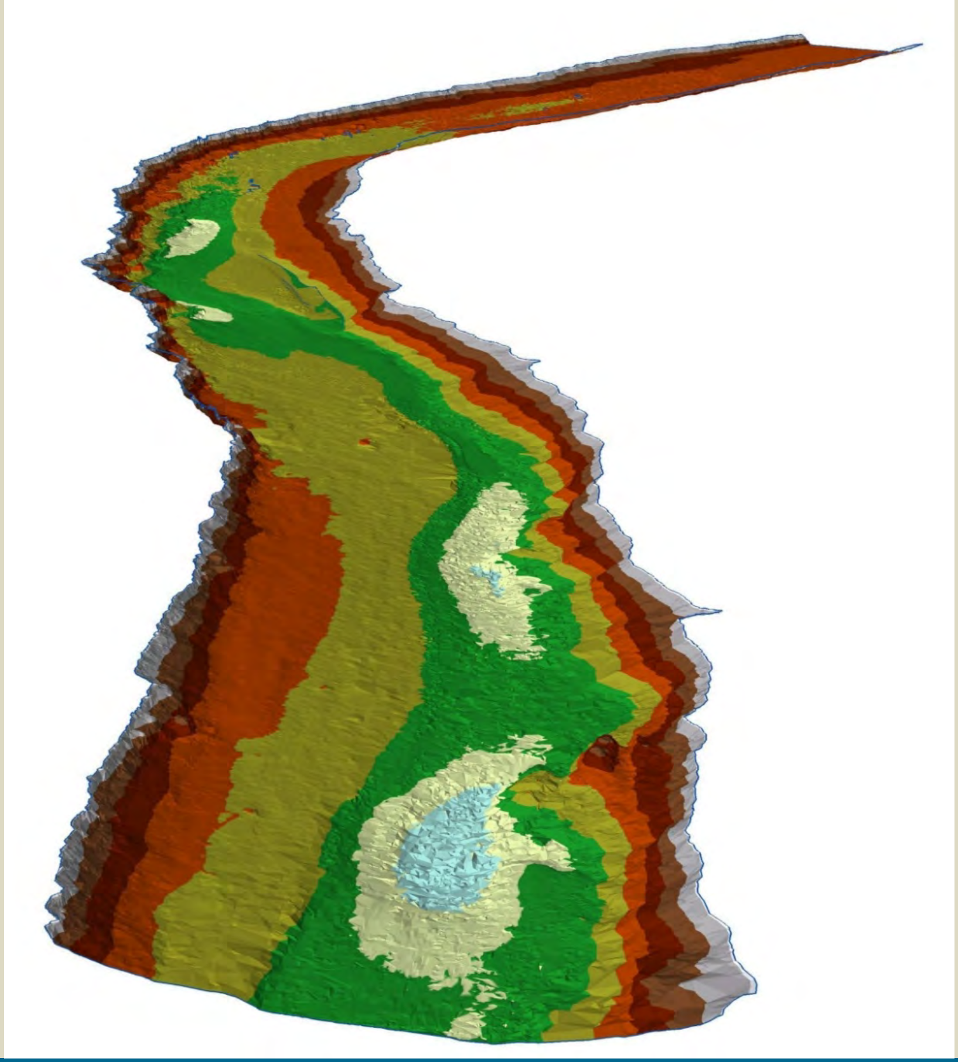
Upper Tuolumne River Instream Flow Study
Example of Observed Data: Mohican



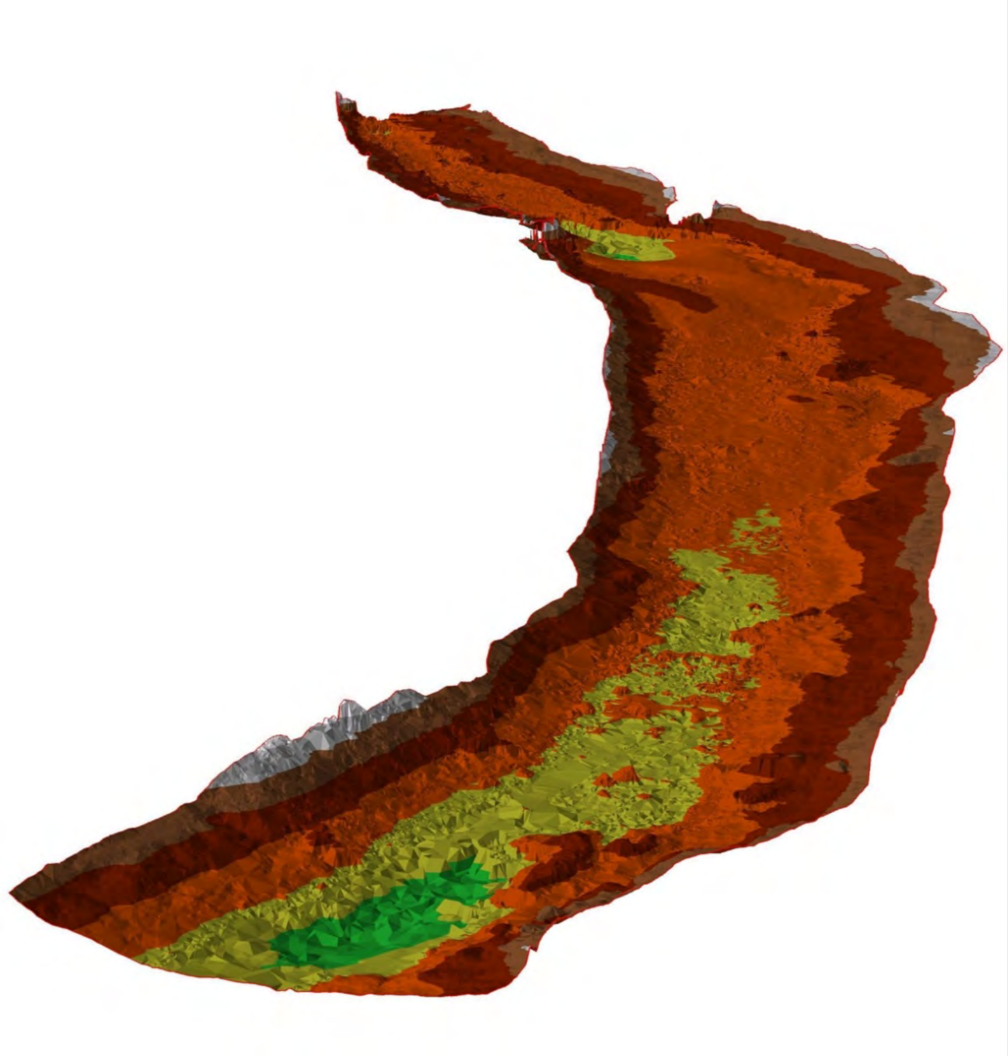
Upper Tuolumne River Instream Flow Study
Topography: Tin Can Cabin



Upper Tuolumne River Instream Flow Study
Topography: Wheelbarrow



Upper Tuolumne River Instream Flow Study
Topography: Mohican



Upper Tuolumne River Instream Flow Study
Study Status

- Model development, calibration, and validation are underway.
- Modeling and study report development is anticipated to occur through the summer.

Questions?

LA GRANGE HYDROELECTRIC PROJECT

REINTRODUCTION ASSESSMENT FRAMEWORK
MAY 18, 2017 PLENARY GROUP MEETING

ATTACHMENT B

NMFS STUDY UPDATE

Deason, Jesse

From: William Foster - NOAA Federal <william.foster@noaa.gov>
Sent: Monday, May 15, 2017 8:00 AM
To: Staples, Rose; Deason, Jesse; Le, Bao; Johnson, Laura
Cc: Edmondson, Steve; Jean Castillo - NOAA Federal
Subject: Re: Materials for La Grange May 18 2017 Plenary Group Meeting

Dear Rose and Others:

Below is an update on NMFS' upper Tuolumne River studies.

Status of NMFS' Upper Tuolumne River Studies, May 2017.

In response to requests made during the first and subsequent Fish Passage Workshops to better explain the fish passage decision making process and cooperate in conducting and paying for studies, NMFS competed annually for internal funds to assist in fish passage study efforts. To date we hosted a 2-day public workshop titled: "*Fish Passage Over High Head Dams Workshop*" (presentations posted on-line by the District's consultant); and publicly released the "*Reintroducing Fish Upstream of Rim Dams; Providing Passage to Advance Salmon Recovery in California's Central Valley - Frequently Asked Questions*" document (posted on NMFS web-site). In addition NMFS funded the following studies:

Habitat Assessment and Carrying Capacity Study:

NMFS expects a "non-Public" draft report to be completed in May or June for internal NMFS review.

Fish Passage Engineering Study:

NMFS had a site visit with the Districts and NMFS's consultant, ANCHOR QEA, LLC, on March 14th. Since then the consultant has been gathering, reviewing, and analyzing project data to develop fish passage feasibility concepts that will provide safe, timely, and efficient passage and contribute to the recovery of ESA-listed salmonids in the Central Valley. NMFS anticipates a "non-Public" draft of the conceptual designs from the consultant by the end of June for internal NMFS review.

***O. mykiss* Genetics Study:**

A "non-Public" draft report is expected at the end of June for internal NMFS review.

Thanks, see you at meeting

William E. Foster, M.S., Fishery Biologist
NOAA Fisheries, West Coast Region
California Central Valley Area Office
FERC Branch, Sacramento, CA
(916) 930-3617

