

**INITIAL STUDY REPORT**

**APPENDIX D**

**UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE  
MONITORING AND MODELING STUDY  
PROGRESS REPORT**

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# **UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE MONITORING AND MODELING STUDY PROGRESS REPORT**

**LA GRANGE HYDROELECTRIC PROJECT  
FERC NO. 14581**



**Prepared for:**  
**Turlock Irrigation District – Turlock, California**  
**Modesto Irrigation District – Modesto, California**

**Prepared by:**  
**Watercourse Engineering, Inc.**

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# Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study

## Progress Report

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**List of Attachments**

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Attachment B	QA/QC Approach
Attachment C	Data Inventory
Attachment D	Maps of Study Area Including Locations of Data Collection Sites
Attachment E	Workshop Meeting Notes and Materials

## List of Acronyms and Abbreviations

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ac-ft	acre-foot
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
CCSF	City and County of San Francisco
CDFG	California Department of Fish and Game, now CDFW
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CG	Conservation Group
Districts	Turlock Irrigation District and Modesto Irrigation District
FERC	Federal Energy Regulatory Commission
FLA	Final License Application
FPA	Federal Power Act
GIS	geographic information system
ILP	Integrated Licensing Process
ISR	Initial Study Report
LGDD	La Grange Diversion Dam
LP	Licensing Participant
M&I	municipal and industrial
MID	Modesto Irrigation District
NMFS	National Marine Fisheries Service
NPS	National Park Service
O&M	operation and maintenance
PAD	Pre-Application Document
PSP	Proposed Study Plan
QA/QC	quality assurance/quality control
RM	river mile
RSP	Revised Study Plan
SD2	Scoping Document 2
SPD	Study Plan Determination
TAF	thousand acre-feet
TID	Turlock Irrigation District
TM	technical memorandum
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USR	Updated Study Report

## **1.0 INTRODUCTION**

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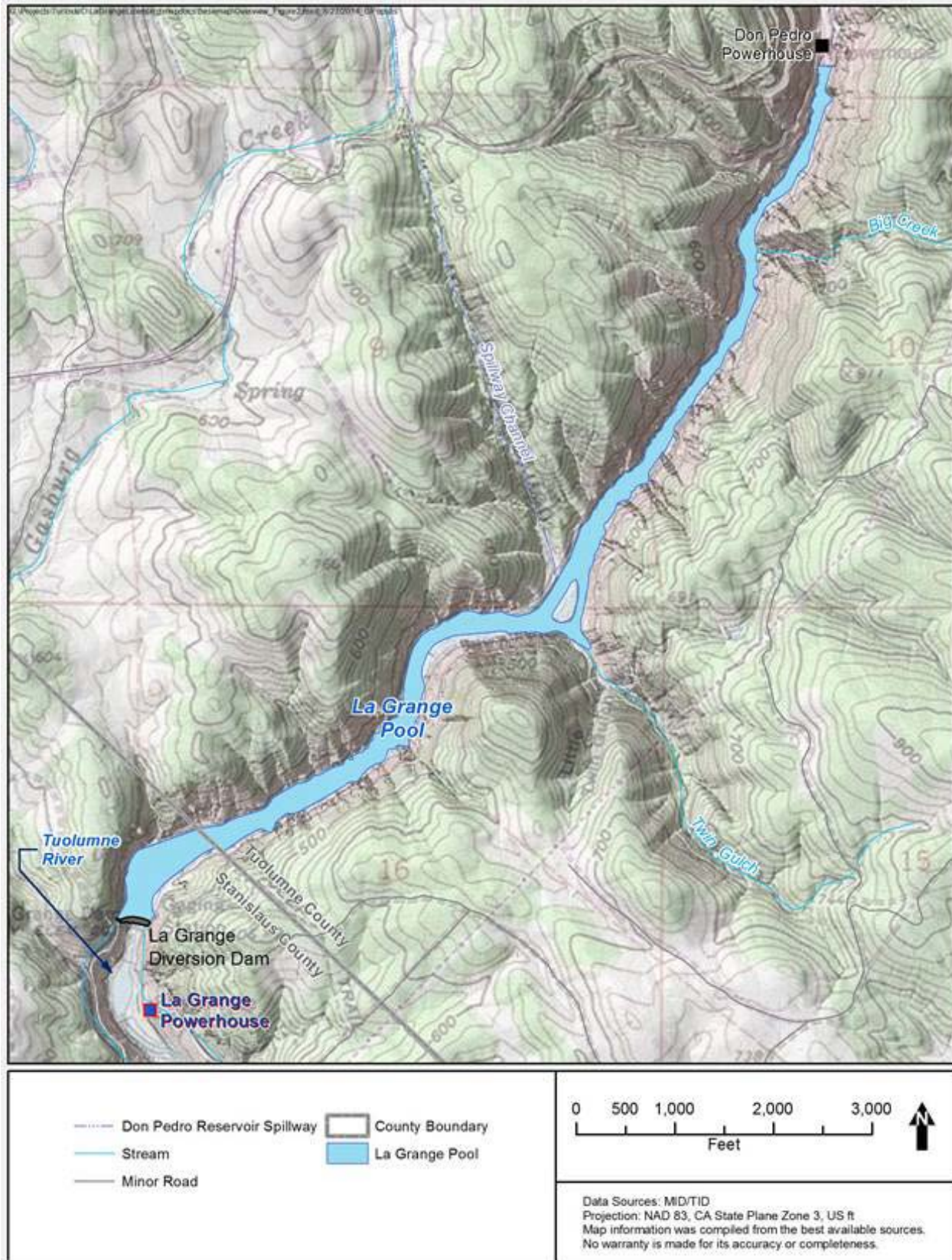
### **1.1 Background**

The Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) own the La Grange Diversion Dam (LGDD) located on the Tuolumne River in Stanislaus County, California (Figures 1.1-1 and 1.1-2). LGDD is 131 feet high and is located at river mile (RM) 52.2 at the exit of a narrow canyon, the walls of which contain the pool formed by the diversion dam. Under normal river flows, the pool formed by the diversion dam extends for approximately one mile upstream. When not in spill mode, the water level upstream of the diversion dam is between elevation 294 feet and 296 feet approximately 90 percent of the time. Within this 2-foot range, the pool storage is estimated to be less than 100 acre-feet of water.

The drainage area of the Tuolumne River upstream of LGDD is approximately 1,550 square miles. Tuolumne River flows upstream of LGDD are regulated by four upstream reservoirs: Hetch Hetchy, Lake Eleanor, Cherry Lake, and Don Pedro. The Don Pedro Hydroelectric Project (Federal Energy Regulatory Commission [the Commission or FERC] No. 2299) is owned jointly by the Districts, and the other three dams are owned by the City and County of San Francisco (CCSF). Inflow to the La Grange pool is the sum of releases from the Don Pedro Project, located 2.3 miles upstream, and very minor contributions from two small intermittent streams downstream of Don Pedro Dam.

LGDD was constructed from 1891 to 1893 displacing Wheaton Dam, which was built by other parties in the early 1870s. LGDD raised the level of the Tuolumne River to permit the diversion and delivery of water by gravity to irrigation systems owned by TID and MID. The Districts' irrigation systems currently provide water to over 200,000 acres of prime Central Valley farmland and drinking water to the City of Modesto. Built in 1924, the La Grange hydroelectric plant is located approximately 0.2 miles downstream of LGDD on the east (left) bank of the Tuolumne River and is owned and operated by TID. The powerhouse has a capacity of slightly less than five megawatts. The La Grange Hydroelectric Project (La Grange Project or Project; FERC No. 14581) operates in a run-of-river mode. The LGDD provides no flood control benefits, and there are no recreation facilities associated with the Project or the La Grange pool.





**Figure 1.1-1. La Grange Hydroelectric Project location map.**





**Figure 1.1-2. La Grange Hydroelectric Project site plan.**

## 1.2 Licensing Process

On January 29, 2014, the Districts commenced the pre-filing process for the licensing of the La Grange Project by filing a Pre-Application Document (PAD) with FERC<sup>1</sup>. The Districts' PAD included descriptions of the Project facilities, operations, and lands as well as a summary of existing information available on Project area resources.

On September 5, 2014, the Districts filed their Proposed Study Plan (PSP) to assess Project effects on fish and aquatic resources, recreation, and cultural resources in support of their intent to license the Project. On October 6, 2014, the Districts held a PSP meeting at MID's offices in Modesto, California. Based on discussion at the PSP meeting, the Districts prepared an Updated Study Plan document that went to licensing participants (LP) for review and comment on November 21, 2014. On December 4, 2014, the National Marine Fisheries Service (NMFS), the Conservation Groups (CG), and the California Department of Fish and Wildlife (CDFW) filed comments on the PSP and/or Updated Study Plan.

On January 5, 2015, in response to comments from LPs, the Districts filed their Revised Study Plan (RSP) containing three study plans: (1) Cultural Resources Study Plan; (2) Recreation Access and Safety Assessment Study Plan; and (3) Fish Passage Assessment Study Plan<sup>2</sup>. Comments on the RSP were received from CDFW on January 16, 2015, and from NMFS, the CGs and the City of Modesto on January 20, 2015.

On February 2, 2015, FERC issued the Study Plan Determination (SPD), approving or approving with modifications six studies (Table 1.2-1). Of those six studies, five had been proposed by the Districts in the RSP. The Districts note that although FERC's SPD identified the Fish Passage Barrier Assessment, Fish Passage Facilities Alternatives Assessment, and Fish Habitat and Stranding Assessment below La Grange Diversion Dam as three separate studies, all three assessments are elements of the larger Fish Passage Assessment as described in the RSP. The sixth study approved by FERC, Effects of the Project and Related Activities on the Losses of Marine-Derived Nutrients in the Tuolumne River, was requested by NMFS in its July 22, 2014 comment letter. Of the eight studies requested by LPs, FERC approved only the NMFS study noted above.

Although FERC's SPD did not require the Districts to undertake the Upper Tuolumne River Basin Habitat Assessment studies contained in the RSP, the Districts are voluntarily conducting the Upper River Barriers Study and the Water Temperature Monitoring and Modeling Study. Regarding the third component of the Upper Tuolumne River Basin Habitat Assessment, the ongoing upstream habitat characterization work being completed by NMFS, the Districts anticipate the results of this work becoming available for consideration in this licensing proceeding.

<sup>1</sup> On December 19, 2012, Commission staff issued an order finding that the La Grange Hydroelectric Project is required to be licensed under Section 23(b)(1) of the Federal Power Act. Turlock Irrigation District and Modesto Irrigation District, 141 FERC ¶ 62,211 (2012), aff'd Turlock Irrigation District and Modesto Irrigation District, 144 FERC ¶ 61,051 (2013). On May 15, 2015, the U.S. Court of Appeals for the District of Columbia Circuit denied the Districts' appeal and affirmed the Commission's finding that the La Grange Hydroelectric Project requires licensing. Turlock Irrigation District, et al., v. FERC, et al., No. 13-1250 (D.C. Cir. May 15, 2015).

<sup>2</sup> The Fish Passage Assessment Study Plan contained a number of individual, but related, study elements.



**Table 1.2-1. Studies approved or approved with modifications in FERC's Study Plan Determination.**

No.	Study	Approved by FERC in SPD without Modifications	Approved by FERC in SPD with Modifications
1	Recreation Access and Safety Assessment		X
2	Cultural Resources Study		X
3	Fish Passage Barrier Assessment		X <sup>1</sup>
4	Fish Passage Facilities Alternatives Assessment		X
5	Fish Habitat and Stranding Assessment below La Grange Dam		X
6	Effects of the Project and Related Activities on the Losses of Marine-Derived Nutrients in the Tuolumne River	X <sup>2</sup>	

<sup>1</sup> Page A-1 of Appendix A of FERC's SPD states that FERC approved with modifications the Fish Passage Barrier Assessment. However, the Districts found no modifications to this study plan in the SPD and page B-7 of the SPD states that "no modifications to the study plan are recommended."

<sup>2</sup> FERC directed the Districts to conduct the study plan as proposed by NMFS.

In addition to the six studies noted in Table 1.2-1, the SPD required the Districts to develop a plan to monitor anadromous fish movement in the Project's powerhouse draft tubes and to determine the potential for injury or mortality from contact with the turbine runners. Per the SPD, the Districts developed a study plan in consultation with NMFS and other LPs. The Districts filed the Investigation of Fish Attraction to La Grange Powerhouse Draft Tubes study plan with FERC on June 11, 2015, and on August 12, 2015, FERC approved the study plan as filed.

This progress report describes the objectives, methods, and preliminary results of the Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study (herein referred to as the Water Temperature Monitoring and Modeling Study) as implemented by the Districts in accordance with FERC's SPD. The Water Temperature Monitoring and Modeling Study is one of the three study components of the Upper Tuolumne River Basin Habitat Assessment as described in the RSP and in Section 1.3 below. Documents relating to the Project licensing are publicly available on the Districts' licensing website at [www.lagrange-licensing.com/](http://www.lagrange-licensing.com/).

### 1.3 Study Plan

The Recovery Plan for the Evolutionary 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 (herein referred to as the Recovery Plan) (NMFS 2014) identifies the Tuolumne River above Don Pedro Reservoir as a candidate area for reintroduction of Central Valley steelhead and spring-run Chinook salmon. Recovery actions proposed in the Recovery Plan include a feasibility evaluation of a steelhead and spring-run Chinook passage program for La Grange and Don Pedro dams. The Recovery Plan states, "The program should include feasibility studies, habitat evaluations, fish passage design studies, and a pilot reintroduction phase prior to implementation of the long-term reintroduction program." However, little information exists to reliably assess the current quantity and quality of suitable habitat for the adult, juvenile, fry, and egg life stages of these salmonid species in the upper

Tuolumne River watershed. NMFS requested information on upstream fish migration barriers and water temperatures in the upper basin to inform its decision making in the context of potential Federal Power Act Section 10(j) recommendations and Section 18 fishway prescriptions as well as Endangered Species Act consultation.

In the RSP, the Districts proposed to conduct an Upper Tuolumne River Basin Habitat Assessment, of which there are three components: (1) a two-year phased assessment of physical barriers in the upper Tuolumne River; (2) a two-year phased assessment of water temperatures in the upper Tuolumne River; and (3) a summary of data from the upper Tuolumne River habitat evaluation being conducted by NMFS and identification of additional information needs following completion of upper Tuolumne River studies. FERC's SPD did not recommend that the Districts conduct the proposed Upper Tuolumne River Basin Habitat Assessment because potential anadromous fish habitat in the upper Tuolumne River above the Don Pedro Project is not affected by operation of either the La Grange or Don Pedro projects and, consequently, there is no nexus between the project operations and effects on anadromous fish habitat in the upper Tuolumne River. Nonetheless, to more fully support LPs in their development of information to supplement the fish passage studies approved by FERC in the SPD, to provide further useful information, to document river conditions between CCSF's Early Intake and the upstream end of the Don Pedro Reservoir, and to foster collaboration among all parties, the Districts decided voluntarily to conduct Items (1) and (2) above.

The Water Temperature Monitoring and Modeling Study Progress Report describes progress on completing Item (2). Progress on Item (1) is presented in the Upper Tuolumne River Basin Fish Migration Barriers Study Progress Report (TID/MID 2016). Item (3) will be completed when the NMFS habitat evaluation results are available to LPs for review.

## 2.0 STUDY GOALS AND OBJECTIVES

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The study goals and objectives of the Water Temperature Monitoring and Modeling Study are as follows:

- Use existing data to characterize the thermal regimes of the upper Tuolumne River and tributaries from Early Intake to above Don Pedro Reservoir and includes portions of the North and South forks of the Tuolumne River, Cherry Creek, and the Clavey River. This will form the basis of future work that will identify potential locations where temperatures may be suitable for reintroduction of anadromous salmonids (species to be determined but may include Central Valley steelhead and spring-run Chinook salmon).
- Depending on the availability of information, logistical feasibility, and safety, 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 Reservoir.

### 3.0 STUDY AREA

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The Water Temperature Monitoring and Modeling Study area includes the mainstem Tuolumne River from below Early Intake (RM 106) to above Don Pedro Reservoir (approximately RM 77) (Figure 3.0-1). Through this reach, the Tuolumne River receives notable tributary flow contributions from Cherry Creek, South Fork Tuolumne River, Clavey River, and North Fork Tuolumne River, as well as minor flow contributions from numerous small tributaries. Summary physiographic information is provided in Table 3.0-1. The study area includes the major tributaries listed above, from their confluence with the Tuolumne River upstream to the first complete barrier to fish migration. Locations of barriers to fish passage are still to be determined, pending completion of the Upper Tuolumne River Basin Fish Migration Barriers Study (TID/MID 2016). For this progress report, water temperature data and thermal conditions will be assessed in each tributary to the most upstream location where temperature data are available.