LA GRANGE HYDROELECTRIC PROJECT

REINTRODUCTION ASSESSMENT FRAMEWORK
MAY 18, 2017 PLENARY GROUP MEETING

ATTACHMENT C

UPDATED WTI TABLE AND UPPER RIVER STUDIES PRESENTATION

SEE SEPARATE FILE FOR UPDATED UPPER RIVER STUDIES PRESENTATION DUE TO FILE SIZE

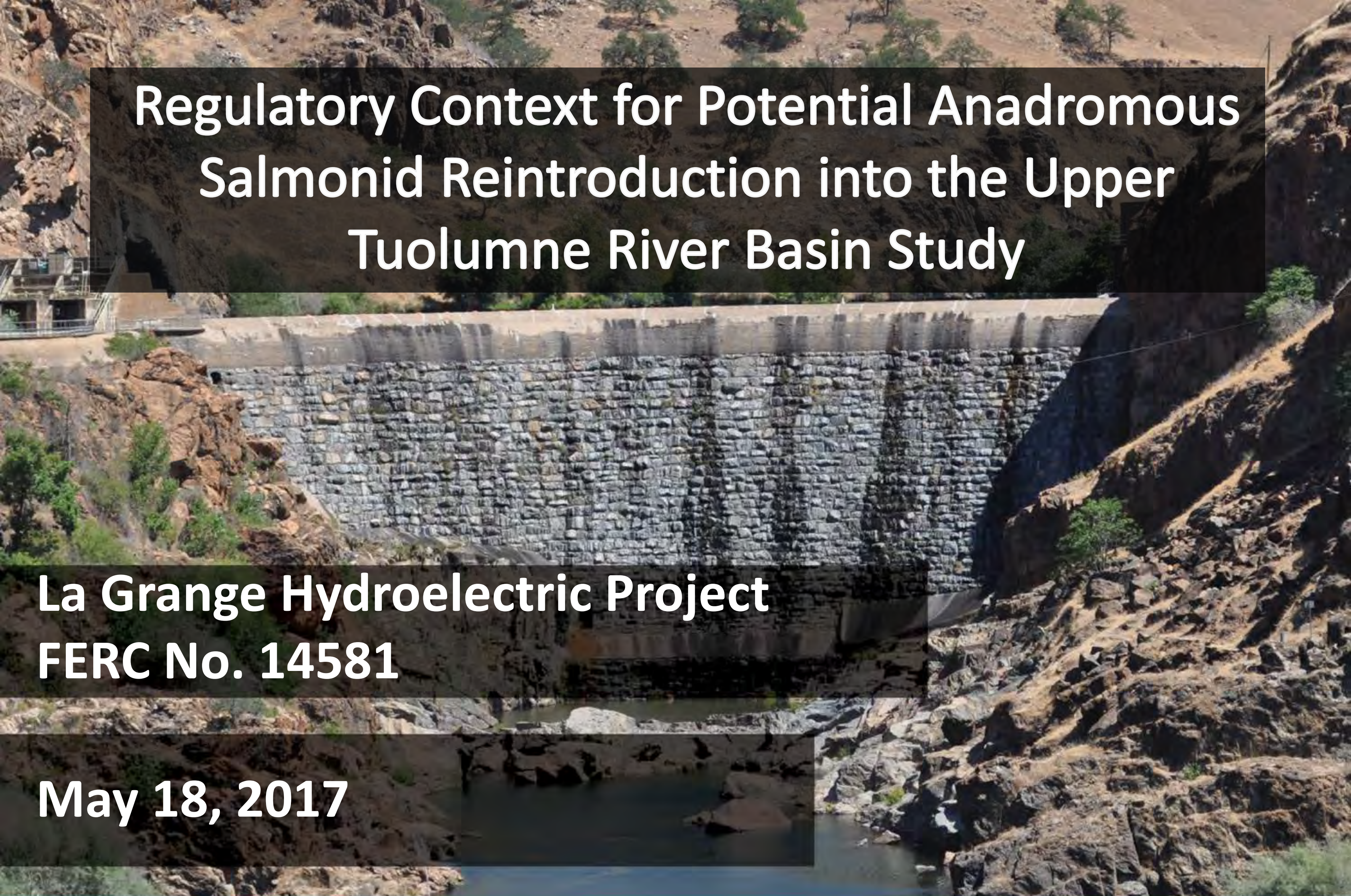
	UOWTI (MWAT)	UTWTI (MWAT)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spring-run Chinook Salmon[1,2]														
Adult Upstream Migration	64	68												
Adult Holding	61	65												
Adult Spawning	56	58												
Embryo Incubation and Emergence	56	58												
Fry Rearing	65	68												
Juvenile Rearing and Downstream Movement	65	68												
Smolt Outmigration	63	68												
Steelhead[1,2]														
Adult Upstream Migration	64	68												
Holding	61	65												
Adult Spawning	54	57												
Embryo Incubation and Emergence	54	57												
Fry Rearing	68	72												
Juvenile Rearing and Downstream Movement	68	72												
Smolt Outmigration	55	57												

UOWTI = Upper Optimum Water Temperature Index
UTWTI = Upper Tolerable Water Temperature Index
MWAT = Maximum Weekly Average Temperature

June 2017

[1] Dark shaded areas represent known peak periods for the specified lifestage whereas light shaded areas represent presence.

[2] The absence of dark shaded areas for any lifestage indicates that the Technical Committee did not identify any particular peak period based on the available data.



Regulatory Context for Potential Anadromous Salmonid Reintroduction into the Upper Tuolumne River Basin Study

La Grange Hydroelectric Project
FERC No. 14581

May 18, 2017

WATER & POWER
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Modesto Irrigation District
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Regulatory Context for Potential Reintroduction Study Goals and Objectives

- Identify applicable existing legal precedent, regulatory guidance and resource management plans in the study area
- Identify additional regulatory guidance and rules that may apply to or affect the reintroduction of fall-run and spring-run Chinook and/or steelhead
- Identify federal, state, and local regulatory issues associated with a potential fish passage/reintroduction program

Regulatory Context for Potential Reintroduction Study Area

- Entire Tuolumne River basin, including Don Pedro Reservoir and the mainstem Tuolumne River
- Associated tributaries (North Fork Tuolumne River, Clavey River, Cherry Creek, etc.) and surrounding public and private land

Regulatory Context for Potential Reintroduction Study Methodology

- Step 1: identify and assemble relevant documents for the study area, including plans provided by state and federal agencies
- Step 2: review the resource management documents and create a comprehensive summary of planning goals and regulations relevant to potential reintroduction of Chinook and/or steelhead or fish passage in the basin

Regulatory Context for Potential Reintroduction

Documents Reviewed for Potential Applicability

- California Water Action Plan 2016 Update (State of California [California Natural Resources Agency (CNRA), CDFA, and California Environmental Protection Agency (CalEPA)] 2016)
- Sierra Nevada Watershed Improvement Program Regional Strategy DRAFT (Sierra Nevada Conservancy and USFS 2016)
- Stanislaus Urban County and City of Turlock Regional Consolidated Plan Fiscal Years 2015-2020 (Stanislaus County 2015)
- Stanislaus County General Plan (Stanislaus County 2015)
- Sierra Nevada Forest and Community Initiative (SNFCI) Action Plan (Sierra Nevada Conservancy 2014)
- California State Wildlife Action Plan 2015 Update (CDFW 2015)
- The State of the Sierra Nevada's Forests (Sierra Nevada Conservancy 2014)
- Tuolumne Wild and Scenic River Comprehensive Management Plan Record of Decision and supporting documents (National Park Service [NPS] 2014)
- Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead (NMFS 2014)
- Watershed Condition Framework (USFS 2011)
- Stanislaus National Forest Plan Direction (USFS 2010)
- Sierra Resource Management Plan (BLM 2008)
- City of Waterford General Plan Update Vision 2025 (City of Waterford 2006)
- Sierra Nevada Forest Plan and Amendments (USFS 2004, 2013)
- 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)
- City of Ceres General Plan (City of Ceres 1997)
- Tuolumne County General Plan, Policy Document (Tuolumne County 1996)
- Steelhead Restoration and Management Plan for California (California Department of Fish and Game 1996)
- Restoring Central Valley Streams: A Plan for Action (CDF&G 1993)
- Tuolumne Wild and Scenic River Management Plan (USFS 1988)
- Final Red Hills Management Plan and Environmental Assessment (BLM 1985)
- Yosemite National Park, General Management Plan (Visitor Use/Park Operations/Development) (NPS 1980)

Regulatory Context for Potential Reintroduction Study Update

- Relevant plans and policies identified (continued):
  - Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead (NMFS 2014)
  - California State Wildlife Action Plan 2015 Update (CDFW September 2015)
  - Tuolumne Wild and Scenic River Comprehensive Management Plan Record of Decision and supporting documents (NPS 2014)
  - Sierra Nevada Forest Plan and Amendments (USFS 2004, 2013)
  - Stanislaus National Forest, Forest Plan Direction (USFS 2010)

Regulatory Context for Potential Reintroduction Study Update

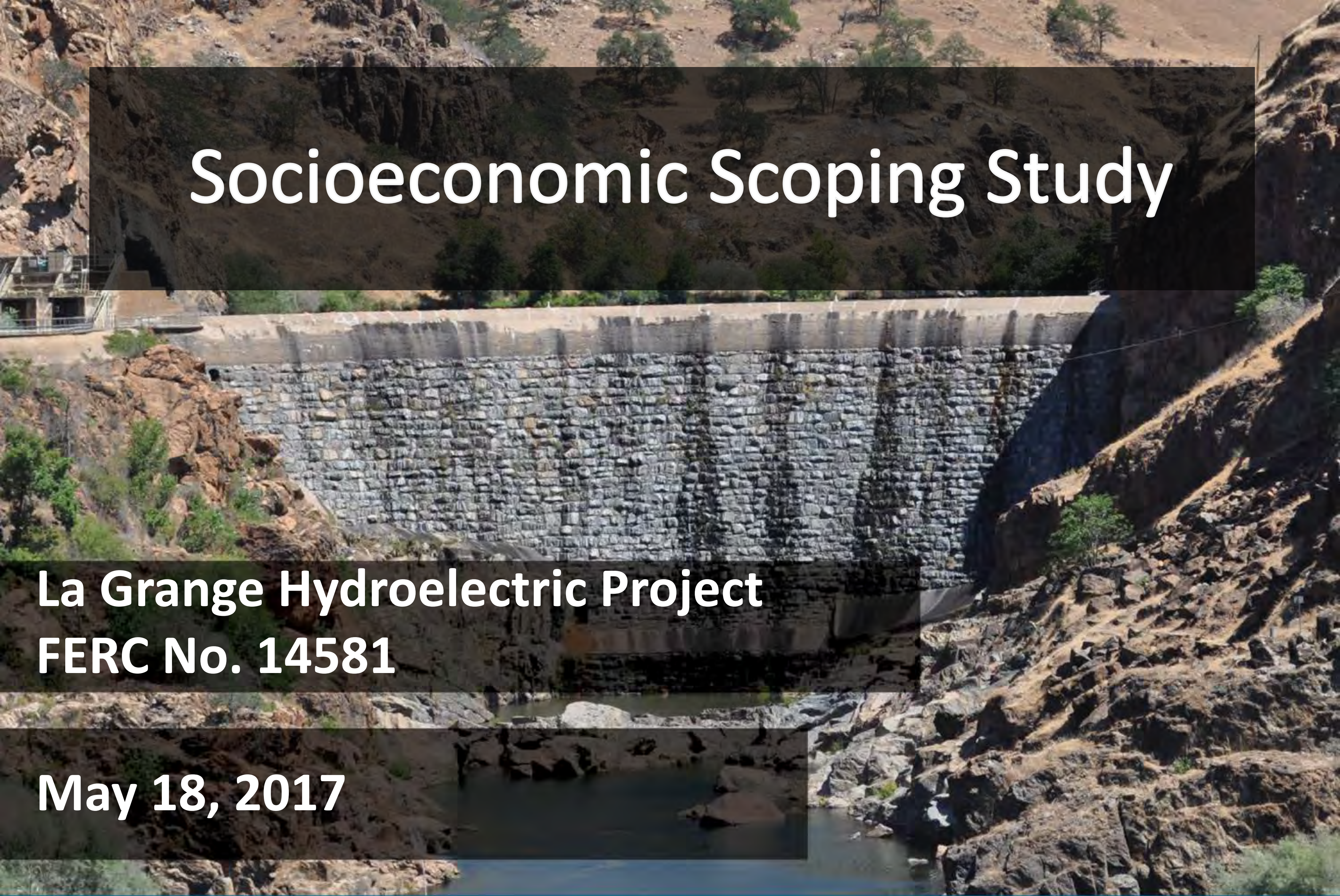
- Relevant plans and policies identified (continued):
  - Sierra Resource Management Plan and Record of Decision (BLM 2008)
  - Final Restoration Plan for the Anadromous Fish Restoration Program: A Plan to Increase Natural Production of Anadromous Fish in the Central Valley of California (USFWS 2001)
  - Steelhead Restoration and Management Plan for California (CDF&G and Sport Fish Restoration 1996)
  - National Forest Management Act (1976)

Regulatory Context for Potential Reintroduction Study Status

- Data has been collected and compiled
- Report preparation is ongoing

Questions?