**Table 3.0-1. Summary statistics for principal tributaries of the Tuolumne River in the study area.**

Name	Stream Length (miles)	Watershed Area (square miles)	Basin Elevation (feet)
Cherry Creek <sup>1,2</sup>	42	234	10,800
South Fork Tuolumne River <sup>1,3</sup>	35	164	9,600
Clavey River <sup>1,4,5</sup>	36	157	9,250
North Fork Tuolumne River <sup>1</sup>	37	100	8,150

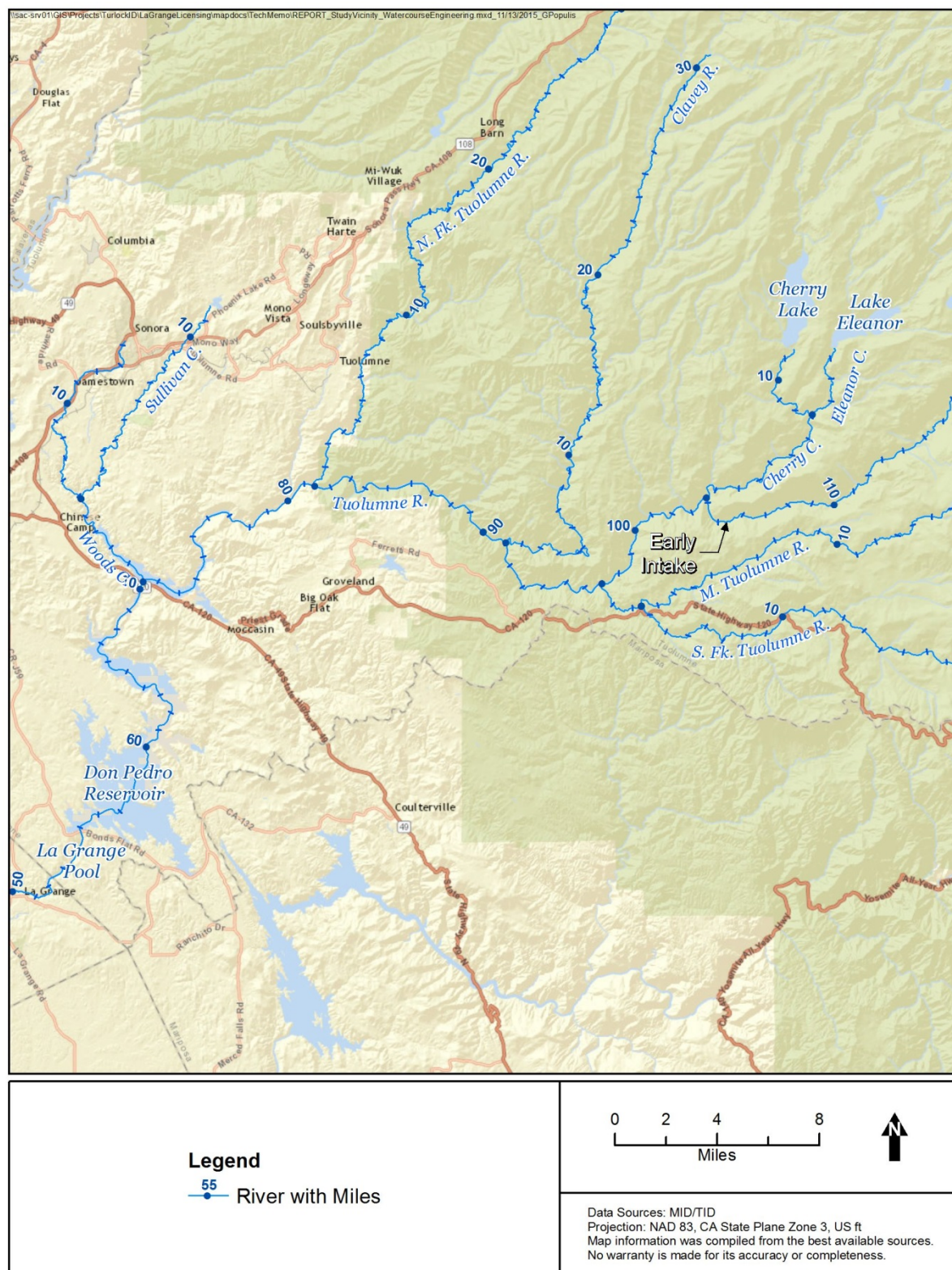
<sup>1</sup> <http://streamstatsags.cr.usgs.gov>.

<sup>2</sup> U.S. Geological Survey. 2013. Cherry Creek below Dion R. Holm Powerplant, near Mather, CA Water Data Report.

<sup>3</sup> U.S. Geological Survey. 2015. "Surface-Water Monthly Statistics". Surface Water data for USA. (<http://nwis.waterdata.usgs.gov>). Retrieved 11-14-15.

<sup>4</sup> U.S. Forest Service. 1997. Clavey River: Wild and Scenic River Value Review, Appendix A. Environmental Impact Statement Stanislaus National Forest Land and Resource Management Plan. U.S. Department of Agriculture Pacific Southwest Region, Stanislaus National Forest, December.

<sup>5</sup> U.S. Forest Service. 1997. Clavey River Watershed Analysis. U.S. Department of Agriculture, Pacific Southwest Region. Stanislaus National Forest. July 28. 16 pp.



**Figure 3.0-1. Upper Tuolumne River Basin Water Temperature Monitoring and Modeling Study area.**



## 4.0 METHODOLOGY

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The Water Temperature Monitoring and Modeling Study methodology includes the following tasks:

- Identifying, synthesizing and interpreting existing data (temperature, flow, meteorological, etc.);
- Installing additional water temperature and stage data loggers as needed;
- Water temperature and stage data collection and review; and
- Water temperature modeling.

In 2015, existing geometric, flow and stage, water temperature and meteorological data was used to characterize the thermal regimes of the Tuolumne River below CCSF's Early Intake and upstream of Don Pedro Reservoir. Temperature data were identified for the mainstem Tuolumne River from Early Intake to above Don Pedro Reservoir, and the principal tributaries including Cherry Creek (including Eleanor Creek above the confluence with Cherry Creek) South Fork Tuolumne River, Clavey River, and North Fork Tuolumne River. Based on these data, a collaborative effort was undertaken by the Districts and LPs to identify locations where additional temperature monitoring stations could be established. Locations for deploying temperature data loggers were selected to provide a general characterization of mainstem and tributary reaches. For the sampling plan developed for monitoring water temperature, see Attachment A. For an overview of the quality assurance/quality control processing (QA/QC) process developed for temperature monitoring, see Attachment B.

In 2016, existing stream description (geometry), flow and stage, temperature, meteorological data will be used to develop a water temperature model to simulate the thermal regimes in the Tuolumne River below Early Intake and in portions of the principal tributaries (South Fork Tuolumne River, Clavey River, and North Fork Tuolumne River) that are identified as potentially accessible to reintroduced steelhead and Chinook salmon.

The RMA-2 and RMA-11 suite of models have been preliminarily selected because they are suitable for simulating conditions in the study area. Namely, the RMA models can model both flow and temperature in extremely steep reaches under dynamic flow regimes and report sub-daily water temperature. The phases of model development include model implementation (populating the model with field data and testing), model calibration (fitting the model to measured flow and temperatures) and sensitivity analysis, and model application. The model will ultimately be used to simulate thermal conditions under a range of potential flow regimes to assess a range of possible thermal responses.

## 4.1 Data Development

Data development includes aggregating all data necessary to implement a model.<sup>3</sup> For a river flow and temperature model, these data include geometry, hydrology, water temperature, and meteorology data. Geometry data are used to mathematically describe the river planform (e.g., Universal Transverse Mercator (UTM) coordinates or latitude/longitude descriptions of the river) and gradient. Local cross-section information describes the “shape” or morphology of the river. Hydrology data includes headwater inflows, tributary inflows, diversions and/or known outflows and stage data at the aforementioned locations. Water temperature data includes water temperature at inflow locations. In addition, there is a need for flow, stage, and water temperature data at locations within the model domain to calibrate the model. Meteorological data includes solar radiation, air temperature, wet bulb or dew point temperature, wind speed (and in certain instances, direction), cloud cover, and barometric pressure.

Datasets are developed through gathering, synthesis and review of existing data, and QA/QC of newly collected data. The following sections will introduce each data type and the associated data identified, compiled, and developed for the study through the end of 2014. Subsequently, provisional temperature data for 2015 is summarized. Analysis of water temperature data to characterize the thermal regime of the upper Tuolumne River Basin prior to study implementation is discussed separately in Section 5.

### 4.1.1 Geometry Data

#### 4.1.1.1 General Geometry Data Requirements for Modeling

The numerical models used in this study require a detailed description of the stream’s physical characteristics: planform, gradient, and cross-section data. Geometric data is assumed “static” for the purpose of this modeling effort (i.e., sediment transport and associated changes in bed morphology are not assessed) and includes:

- (x-y): a plan view of the river, usually in UTM coordinates or latitude/longitude, to identify the location and aspect of the river system and locations of important tributaries and outflow locations. These data may be derived from stream surveys, a digital elevation model (DEM) or other geographic information system (GIS) dataset, digitized aerial photos or topographic maps, or other sources.
- Gradient (z): longitudinal profile (bed slope); may be derived from a stream survey or DEM that provides elevations along the river to characterize a continuous description of stream gradient.
- Cross sections: cross sectional geometry describes the shape of the river channel and consist of distance and elevation measurements from one river bank to the other that are transverse to the principal axis of flow. Several sources can be used to compile the necessary data (e.g., LiDAR data, existing DEMs, aerial photos, habitat studies, stream flow site cross section). A

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<sup>3</sup> This section discusses the data development needed for a generic model. Specific modeling needs for the RMA-2 and RMA-11 models are discussed in Section 6.2.

sufficient number of cross sections representing the overall reach morphology are typically required to effectively simulate flow and temperature conditions in a stream reach.