Socioeconomic Scoping Study



La Grange Hydroelectric Project
FERC No. 14581

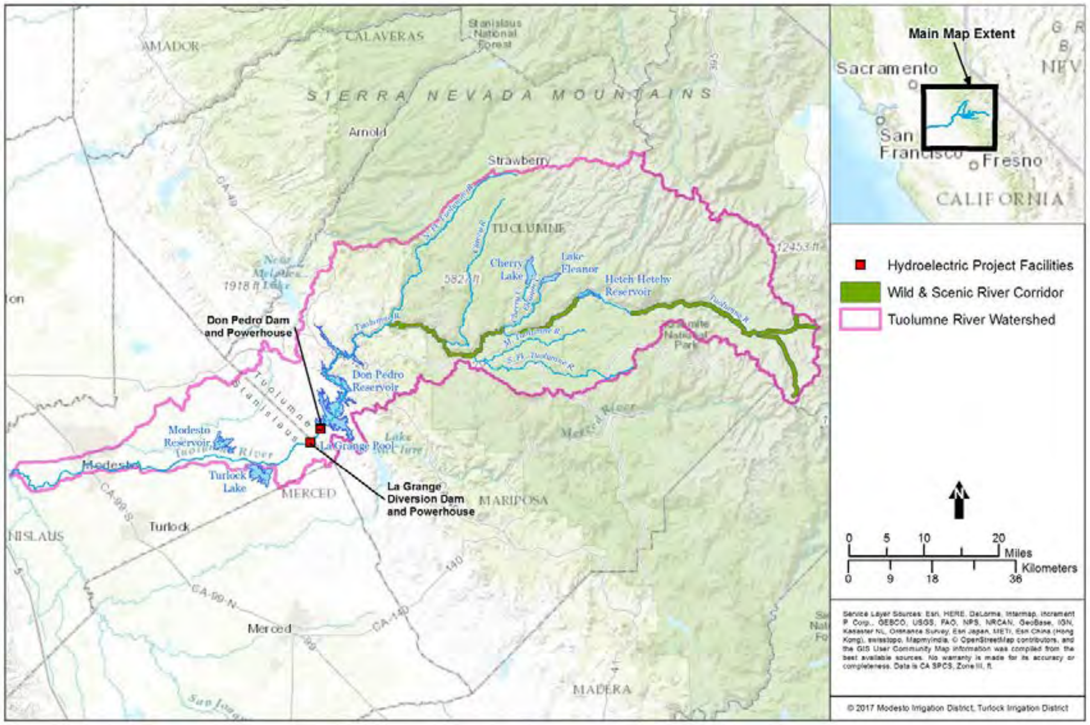
May 18, 2017

Socioeconomic Scoping Study
Study Goals

- Develop a comprehensive description of the human environment, activities, and current uses of the resources and facilities in the study area
- Assess the potential positive and negative impacts to socioeconomic resources as a result of constructing and/or operating fish passage facilities and the introduction of anadromous fish

Socioeconomic Scoping Study
Study Area

The study area included the Tuolumne River basin including the Upper Tuolumne River, as well as Don Pedro Reservoir and the mainstem Tuolumne River to its confluence with the San Joaquin River



Socioeconomic Scoping Study
Study Update

- Economic activities directly or indirectly related to activities in the Upper Tuolumne River basin, including Don Pedro Reservoir:
  - Power generation
  - Retail businesses
  - Timber harvest
  - Agricultural use
  - Municipal and Industrial use
  - Recreational use (e.g., camping, fishing, hiking, rafting, boating, swimming)
  - Flood control

Socioeconomic Study
Study Update

Economic activities directly or indirectly related to activities in the Tuolumne River basin:

- Agricultural irrigation
- Municipal and Industrial water supply
- Recreational activities
  - Whitewater rafting within the National Wild and Scenic River corridor
  - Don Pedro Reservoir activities and amenities, including marinas, houseboat and other motorized watercraft use, developed and remote camping access, and reservoir fishing
  - Lower Tuolumne River basin activities, including fishing, swimming, camping, and boating
- Hydropower generation in the Upper Tuolumne River basin, Don Pedro Reservoir, and the Lower Tuolumne River basin
- Flood control measures within the Lower Tuolumne River basin
- Potential changes in land use, including private timber practices, farming and ranching, rural residential development, and urban development

Socioeconomic Scoping Study
Study Status

- Literature review is continuing, data has been collected and compiled
- Report preparation is ongoing

Questions?

Upper Tuolumne River Voluntary Studies Progress Update

La Grange Hydroelectric Project
FERC No. 14581

May 18, 2017

Upper Tuolumne River Voluntary Studies Progress Update

- Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
- Upper Tuolumne River Habitat Mapping Assessment
- Upper Tuolumne River Macroinvertebrate Assessment
- Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
- Upper Tuolumne River Instream Flow Study

Upper Tuolumne River Chinook Salmon and Steelhead* Spawning Gravel Mapping Study Study Goals and Objectives

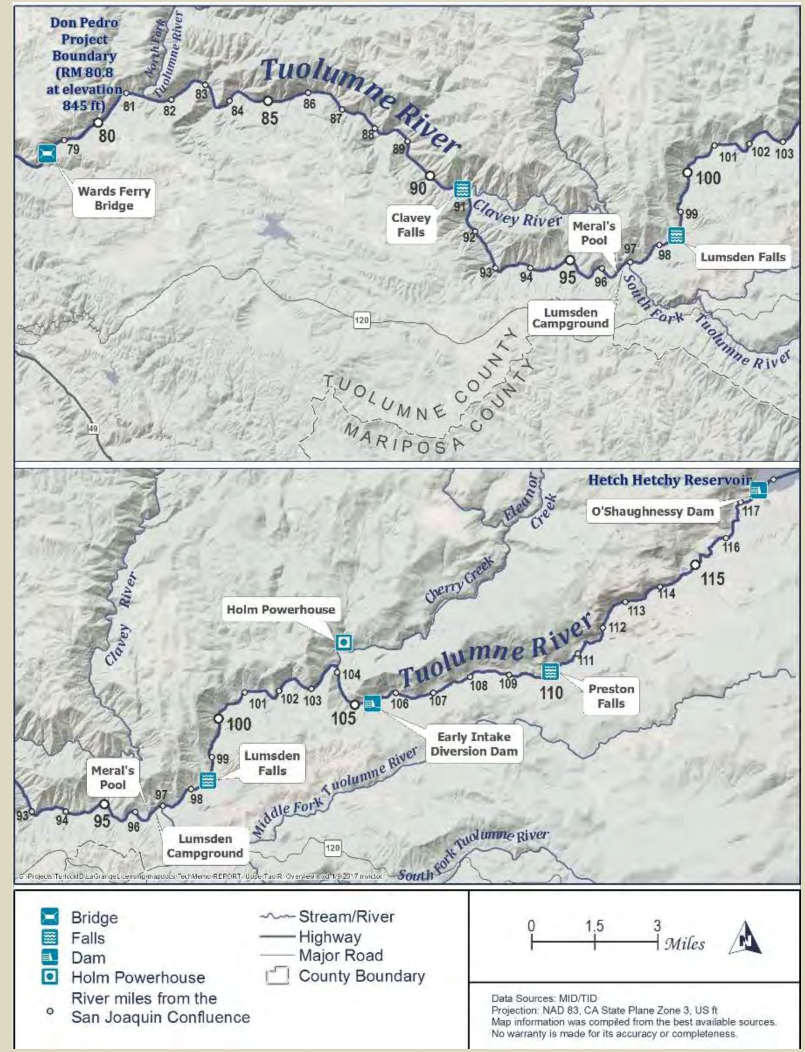
- Map the distribution of potentially suitable spawning gravel available for Chinook salmon and steelhead in the upper Tuolumne River.
- Quantify the amount of suitable spawning gravel by species and geomorphic reach.
- Assess the quality of potentially suitable spawning gravel based on particle characteristics (i.e., size, sorting, angularity, and embeddedness), gravel depth, and permeability.

* "Steelhead" refers only to steelhead and does not include resident *O. mykiss*.

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study

Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Spawning Gravel Mapping Methodology

- Spawning gravel initially desktop mapped within modeled ~2,000 cfs inundation area using 2007 air photos provided by Towill Surveying and GIS Services, Inc.
- ~130 cfs inundation empirically defined from water edge in 2007 air photos.
- Field reconnaissance to calibrate and validate desktop mapping.
- Detailed field delineation of gravel patches from Cherry Creek to Don Pedro Reservoir:
  - Mapping: two-person crew using support of two whitewater rafts from July 18-24, 2016.
  - Field tiles: desktop mapping, 2007 air photo, river stationing, and 2,000 cfs inundation.
  - Patch descriptions: surface texture, grain size (D_{50}, D_{84} and D_{16}), quality (substrate depth, particle sorting, angularity, and embeddedness), and geomorphic feature type.
  - Overall gravel quality rating from 1 (poor) to 10 (good) assigned to each patch and later classified by category; good (7–10), fair (4–6), and poor (1–3).

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Permeability Methodology

- Based on spawning gravel mapping results, gravel permeability sampling strategy developed to characterize conditions influencing Chinook salmon and steelhead egg incubation and survival-to-emergence.
- Permeability sampled in select spawning gravel patches from pool tail, point bar, medial bar, and lateral bar geomorphic units with Gr dominant facies, Co or finer subdominant facies, and $D_{84} \leq 128$ mm.
- Survival-to-emergence will be estimated using published empirical relationships.

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study Permeability Methodology

Upper Tuolumne River Chinook Salmon and Steelhead Spawning Gravel Mapping Study
Study Status

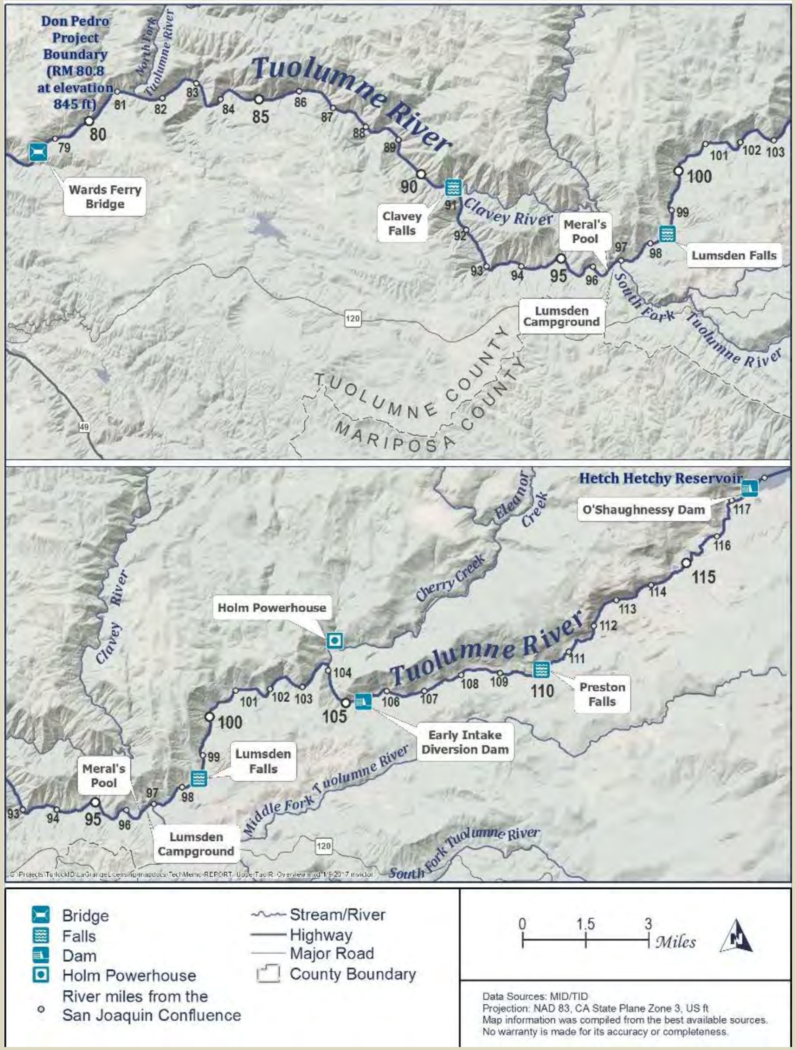
- Data compilation and QC is in process.
- Data analysis and study report development is anticipated to occur this summer.