- Other channel geometry information that may be important is:
  - Riparian and topographic shade: assumptions are made based on local characteristics of riparian vegetation and overall local topography (i.e., river flows through deep canyon vs. open meadow).
  - Stage-Flow relationships: water levels (stage) at various flow rates are useful to assess both a range of hydrologic conditions as well as dynamic flow conditions that may be present during the analysis period.
  - Bed substrate: descriptions of substrate composition are useful when estimating channel roughness characteristics.

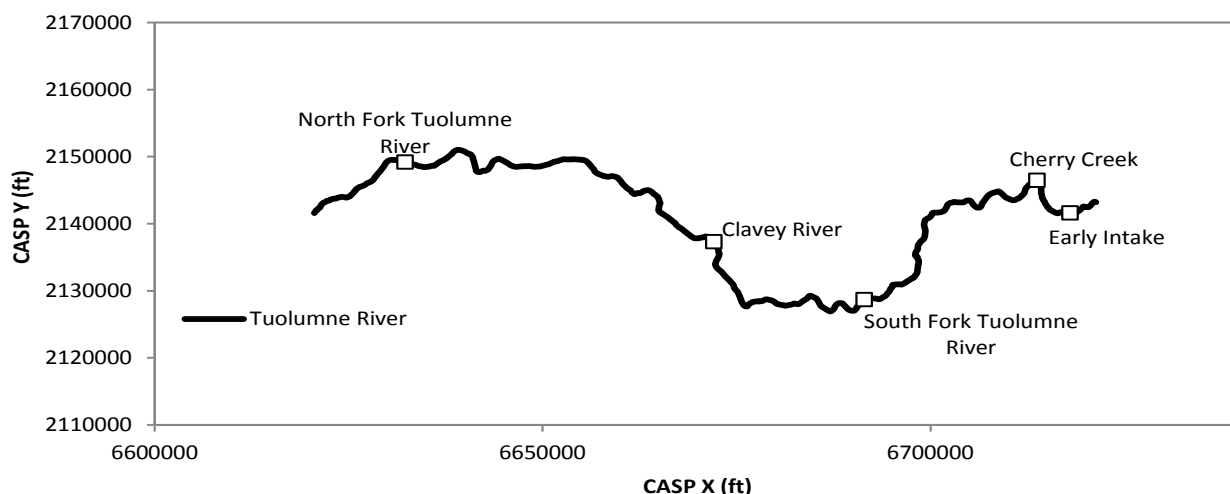
#### 4.1.1.2 Available Geometry Data

Planform, gradient, and cross section data are available for the mainstem Tuolumne River from previous modeling efforts (Jayasundara et al. 2010; TID/MID 2013c; Jayasundara et al 2014; McBain and Trush unpublished data). Tributary data will be developed from available sources. Specifics with regard to available planform, gradient, cross section, and topographic and riparian vegetation data are addressed below.

For this modeling study, the existing mainstem channel geometry grid developed for the RMA models in the mainstem Tuolumne River (Jayasundara et al. 2014) will be employed and refined as necessary. Tributary geometry representation will be supported by LiDAR data to be supplied by the NMFS as noted in Section 1.3.

### **Planform**

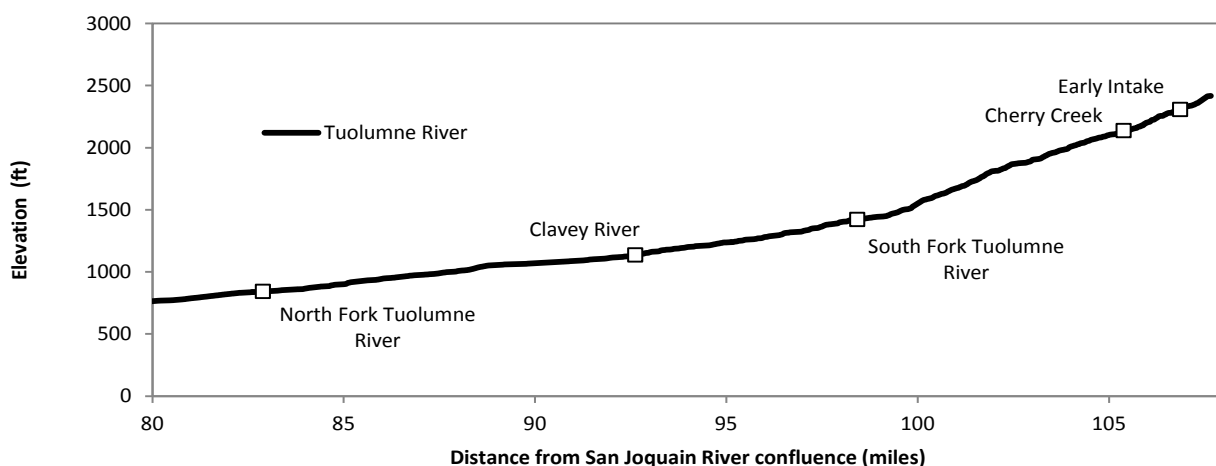
Planform river course data is available throughout the study reach. Planform information from existing modeling efforts will be used for the mainstem Tuolumne River. An example of planform data for the mainstem Tuolumne River in the study reach is shown in Figure 4.1-1. Tributary representations will be derived from available aerial photographs, DEMs, GIS datasets, and/or LiDAR (forthcoming NMFS data). To the extent these data provide additional information to the mainstem, appropriate refinements will be made to the Tuolumne River from Early Intake to above Don Pedro Reservoir.



**Figure 4.1-1. Planform representation of the Tuolumne River from above Early Intake to above Don Pedro Reservoir (near Wards Ferry Bridge), including the locations of major tributaries.**

### Gradient

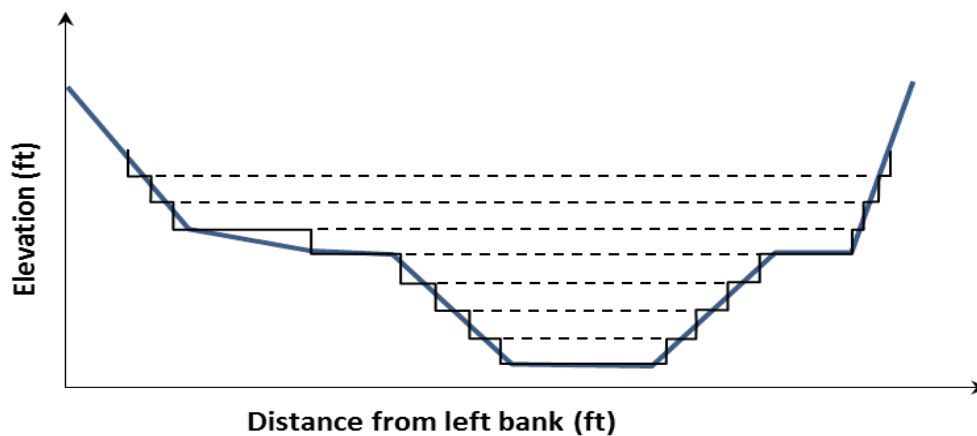
River profile data is available throughout the study reach and can be used to define the gradient throughout the proposed modeling reaches. An example of profile data for the mainstem Tuolumne River in the study reach is shown in Figure 4.1-2. Information from existing modeling efforts will be used for the mainstem Tuolumne River. Tributary representations will be derived from available DEMs, GIS datasets, and/or LiDAR (forthcoming NMFS data). To the extent these data provide additional information to the mainstem, appropriate refinements will be made to the Tuolumne River from Early Intake to above Don Pedro Reservoir.



**Figure 4.1-2. Longitudinal elevation profile (gradient) of Tuolumne River from above Early Intake to above Don Pedro Reservoir (near Wards Ferry Bridge), including the locations of major tributaries.**

## Cross Sections

Cross section information from existing modeling efforts will be used for the mainstem Tuolumne River. Tributary representations will be derived from available field surveys, flow measurements, aerial photographs, DEMs, and/or LiDAR (forthcoming NMFS data). To the extent these data provide additional information to the mainstem, appropriate refinements will be made to the Tuolumne River from Early Intake to above Don Pedro Reservoir. An example of cross section data represented in the model is shown in Figure 4.1-3. There may be a need to define cross sections for representative stream channel units in tributaries, such as runs, riffles, and pools. Where data are limited, these representative cross sections can then be applied throughout the tributaries to characterize channel morphology consistent with the defined channel units to form a comprehensive and continuous representation of stream geometry to use in the models.



**Figure 4.1-3.** Example of a cross-section representation in the RMA-2 and RMA-11 models (looking downstream).

## Shade Attributes

Riparian and topographic shading conditions in the study reaches are variable, but are not expected to impact water temperatures remarkably on a reach scale. Both riparian and topographic shade attributes in the study area are discussed herein.

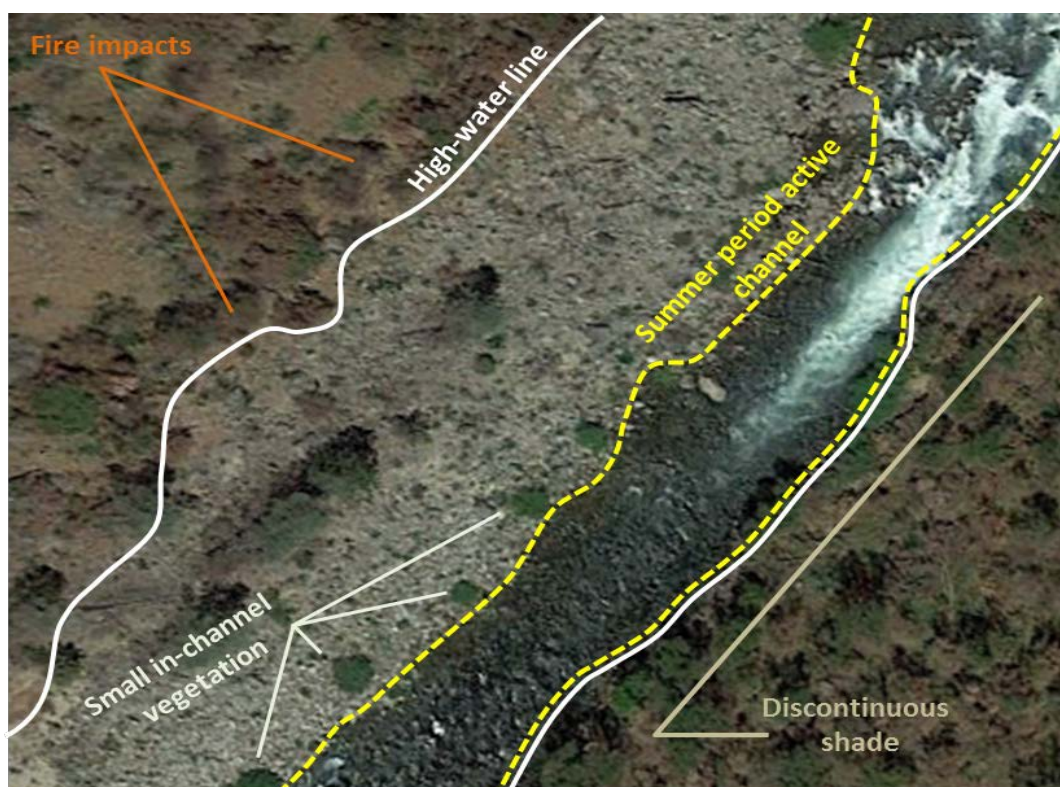
Overall, riparian vegetation shading is minimal for several reasons, including, but not limited to:

- The high gradient reaches in the constrained bedrock channel provide few opportunities for riparian vegetation to colonize above the high-water elevation.
- Vegetation that does colonize these areas is discontinuous or sporadic, and does not represent a continuous shade feature along the stream – a condition necessary for persistent reduction in water temperature during the warmer periods of the year.
- Fire is a frequent event in the area and has directly impacted stream vegetation throughout the study reaches through removal or damage. While such vegetation may regrow, the

discontinuous nature of streamside vegetation does not represent a condition that would be an effective water temperature management strategy.

- Within the channel there is colonization by shoreline vegetation; however, this vegetation is often infrequent, small (providing minimal shade), and typically removed by or markedly diminished during high water events.
- During summer, the active stream channel is narrower than the winter or spring high flow channel (conveying winter precipitation events or springtime snowmelt events). Thus, shoreline or channel margin vegetation is often a considerable distance from the stream margin during summer, notably diminishing the amount of shading that falls upon the active channel.
- Finally, the stream is relatively wide compared to the height of adjacent riparian vegetation, thus limiting the shade cast on the stream surface, particularly when solar altitude is high as occurs during late spring and summer.

Some of the features discussed above are shown in an aerial photo of the Tuolumne River (Figure 4.1-4). These attributes occur both on the mainstem and tributaries throughout the study reach.

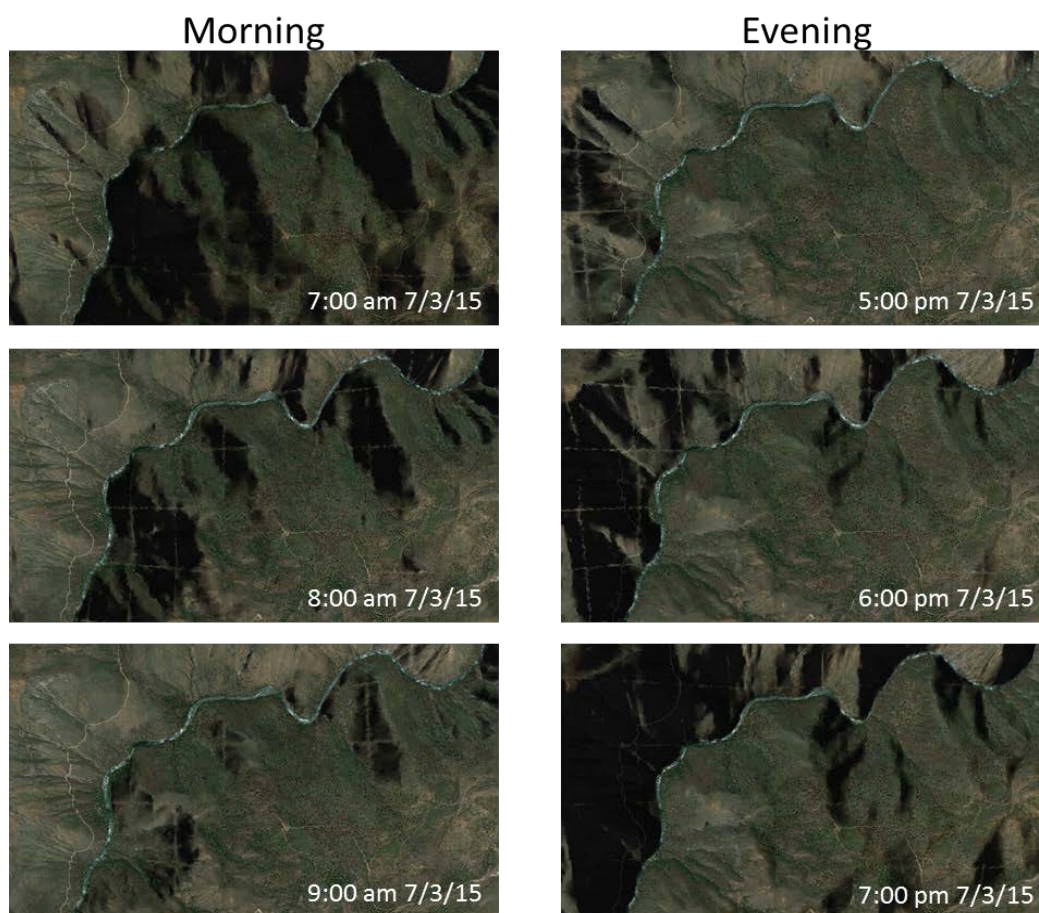


**Figure 4.1-4. Attributes limiting effects of riparian vegetation shading on water temperature conditions, Tuolumne River below Cherry Creek confluence.**