Upper Tuolumne River Habitat Mapping Assessment Study Goals and Objectives

- Document the number, size, and distribution of mesohabitat units in the upper Tuolumne River.
- Collect detailed data on habitat attributes in representative reaches of the upper Tuolumne River.
- Document potential pool habitat for over-summering adult Chinook salmon.

Upper Tuolumne River Habitat Mapping Assessment Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Habitat Mapping Assessment Study Methodology

Objective 1: Documenting mesohabitat units from Early Intake (RM 105) to upstream limit of Don Pedro (RM 80.8).

- Conducted in the field and remotely using standardized methodologies.
- Field:
  - Mesohabitat collected during daily high flow period (~1200 cfs) by raft (July 17 – July 31, 2016).
  - Early Intake to Merals Pool: Georeferenced GoPro video (July 28 – 31, 2016).
  - Merals Pool to Don Pedro Project Boundary: Mapbook and GPS used to complete reconnaissance level effort from 2015 (July 17 – 23, 2016).
- Remote:
  - Post-processing field data to determine habitat lengths and consolidate notes into GIS database.

Upper Tuolumne River Habitat Mapping Assessment Study Methodology

Objective 2: Collecting detailed habitat data in representative reaches.

- CDFW Level III habitat typing methodology.
  - Unit measurements, bankfull width, pool tail crest depth, large woody debris counts, canopy, shelter value and substrate characteristics at every habitat unit.
- Collected during the daily “baseflow” period (~300 cfs).

Upper Tuolumne River Habitat Mapping Assessment Study Methodology

Objective 3: Documenting potential pool holding habitat for over-summering adult Chinook salmon.

- Early Intake to Merals Pool:
  - Pool surface area estimated based on 2007 aerial imagery.
  - Depth was visually estimated .
- Merals Pool to Wards Ferry:
  - Pool surface dimensions were measured using laser rangefinder.
  - Depth data collected using stadia rod or digital depth sounder.

Upper Tuolumne River Habitat Mapping Assessment Study Status

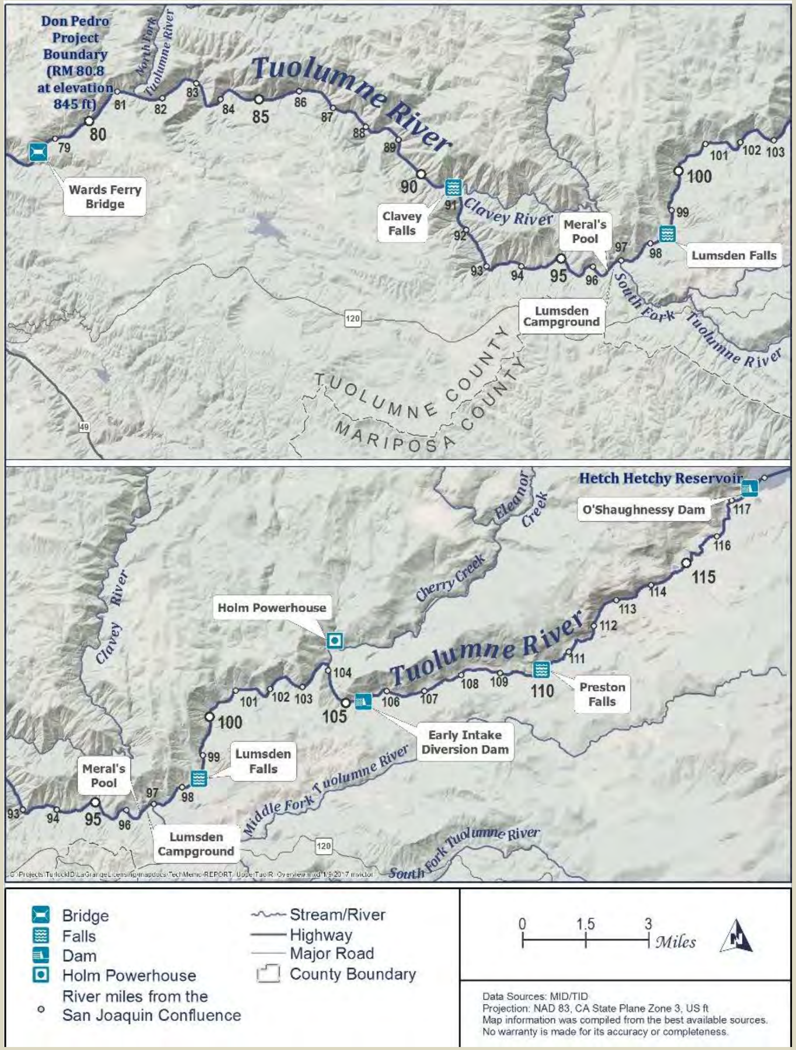
- Data compilation and QC is in process.
- Data analysis and study report development is anticipated to occur this summer.

Upper Tuolumne River Macroinvertebrate Assessment Study Goals and Objectives

- Objectives:
  - (1) Salmonid prey: Determine whether macroinvertebrate drift is consistent with other similar streams currently supporting salmonid populations; and
  - (2) Bioassessment: Use benthic macroinvertebrate (BMI) data to assess aquatic ecosystem health and compare with similar streams and data sets.

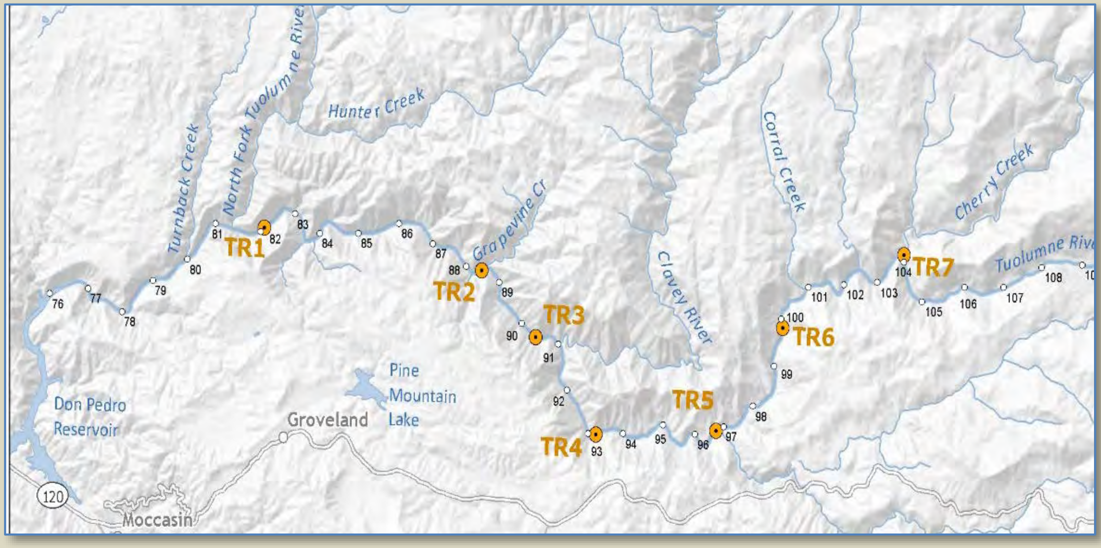
Upper Tuolumne River Macroinvertebrate Assessment Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project Boundary (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Macroinvertebrate Assessment Study Methodology

- Raft-based macroinvertebrate sampling was conducted during summer (July) and fall (October) of 2016.
  - Drift sampling and benthic sampling.
- 7 mainstem sites sampled between N.F. Tuolumne River and Cherry Creek.
- Sampled in riffle and run habitats.
- Physical habitat characteristics, including water velocity and basic water quality parameters were measured at the time of sampling at each site.



Upper Tuolumne River Macroinvertebrate Assessment Study Methodology

- Followed standard protocols for benthic (kick net) and drift sampling.
- Benthic: Modified SWAMP TRC method; 8 subsamples and 1 composited sample per site.
- Drift: 1 nearshore and 1 thalweg drift net per site; nets set for ~3 hrs in evening.
- Laboratory and office: sort, ID, count, density (drift), biomass (drift), bioassessment metrics and indices (benthic).

Upper Tuolumne River Macroinvertebrate Assessment Study Status

- Data compilation and QC is in process.
- Data analysis and study report development is anticipated to occur this summer.

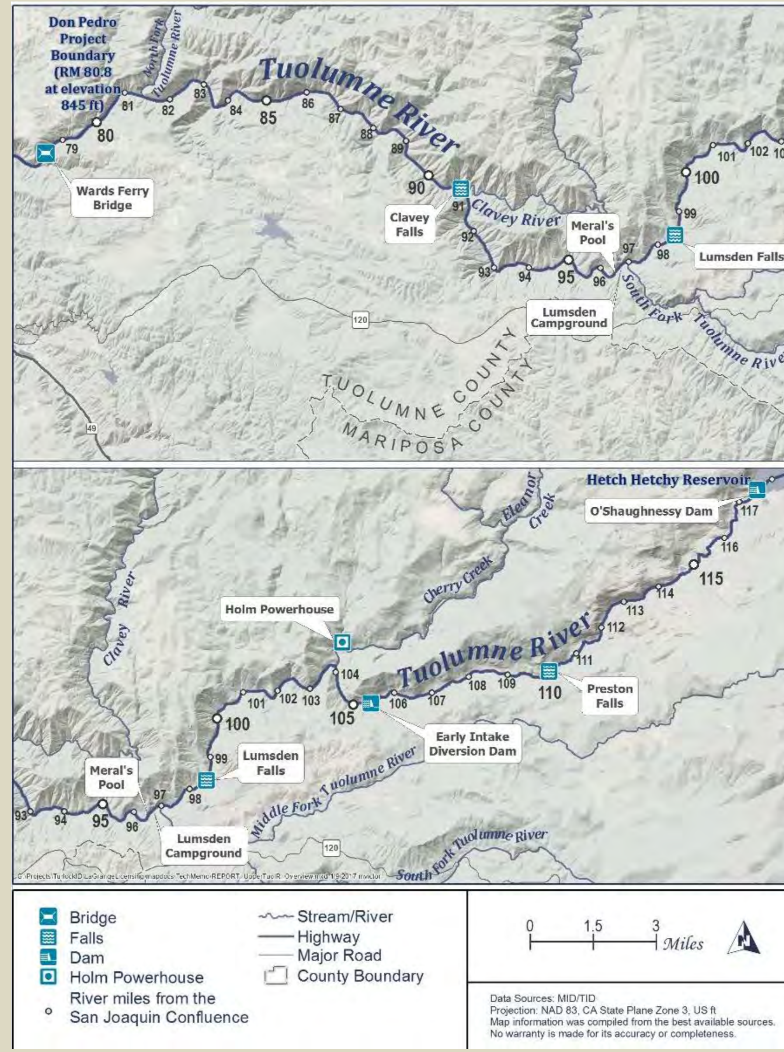
Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Study Goals and Objectives

- Use existing data to characterize the thermal regimes of the upper Tuolumne River and tributaries.
- Install water temperature and/or stage data loggers to obtain additional information at locations for which existing data are inadequate.
- Develop and test a computer model to simulate existing thermal conditions in the Tuolumne River from below Early Intake to above Don Pedro Project Boundary.

Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study

Study Area

- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project Boundary (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Study Methodology

1. Identify, synthesize and interpret existing data (temperature, flow, meteorological, etc.).
2. Install additional water temperature and stage data loggers as needed.
3. Water temperature and stage data collection and review.
4. Water temperature modeling
   - Model Selection
   - Data Development
   - Model Implementation
   - Model Calibration
   - Model Application

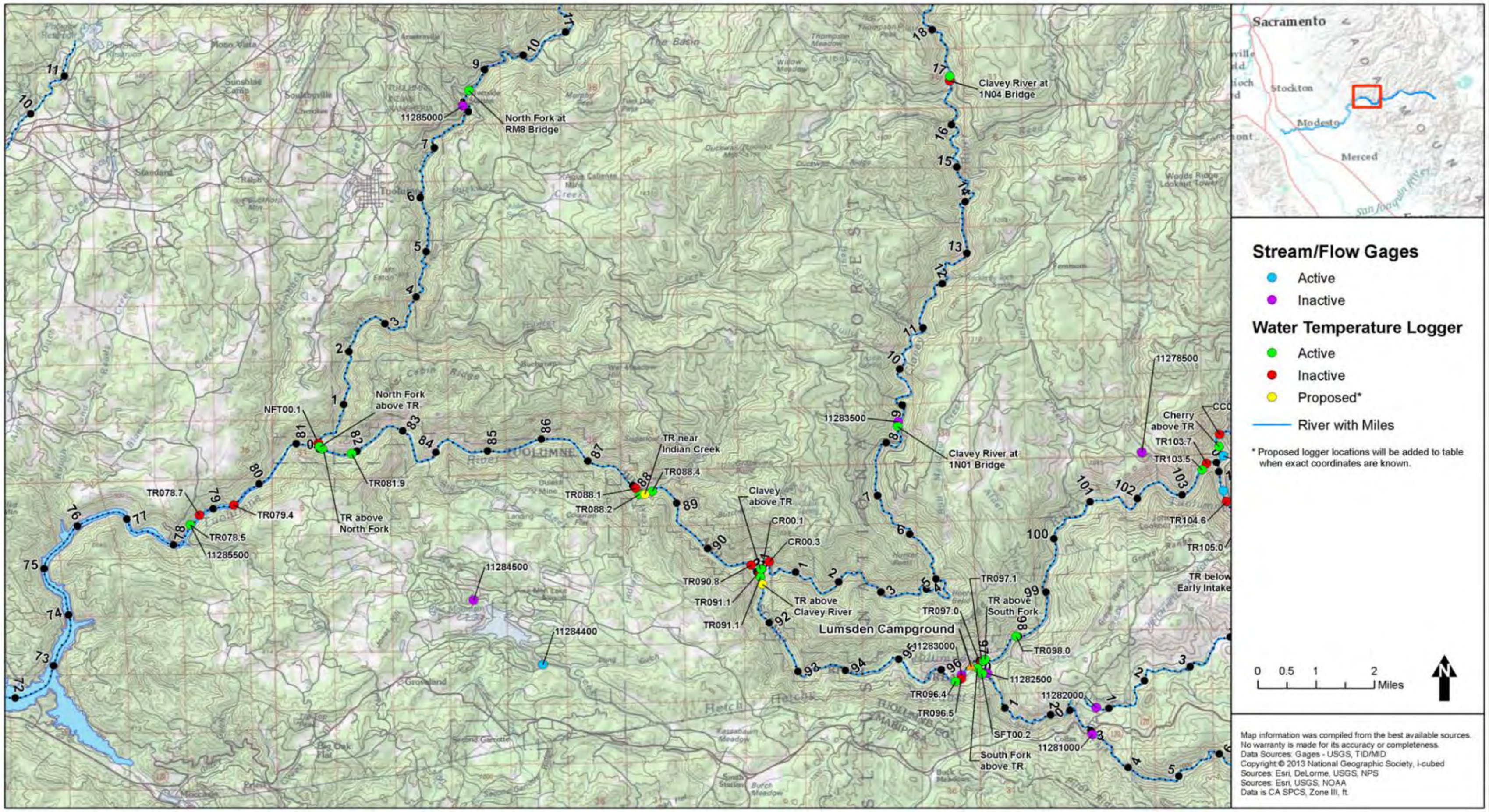
Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Methods: Monitoring

1. Water temperature
2. Stage and velocity
3. Cooperative effort (USGS, NMFS, others)

River Mile	Agency	Land Owner	Site_Locations	2015												2016											
				J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
CC00.5	TID/MID	USFS	Cherry Ck. bel. Dion Holm Powerhouse																								
CC02.0	TID/MID	USFS	Cherry Ck. ab. Dion Holm Powerhouse																								
SFT00.1	TID/MID	USFS*	SF Tuolumne R. ab. Tuolumne R.																								
CR00.1	TID/MID	USFS*	Clavey R. ab. Tuolumne R.																								
CR08.4	TID/MID	USFS	Clavey R. at 1N01 Bridge																								
CR16.9	TID/MID	USFS	Clavey R. at 1N04 Bridge																								
NF00.1	TID/MID	BLM*	NF Tuolumne R. ab. Tuolumne R.																								
NF08.4	TID/MID	USFS	NF Tuolumne R, near 1N01 Bridge																								
TR81.3	TID/MID	USFS*	Tuolumne R. ab. NF Tuolumne R.																								
TR091.1	TID/MID	USFS*	Tuolumne R. ab. Clavey R.																								
TR097.0	TID/MID	USFS*	Tuolumne R. ab. SF Tuolumne R.																								
TR105.2	TID/MID	USFS	Tuolumne R. bel. Early Intake																								

*managed under Wild and Scenic River designation

Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Methods: Monitoring



Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Methods: Model Development

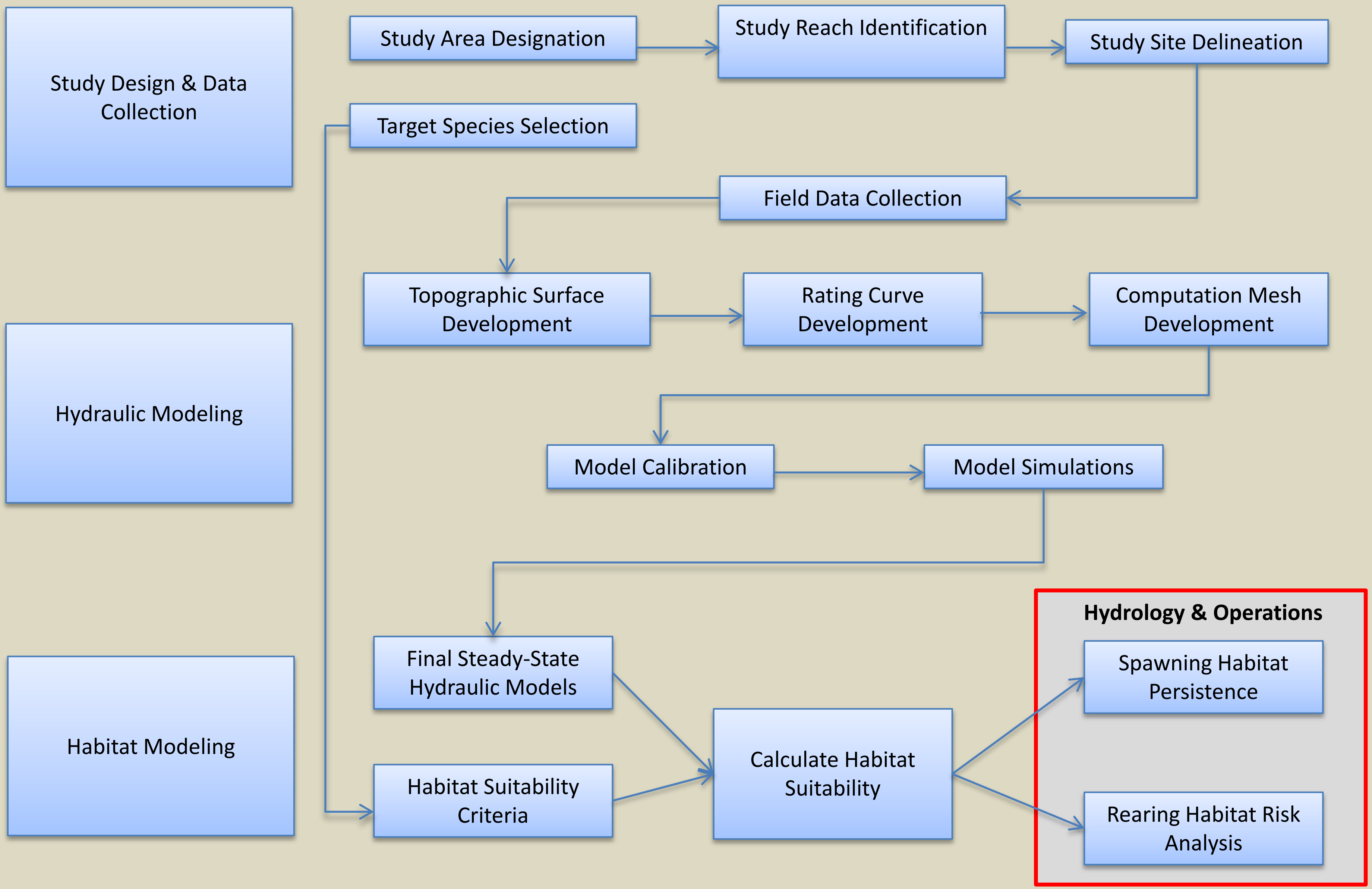
- Domain
  - Early Intake to above Don Pedro
- Model resolution
  - 15 minute time steps
  - 25 meter (82 ft) spatial resolution
- Period of Simulation: 1/1/2008 to 9/30/2016
- Data
  - Geometry
  - Flow
  - Water Temperature
  - Meteorology

Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study
Study Status

- Water temperature model development, calibration, and validation are underway.
- Water temperature modeling and study report development is anticipated to occur this summer.

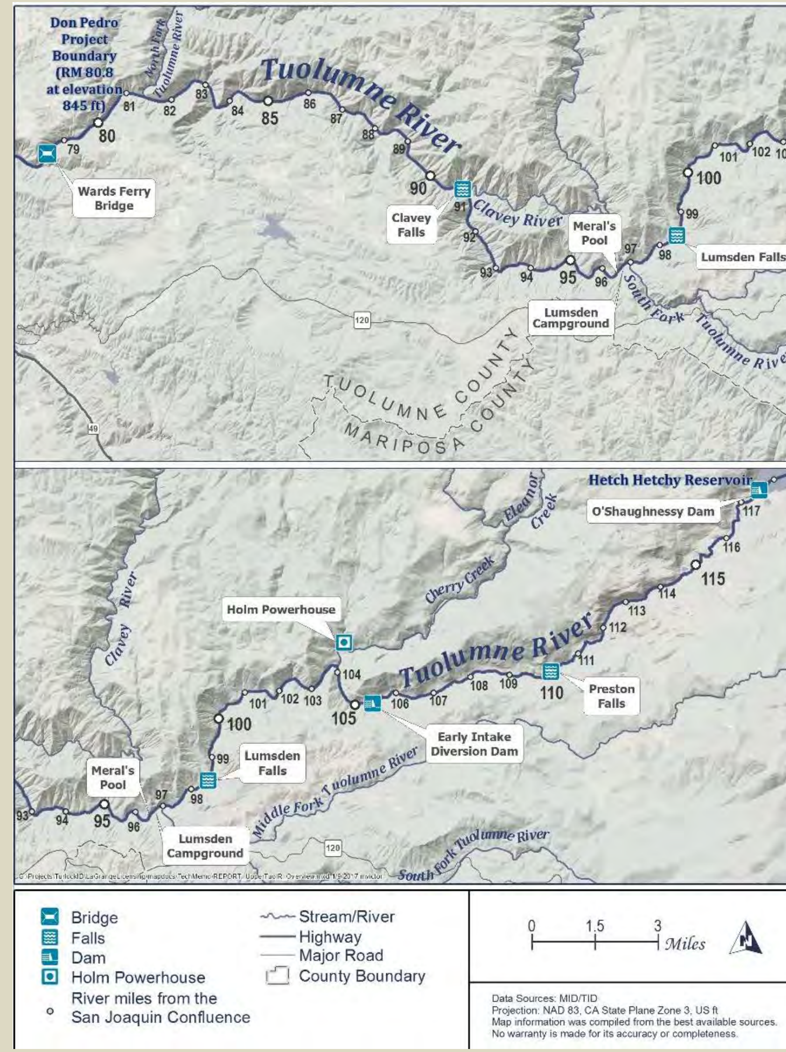
Upper Tuolumne River Instream Flow Study
Study Goals and Objectives

- Model existing aquatic habitat for spring-run Chinook salmon and steelhead.
- Evaluate the existing aquatic habitat over a representative range of observed water years and City and County of San Francisco's operations.
- Provide quantifiable metrics of aquatic habitat suitability in the context of potential reintroduction.


Study Design & Data Collection
Hydraulic Modeling
Habitat Modeling
Study Area Designation
Study Reach Identification
Study Site Delineation
Target Species Selection
Field Data Collection
Topographic Surface Development
Rating Curve Development
Computation Mesh Development
Model Calibration
Model Simulations
Final Steady-State Hydraulic Models
Habitat Suitability Criteria
Calculate Habitat Suitability
Hydrology & Operations
Spawning Habitat Persistence
Rearing Habitat Risk Analysis

Upper Tuolumne River Instream Flow Study
Study Area

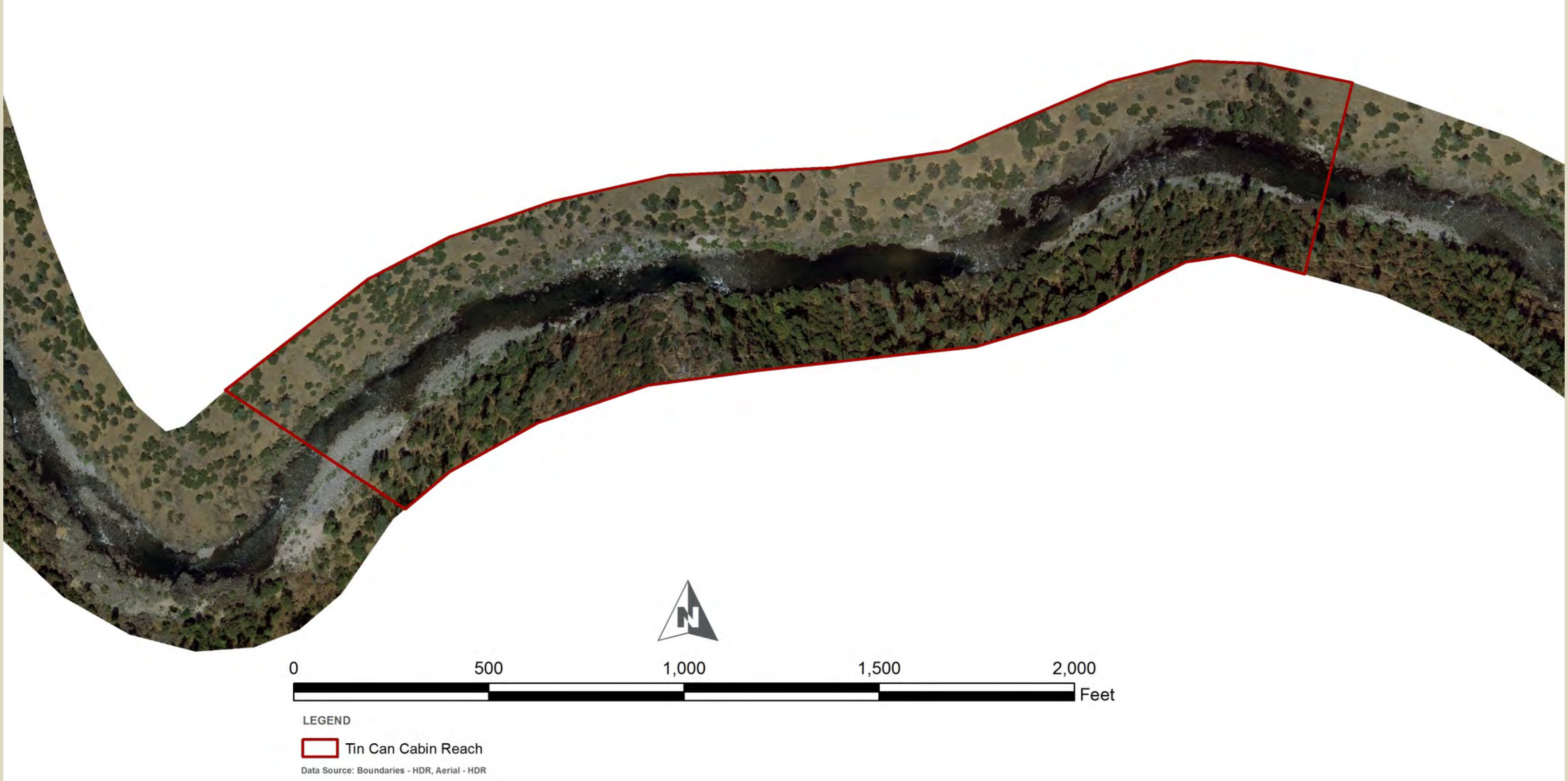
- Mainstem of the Upper Tuolumne River from the upstream limit of the Don Pedro Project Boundary (approximately RM 80.8) to Early Intake (approximately RM 105)



Upper Tuolumne River Instream Flow Study
Study Sites

- Tin Can Cabin ~ 2,678 ft (0.5 miles, RM 93.2-93.8)
  - 12 habitat units
- Wheelbarrow ~ 3,801 ft (0.72 miles, RM 87.0-87.7)
  - 11 habitat units
- Mohican ~ 3,040 ft (0.57 miles, RM 81.7-82.2)
  - 12 habitat units

Upper Tuolumne River Instream Flow Study
Study Site: Tin Can Cabin



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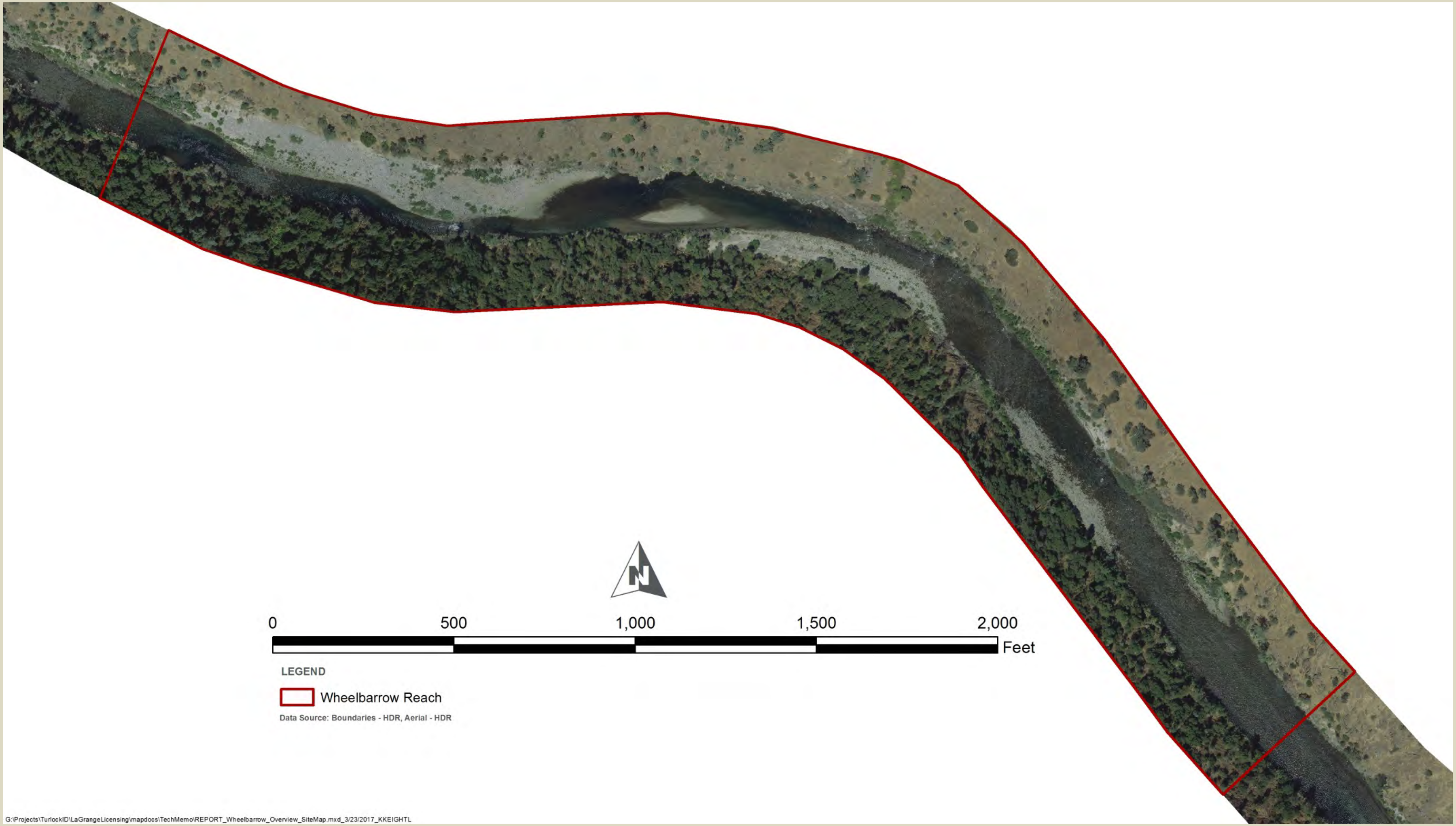
Upper Tuolumne River Instream Flow Study
Study Site: Tin Can Cabin




Upper Tuolumne River Instream Flow Study
Study Site: Wheelbarrow



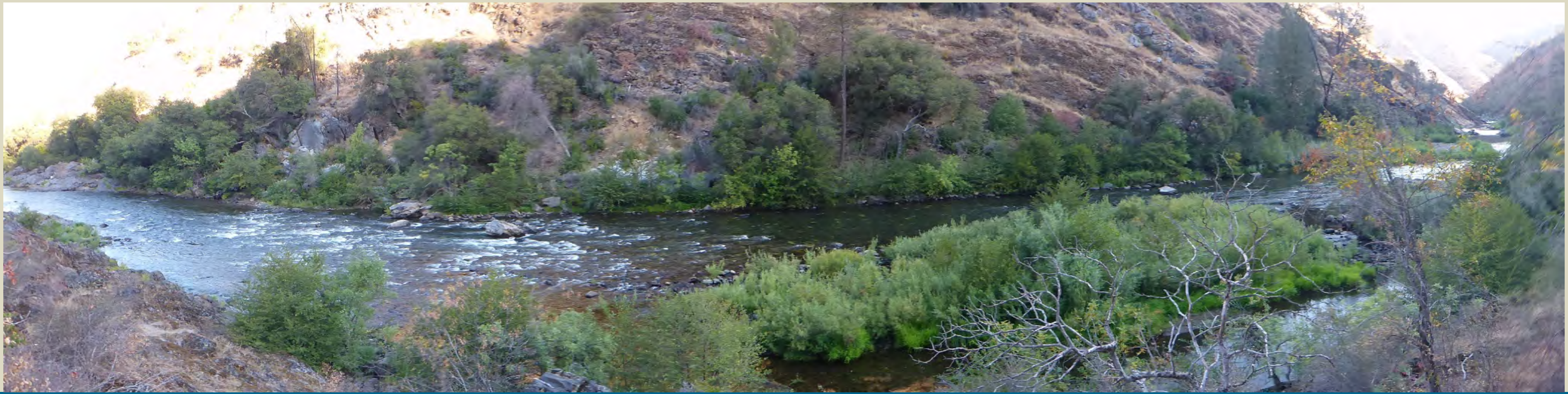
Upper Tuolumne River Instream Flow Study
Study Site: Wheelbarrow