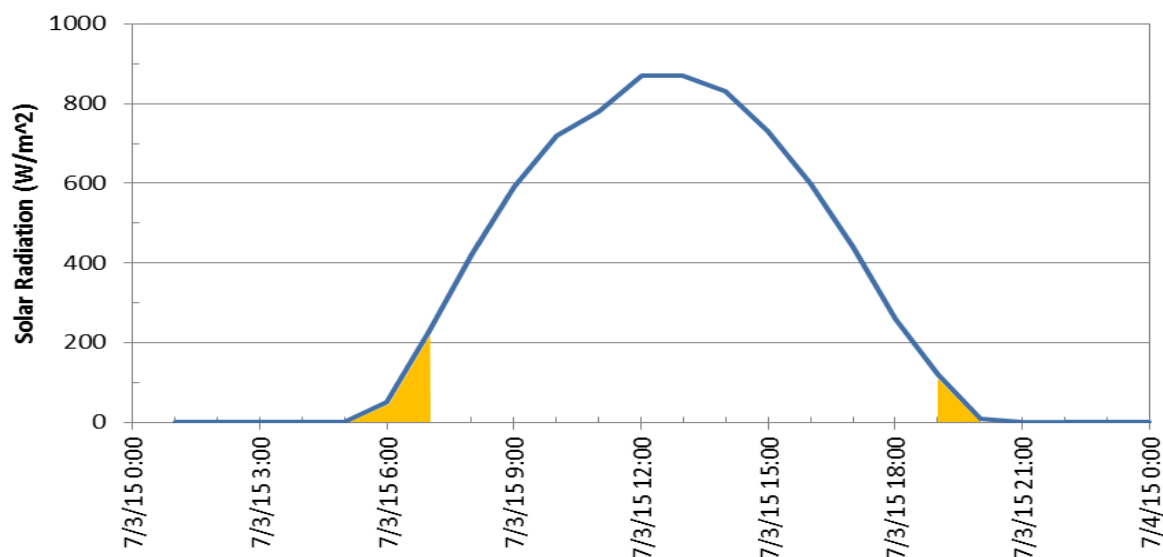
Topographic shading in the upper Tuolumne River reach and study area tributaries may have minimal or modest impacts on river temperature. During the long days of late spring and summer, when solar altitude is at or near a seasonal maximum, the mainstem experiences



considerable thermal loading. While this area is mountainous, much of the river experiences solar radiation loading for the majority of the day. Limited daytime shading of the river occurs prior to approximately 7:00 a.m. and after approximately 7:00 p.m. (Figure 4.1-5). Using the U.S. Forest Service Remote Automated Weather Station (RAWS), solar radiation data was downloaded for a representative day (July 3, 2015) from the Smith Peak station. These data are plotted in Figure 4.1-6, with typical periods of topographic shading identified (yellow regions), and illustrate that over 95 percent of the daily solar radiation reaches much of the river even in this mountainous area. While there are areas where more or less shading may occur, persistent or continuous shade is not present in these reaches. Topographic shade in certain reaches of certain tributaries may play a larger role. For example, the north-south portion of the Clavey River, starting approximately five miles upstream from the confluence with the Tuolumne River, may experience more shading than the mainstem. Also, in the smaller tributaries, local features, such as the adjacent stream banks and walls, may play a role. Tributaries with these attributes can be assessed on a reach-by-reach basis in the subsequent modeling phase.



**Figure 4.1-5.** Morning and evening on a representative reach of the Tuolumne River in the study area, July 3, 2015 (Source: Google Earth terrain-shade model).



**Figure 4.1-6.** Smith Peak solar radiation, July 3, 2015. (NWS ID#: 044115, <http://www.raws.dri.edu>). Orange ranges indicate approximate topographic-shaded periods of the day.

## Summary

A summary of the various geometry data types necessary to support flow and temperature modeling in the study area are shown in Table 4.1-1. These needs may be revisited during model development if additional information or refinements are identified in that future phase.

**Table 4.1-1.** Summary of information needs and general availability to support temperature modeling in the study area.

Stream Geometry Data Type	Mainstem Tuolumne River	Cherry Creek	South Fork Tuolumne River	Clavey River	North Fork Tuolumne River
Planform	Yes	Yes	Yes	Yes	Yes
Gradient	Yes	Yes	Yes	Yes	Yes
Cross Section	Yes	Yes	Yes	Yes	Yes
Shading	N/A	TBD	TBD	TBD	TBD

## 4.1.2 Flow Data

### 4.1.2.1 General Flow Data Requirements

Time-series flow data are required at all boundary condition locations (i.e., at the “edge” of the modeling domain) for modeling. Boundary conditions include inflows to the system (e.g., headwater and tributary contributions) and outflows from the system (e.g., diversions). A stage-flow relationship may be employed to represent a downstream boundary condition for flow modeling. Stage data, as it relates to flow, can also be useful to assess dynamic flow conditions, such as a hydropower peaking operations. In this case, stage data can be used to characterize travel time through river reaches and assist in model representation and calibration. Stage data coupled with velocity measurements can also be used to develop flow rates and if a sufficient range of flow rates are measured stage-discharge relationship can be developed from the data. In



addition to boundary condition data, flow information from within the model domain (i.e., not at the boundaries) is useful for model calibration.

The study area has five discrete reaches, the mainstem and the four principal tributaries. While the model can be simulated as a network, i.e., a single model formulation, for purposes of this discussion, the reaches will be discussed as discrete reaches because the final modeling domain has not been fully defined at this time. Boundaries for the flow and water temperature model are listed in Table 4.1-2. Associated depths, velocities, and widths at the boundary locations are needed for model implementation and calibration, as well as at intermediate locations.

Flow data may be from natural flow regimes (typically reported as daily average flow rates) or from hydropower and water management operations (typically reported as hourly average to capture fluctuations in flow). Accretions and depletions to the system are typically calculated using a mass balance.

**Table 4.1-2. Boundary conditions for upper Tuolumne River flow and temperature model.**

Location	RM	Boundary Type
Upstream extent of model (Tuolumne River at Early Intake)	106.0	Headwater Inflow
Cherry Creek	103.8	Tributary Inflow
South Fork Tuolumne River	97.0	Tributary Inflow
Clavey River	81.0	Tributary Inflow
North Fork Tuolumne River	81.4	Tributary Inflow
Other tributaries	N/A	Tributary Inflow
Downstream extent of model (Tuolumne River at Don Pedro Reservoir)	77.0 <sup>†</sup>	Outflow

<sup>†</sup> Approximate river mile. The model will terminate at Wards Ferry, but under full pool this location may move upstream slightly.

#### 4.1.2.2 Available Flow Data

Daily or sub-daily flow data is available from eight U.S. Geological Survey (USGS) gages on the mainstem Tuolumne River and on Cherry and Eleanor creeks (Table 4.1-3). Most of the listed gages include records from before 2005 through present. The other tributaries (South Fork Tuolumne, Clavey, and North Fork Tuolumne rivers) do not have active flow gaging stations or long-term historical records. A detailed inventory of flow data is included in Attachment C. USGS gage data from the most recent six to nine months are typically termed provisional and are subject to change during the USGS quality assurance process. Data that have passed the USGS quality assurance process may still have gaps that need to be filled for modeling. Sub-daily data are available from USGS (typically fifteen-minute data) upon request for the stations listed; however, older sub-daily data series may not be complete.

**Table 4.1-3. Active USGS gages collecting flow and stage data in study area.**

Gage Number	Name	RM	Data Type <sup>1</sup>
<b>Tuolumne River</b>			
11276500	Tuolumne River near Hetch Hetchy CA <sup>2</sup>	TR 116.4	N/A
11276600	Tuolumne River above Early Intake near Mather CA	TR 106	BC
11276900	Tuolumne River below Early Intake, Mather CA	TR 104.4	CAL
11285500	Tuolumne River at Wards Ferry Bridge near Groveland CA	TR 78.5	CAL
<b>Cherry Creek</b>			
11277300	Cherry Creek below Valley Dam near Hetch Hetchy CA	CC 10.9	BC
11278300	Cherry Creek near Early Intake CA	CC 1.2	BC/CAL
11278400	Cherry Creek below Dion R Holm Powerhouse near Mather CA	CC 0.2	BC/CAL
11278000	Eleanor Creek near Hetch Hetchy CA	EC 3.1	BC
<b>South Fork Tuolumne River</b>			
	No active stations/long-term records	N/A	N/A
<b>Clavey River</b>			
	No active stations/long-term records	N/A	N/A
<b>North Fork Tuolumne River</b>			
	No active stations/long-term records	N/A	N/A

<sup>1</sup> BC – boundary condition data, CAL – calibration data. Certain locations could also serve as a BC for the mainstem Tuolumne River model or a CAL location for the tributary.

<sup>2</sup> The Tuolumne River near Hetch Hetchy is above the proposed study reach, but is included due to its proximity.

The lack of data in the principal tributaries downstream of Cherry Creek led to additional monitoring in the South Fork Tuolumne River, Clavey River, and North Fork Tuolumne River. Stage data were collected at 15-minute intervals throughout the study area (Table 4.1-4). Velocity and discharge measurements were collected during field visits and these observations will be used to formulate stage-discharge curves and create extended flow records for the major tributaries where flow data are unavailable. Stage data were collected in the mainstem Tuolumne River, but velocity measurements were not collected due to the size of the river. Rather, these stage data will be useful for calibrating the hydrodynamic model by capturing stage change associated with hydropower peaking operations.