Upper Tuolumne River Instream Flow Study
Study Site: Mohican

Upper Tuolumne River Instream Flow Study
Study Site: Mohican



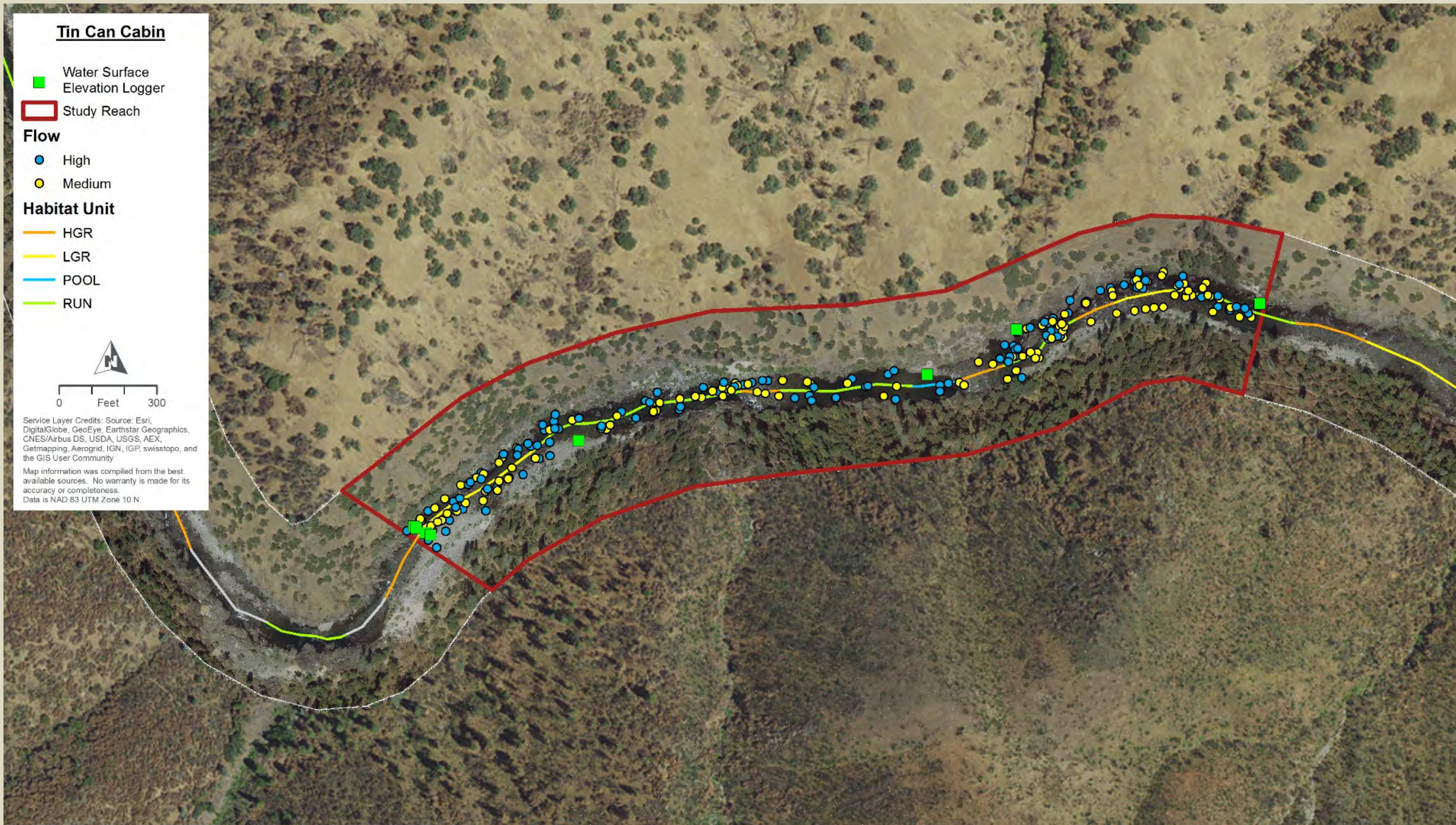
Upper Tuolumne River Instream Flow Study
Field Data Collection

- Field Data Collection
  - Methods
    - RTK GPS Survey
    - Total Station Survey
    - Single beam bathymetry
    - Acoustic Doppler Current profiler (ADCP)
    - Flow meter
    - Stage recorders – (Level Loggers)

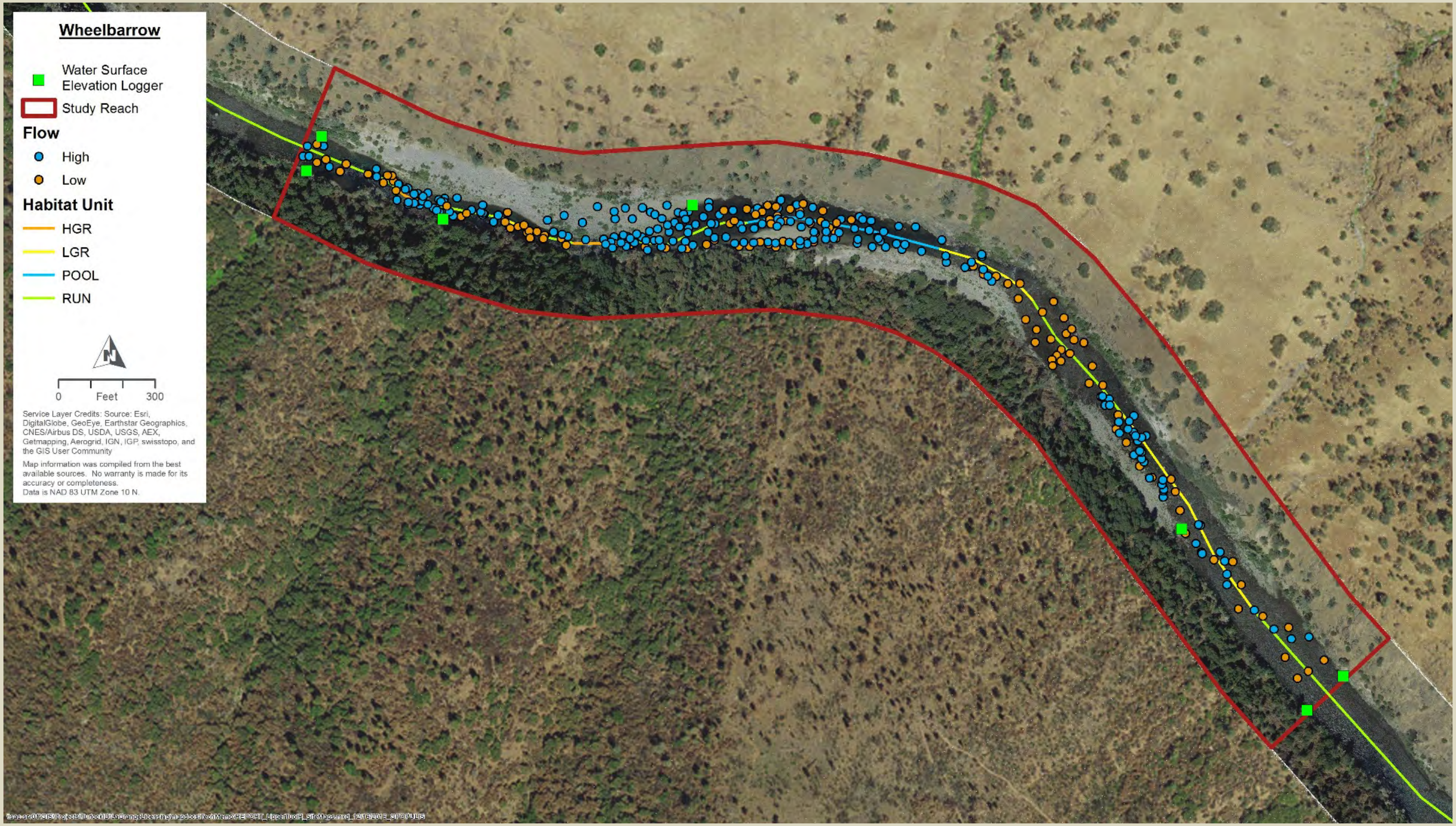
Upper Tuolumne River Instream Flow Study
Field Data Collection

Upper Tuolumne River Instream Flow Study
Field Data Collection

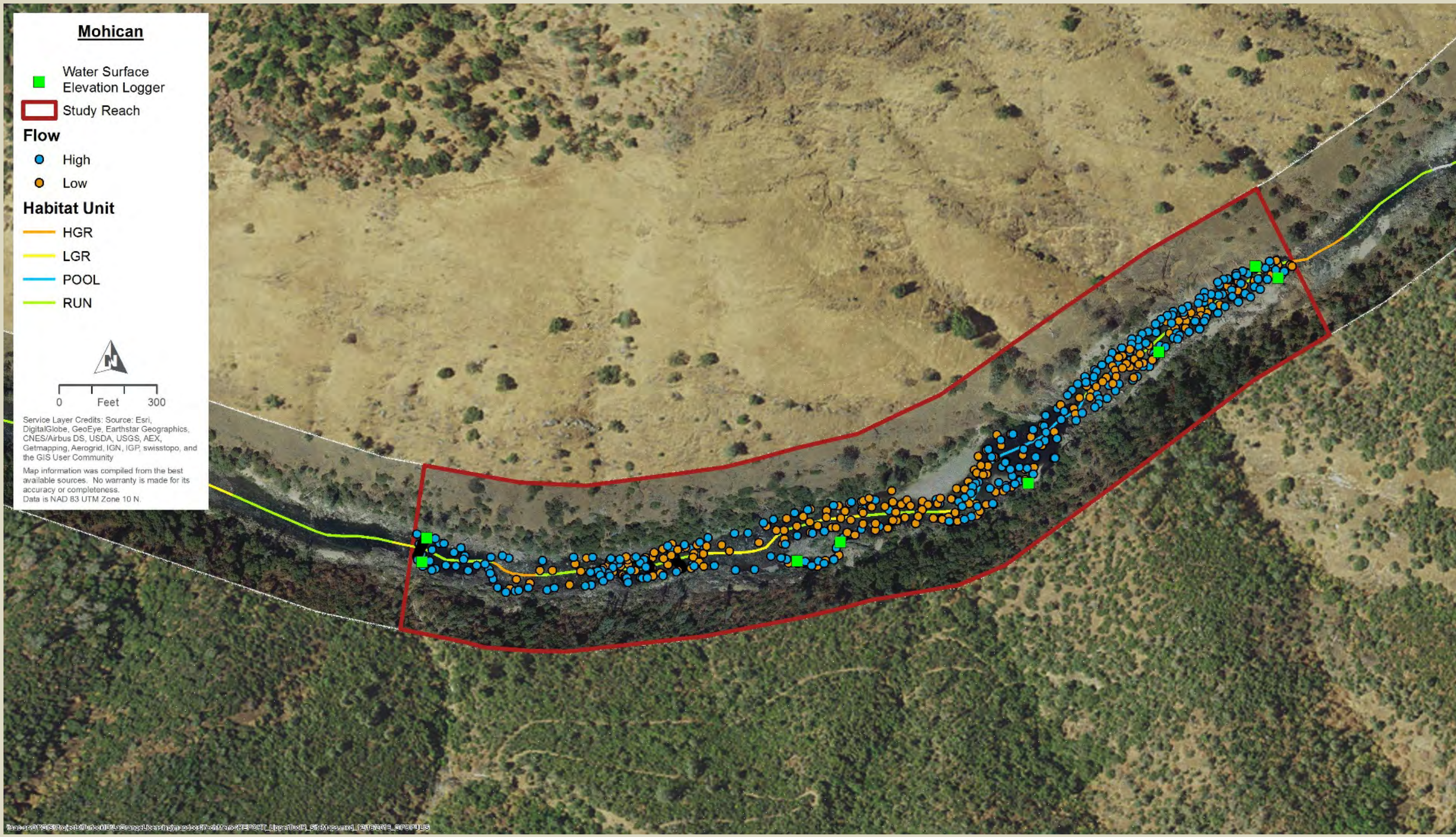
Upper Tuolumne River Instream Flow Study
Example of Observed Data: Tin Can Cabin



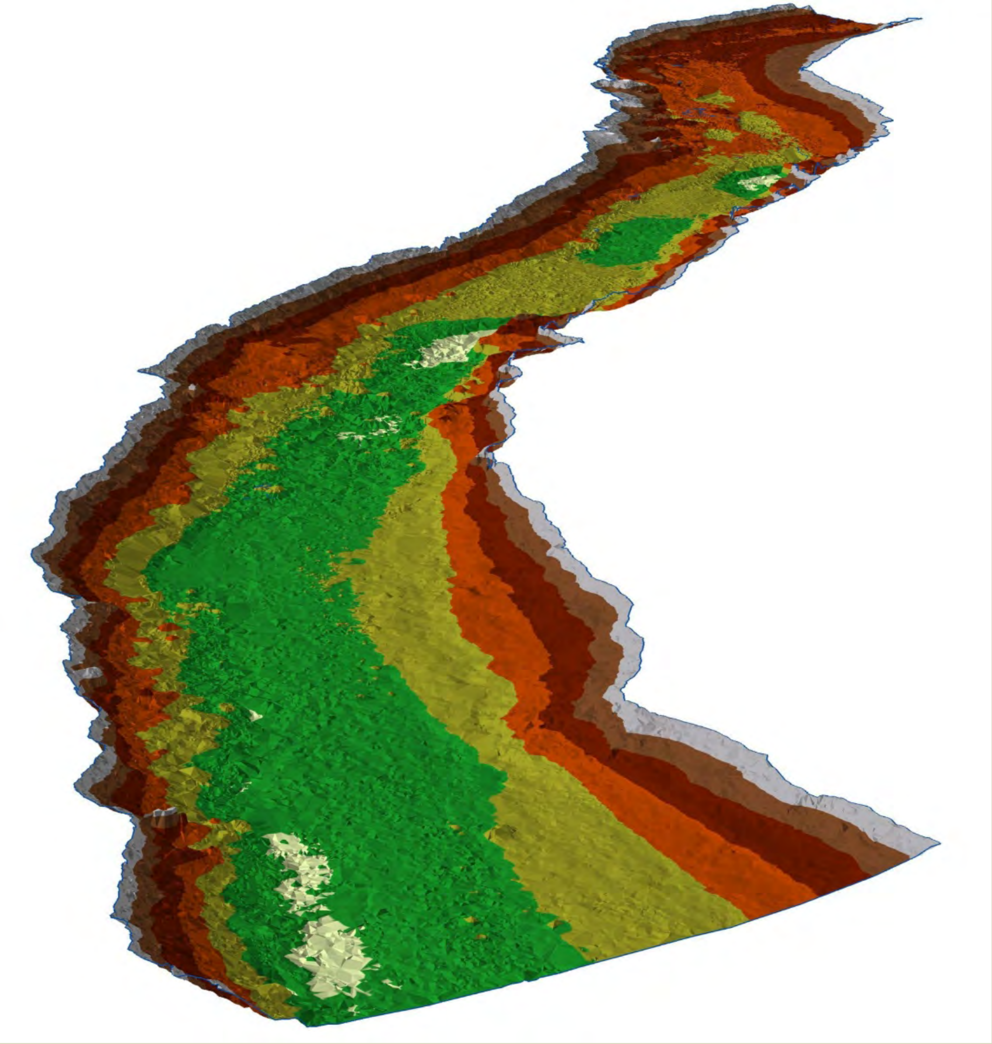
Upper Tuolumne River Instream Flow Study
Example of Observed Data: Wheelbarrow



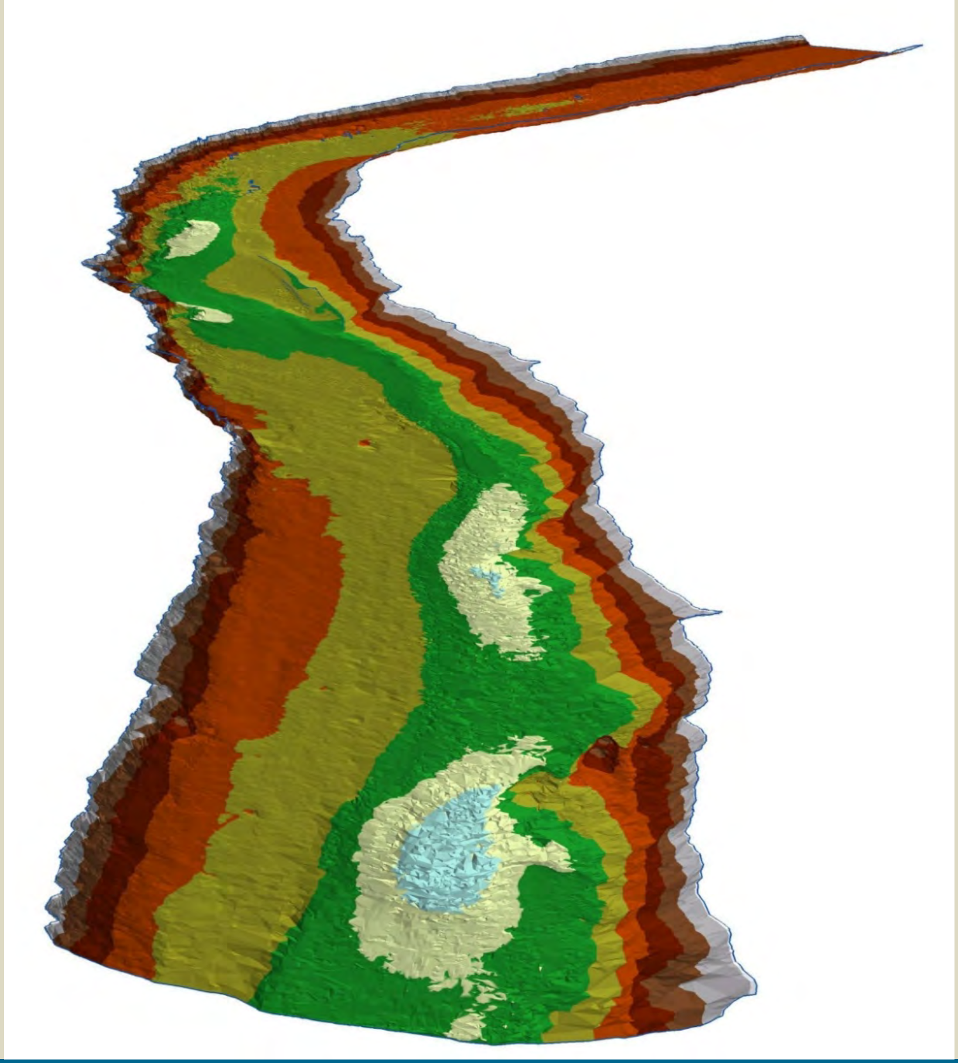
Upper Tuolumne River Instream Flow Study
Example of Observed Data: Mohican



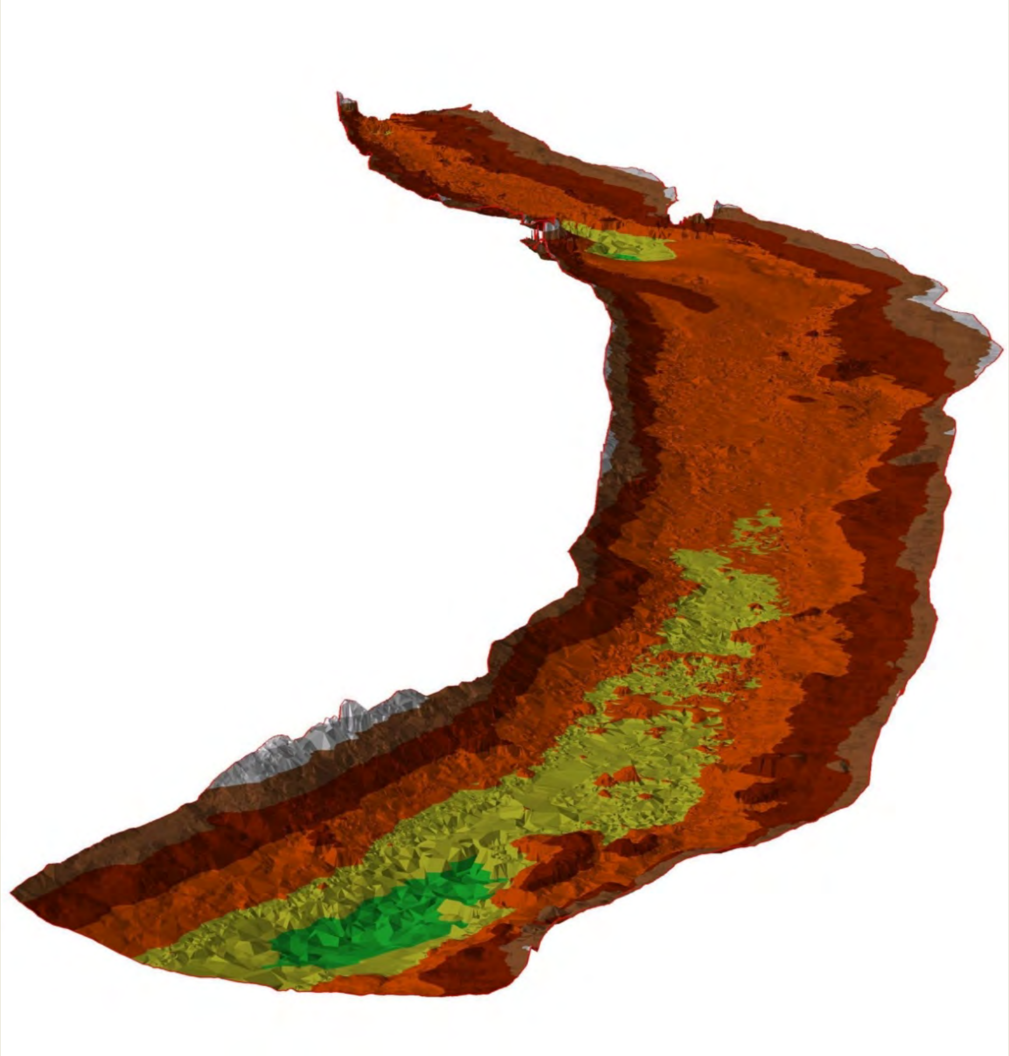
Upper Tuolumne River Instream Flow Study
Topography: Tin Can Cabin



Upper Tuolumne River Instream Flow Study
Topography: Wheelbarrow



Upper Tuolumne River Instream Flow Study
Topography: Mohican



Upper Tuolumne River Instream Flow Study
Study Status

- Model development, calibration, and validation are underway.
- Modeling and study report development is anticipated to occur through the summer.

Questions?