While additional characterization of tributary contributions occurred in 2015, there was still a paucity of flow data for previous years (see Table 4.1-3). Flows recorded at Wards Ferry reflect tributary inflows and any other accretions and depletions to the Tuolumne River downstream of Early Intake. However, historic flows in the study area for major tributaries and accretions were developed based on the HDR proration analysis (TID/MID 2013a). The proration analysis not only identified daily flows for the major tributaries, but also miscellaneous or ungaged accretions on a reach-by-reach basis. An example of the daily flows for Cherry Creek, Clavey River, and North Fork Tuolumne River is shown in Figure 4.1-7. Ultimately, flow conditions throughout the study reach will utilize a range of measured and calculated flows. The mainstem Tuolumne River and the lowest portion of Cherry Creek (below Dion R Holm Powerhouse [Holm Powerhouse]) will utilize sub-daily flow information from USGS and CCSF records to capture hydropower peaking conditions. Tributary flows will utilize available flow data, which may be limited temporally, and the aforementioned proration analysis to represent daily flows.

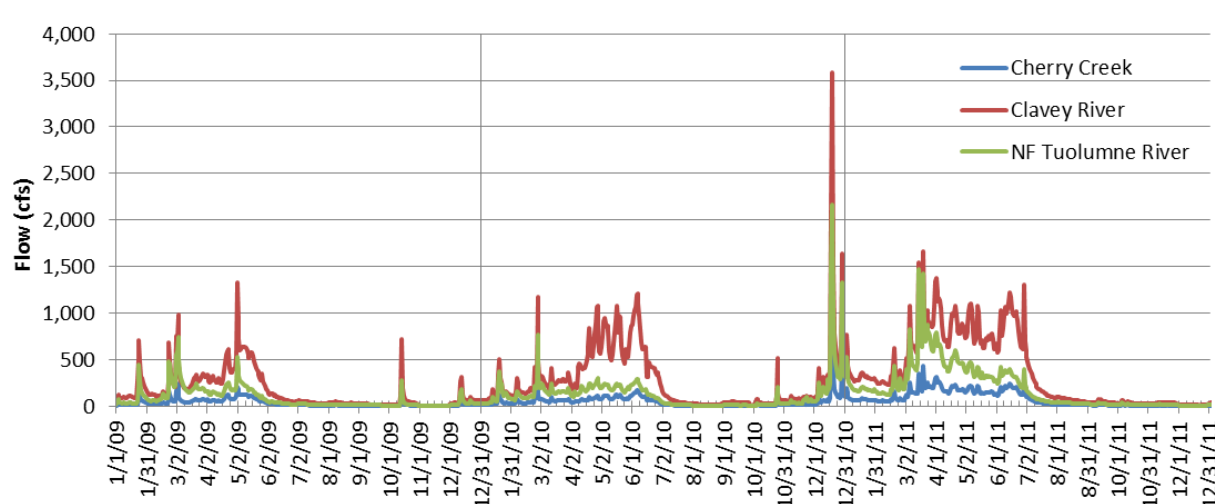
**Table 4.1-4. Additional stage monitoring locations in 2015.**

Logger Location <sup>1</sup>	RM	Data Type <sup>2</sup>
<b>Tuolumne River<sup>3</sup></b>		
Tuolumne River upstream of South Fork Tuolumne River (stage only)	TR 97.0	CAL
Tuolumne River upstream of Clavey River (stage only)	TR 88.2	CAL
Tuolumne River upstream of North Fork Tuolumne River (stage only)	TR 81.3	CAL
<b>Cherry Creek</b>		
None installed in 2015.		
<b>South Fork Tuolumne River</b>		
South Fork Tuolumne River upstream of Tuolumne River	SF 0.1	BC
<b>Clavey River</b>		
Clavey River at USFS Bridge (1N04 Bridge)	CR16.9	BC
Clavey River at USFS Bridge (1N01 Bridge)	CR 8.4	BC
Clavey River upstream of Tuolumne River	CR 0.1	BC/CAL
<b>North Fork Tuolumne River</b>		
North Fork Tuolumne River at USFS Bridge (1N01 Bridge)	NF 8.4	BC
North Fork Tuolumne River upstream of Tuolumne River	NF 0.1	BC/CAL

<sup>1</sup> USFS = U.S. Forest Service.

<sup>2</sup> CAL = calibration data; BC = Boundary condition data. Certain locations could also serve as a BC for the mainstem Tuolumne River model or a CAL location for the tributary.

<sup>3</sup> Only stage data was collected in the mainstem Tuolumne River; no velocity measurements were collected.



**Figure 4.1-7. Calculated daily flow for Cherry Creek, Clavey River, and North Fork Tuolumne River based on HDR proration analysis (TID/MID 2013a), 2009-2011.**

#### 4.1.2.3 Operations

Finally, operations are an important element of mainstem Tuolumne River and Cherry Creek hydrology. Outlined below are the basic operations, by sub-reach, that will be useful when assessing flow and temperature for potential anadromous fish reintroduction.

#### O'Shaughnessy Dam to Above Cherry Creek

Flows above Hetch Hetchy Reservoir are measured on the mainstem Tuolumne River (USGS Gage 11274790), and the CCSF record storage at Hetch Hetchy Reservoir. Releases from the

reservoir at O'Shaughnessy Dam include power generation via the Canyon Power Tunnel to Kirkwood Powerhouse; controlled releases to the Tuolumne River to meet instream flow requirements; and spill releases during periods of high inflow to Hetch Hetchy Reservoir.

The schedule of minimum base flow releases from O'Shaughnessy Dam is listed in Table 4.1-5 for three year types. In addition to the minimum base flow schedule, an additional 64 cfs must be released to the Tuolumne River from O'Shaughnessy Dam when flow through Canyon Power Tunnel exceeds 920 cfs. While Early Intake is typically operated as a run-of-river facility, discharges from Kirkwood Tunnel to the Tuolumne River at Early Intake occur when flows through Kirkwood Powerhouse exceed the capacity of the Mountain Tunnel diversion to Moccasin Powerhouse (670 cfs) (San Francisco Public Utilities Commission [SFPUC] 2007).

**Table 4.1-5. Minimum baseflow releases from O'Shaughnessy Dam.**

Month	Year Type A (wettest 60% of years)		Year Type B (32% of years)		Year Type C (driest 8% of years)
	Minimum Release <sup>1</sup> (cfs)	Criteria <sup>2,3</sup>	Minimum Release <sup>1</sup> (cfs)	Criteria <sup>2,3</sup>	Minimum Release <sup>1</sup> (cfs)
January	50	8.80 inches	40	6.10 inches	35
February	60	14.00 inches	50	9.50 inches	35
March	60	18.60 inches	50	14.20 inches	35
April	75	23.00 inches	65	18.00 inches	35
May	100	26.60 inches	80	19.50 inches	50
June	125	28.45 inches	110	21.25 inches	75
July	125	575,000 ac-ft	110	390,000 ac-ft	75
August	125	640,000 ac-ft	110	400,000 ac-ft	75
September 1-15	100	-	80	-	75
September 16-30	80	-	65	-	50
October	60	-	50	-	35
November	60	-	50	-	35
December	50	-	40	-	35

<sup>1</sup> Minimum average daily flow as measured at USGS Gage 11276500 (Tuolumne River near Hetch Hetchy).

<sup>2</sup> Precipitation criteria in inches are cumulative, measured at Hetch Hetchy Reservoir, starting October 1. For example, if October 1 through December 31 precipitation is greater than or equal to 8.80 inches, refer to year type A schedule for January.

<sup>3</sup> Inflow criteria in acre-feet (ac-ft) are the cumulative calculated inflow into Hetch Hetchy Reservoir commencing on the previous October 1 of each year.

## Cherry Creek and Eleanor Creek

Water stored in Cherry Lake and Lake Eleanor is utilized for power generation, meeting downstream water rights obligations, and summertime recreational releases (SPFUC 2014) (Table 4.1-6). The Eleanor to Cherry Diversion, which conveys water from Lake Eleanor to Cherry Lake, is used when Cherry Lake has the capacity to accept additional storage from the much smaller Lake Eleanor. Unlike Eleanor Dam, Cherry Valley Dam rarely spills (flows over the spillway). High flows are typically released from the dam outlet works in a controlled manner (SPFUC 2007).

**Table 4.1-6. Cherry Lake and Lake Eleanor information.**

	<b>Cherry Lake</b>	<b>Lake Eleanor</b>
Dam	Cherry Valley Dam	Eleanor Dam
Reservoir Maximum Capacity (acre-ft)	274,300	27,100
Reservoir Maximum Water Surface Elevation (ft)	4703	4661
Drainage Area Upstream of Reservoir (square miles)	117	78.1
USGS Gages	USGS Gage 11277200 Cherry Lake near Hetch Hetchy, CA	USGS Gage 11277500 Lake Eleanor near Hetch Hetchy, CA
	USGS Gage 11277100 Lake Eleanor Diversion Tunnel to Cherry Lake near Hetch Hetchy, CA	
Location of Dam (approximate RMs from mouth of creek)	11.5	3.5
Baseflow Compliance Point Downstream of Dam	USGS Gage 11277300 Cherry Creek downstream of Valley Dam near Hetch Hetchy, CA	USGS Gage 11278000 Eleanor Creek near Hetch Hetchy, CA

Flows are recorded at three gaged sites on Cherry Creek and at one gaged site on Eleanor Creek, a tributary to Cherry Creek. Baseflows in Cherry Creek and Eleanor Creek are controlled by instream flow requirements from Cherry Valley Dam and Eleanor Dam, respectively (Table 4.1-7 and Table 4.1-8). USGS Gage 11277300 measures flow released from Cherry Lake via Cherry Valley Dam and acts as the downstream compliance point for required Cherry Creek baseflows. USGS Gage 11278000 records flow that is released from Lake Eleanor via Eleanor Dam and acts as the downstream compliance point for required Eleanor Creek baseflows. Additional dam releases occur when there are high inflows to the reservoirs.

Flows on Cherry Creek above Holm Powerhouse are recorded at USGS Gage 11278300 and reflect releases from Cherry Valley Dam and Eleanor Dam, as well as natural accretions to Cherry Creek and Eleanor Creek below both dams. Flow to Holm Powerhouse is diverted from Cherry Lake and is conveyed via the Cherry Power Tunnel to the powerhouse located at approximately RM 0.8 on Cherry Creek. Flow in Cherry Creek below Holm Powerhouse is measured by USGS Gage 11278400. The difference between flows recorded at gage #11278400 (below Holm Powerhouse) and flows recorded at USGS Gage 11278300 (above Holm Powerhouse) is the flow through the powerhouse.

During periods of high runoff, Holm Powerhouse is operated approximately at capacity in order to minimize spill at Eleanor and Cherry Valley Dams. During emergency or drought conditions, water from Cherry Lake and Lake Eleanor can be released to Cherry Creek, then diverted at the Lower Cherry Diversion Dam (approximately RM 3.0) to Early Intake and Mountain Tunnel for transport to the Bay Area. This operation has only been utilized once, during the early 1990s (SFPUC 2014).

**Table 4.1-7. Minimum releases from Cherry Valley Dam for baseflows in Cherry Creek.**

Month	Minimum Flow (cfs)
January	5
February	5
March	5
April	5
May	5
June	5
July	15.5
August	15.5
September	15.5
October	5
November	5
December	5

**Table 4.1-8. Minimum releases from Eleanor Dam for baseflows in Eleanor Creek.**

Month	Minimum Flow (cfs) <sup>1</sup>	
	Pumping	Not Pumping
January	5	5
February	5	5
March	10	5
April 1 – April 14	10	5
April 15 – April 30	20	5
May	20	5
June	20	5
July	20	15.5
August	20	15.5
September 1 – September 15	20	15.5
September 16 – September 30	10	15.5
October	- <sup>2</sup>	5
November	5	5
December	5	5

<sup>1</sup> "Pumping" is defined as when water is pumped from Cherry Lake to Lake Eleanor through the Cherry-Eleanor Tunnel.

<sup>2</sup> The 1982 Stipulation does not specify minimum flow releases for October in years when pumping occurs. The SFPUC operational practice in pumping years has been to continue the September 16 - 30 release (10 cfs) through October 31.

### 4.1.3 Water Temperature

#### 4.1.3.1 General Water Temperature Data Requirements

Time-series water temperature data are required at all boundary condition locations (i.e., at the "edge" of the modeling domain) for modeling. Boundary conditions include inflows to the system (e.g., headwater and tributary contributions). In addition to boundary condition data, water temperature information from within the model domain (i.e., not at the boundaries) is useful for model calibration. Collected data is assumed to represent thalweg temperatures.

The study area has five discrete reaches, the mainstem and the four principal tributaries. While the model can be simulated as a network, i.e., a single model formulation, for purposes of this discussion, the reaches will be discussed as discrete reaches because the final modeling domain has not been fully defined at this time.

## 4.1.3.2 Historically Available Water Temperature Data

Historical water temperature data from the mainstem Tuolumne River and on the principal tributaries were assembled from 2005 through 2014. This ten-year period was identified as having sufficient locations to potentially be useful in a thermal assessment of stream reaches in the study area. These data are summarized in Table 4.1-9. A more comprehensive tabulation of site names, locations, agency, active status, RM, and periods of available data are provided in Attachment C. Maps of the study area showing locations of historical data collection sites are included in Attachment D. These data, by and large are assumed to have undergone some level of QA/QC; however, the metadata associated with these programs was not readily available (e.g., field notes, logger manufacturer and specifications, QA protocols, etc.). For the purposes of this study the water temperature data were assumed reasonable unless there were obvious erroneous data (e.g., air temperature data). An analysis of the available water temperature data, based on historic through 2014, as well as additional data collected in 2015 is presented in Section 5 to provide a general characterization of existing thermal conditions in the upper Tuolumne River and its tributaries.

**Table 4.1-9. Historical water temperature data in the study area (pre-2014).**

Station #/Label	Agency	Active	Site Location/Name
<b>Tuolumne River</b>			
TR105.0	CDFG <sup>1</sup>	NO	Tuolumne River at Early Intake
TR104.6	CCSF	NO	Tuolumne River, downstream of Early Intake
11276900	USGS	YES	Tuolumne River below Early Intake near Mather CA
TR103.7	CCSF	NO	Tuolumne River, downstream of Cherry Creek confluence (TR3)
TR103.5	CCSF	NO	Tuolumne River, downstream of Cherry Creek confluence (TR4)
TR097.1	CCSF	NO	Tuolumne River, upstream of South Fork
TR096.5	CDFG	NO	Tuolumne River below the South Fork
TR091.1	UC Davis	NO	Tuolumne River, upstream of Clavey Creek confluence
TR81.3	TID/MID	YES	Tuolumne River, upstream of NF Tuolumne confluence
TR079.4	CCSF	NO	Tuolumne River, upstream of Ward's Ferry
TR078.7	CDFG	NO	Tuolumne River upstream of Wards Ferry Bridge
11285500	USGS	YES	Tuolumne River at Wards Ferry Br near Groveland CA
<b>Cherry Creek</b>			
CC16.1	CCSF	NO	Cherry Creek, upstream of Cherry Lake
11277300	USGS	YES	Cherry Creek below Valley Dam near Hetch Hetchy, CA
CC10.5	CCSF	NO	Cherry Creek, downstream of Cherry Dam
CC09.4	CCSF	YES	Cherry Creek, downstream of Cherry Dam
CC07.1	CCSF	YES	Cherry Creek, upstream of Eleanor Creek confluence
CC07.0	CCSF	YES	Cherry Creek, downstream of confluence with Eleanor Creek
11278300	USGS	YES	Cherry Creek near Early Intake, CA
CC01.2	CCSF	NO	Cherry Creek, upstream of Dion Holm Powerhouse
CC00.6	CDFG	NO	Cherry Creek Power House
11278400	USGS	YES	Cherry Creek, downstream of Holm Powerhouse, near Mather, CA
<b>Eleanor Creek</b>			
11278000	USGS	YES	Eleanor Creek near Hetch Hetchy, CA
EC01.8	CCSF	NO	Eleanor Creek, upstream of Miguel Creek confluence
EC01.7 <sup>2</sup>	CCSF	NO	Eleanor Creek, downstream of Miguel Creek confluence
EC00.0	TID/MID	YES	Eleanor Creek, upstream of Cherry Creek confluence
EC00.0	CCSF	NO	Eleanor Creek, upstream of Cherry Creek confluence
MC00.0	CCSF	NO	Miguel Creek (Eleanor Creek), upstream of Eleanor Creek confluence

Station #/Label	Agency	Active	Site Location/Name
<b>South Fork Tuolumne</b>			
SFT00.2	CCSF	YES	South Fork Tuolumne River near 1N10 Bridge
SFT00.2	CDFG	NO	South Fork of the Tuolumne River near confluence
<b>Clavey River</b>			
CR16.9	CCSF	NO	Clavey River at 1N04 Bridge
CR00.3	UC Davis	NO	Clavey River, upstream of Tuolumne River confluence
<b>North Fork Tuolumne</b>			
NFT00.1	UC Davis	NO	North Fork Tuolumne River near confluence

<sup>1</sup> California Department of Fish and Game.

<sup>2</sup> CCSF had three loggers in this area.

#### 4.1.3.3 2015 Water Temperature

The analysis of available data identified locations of key data gaps, both spatially and temporally. Subsequently, the Districts deployed data loggers to obtain additional water temperature information (Table 4.1-10). The locations of additional monitoring focused on the Clavey River and North Fork Tuolumne River, where little historical data were available. Loggers were also placed in lower Cherry Creek, the South Fork Tuolumne River above the confluence with the mainstem, and in the mainstem Tuolumne River. Additional data will continue to be downloaded and analyzed in 2016. Data presented herein are considered provisional pending completion of Quality Assurance/ Quality Control (QA/QC) analysis (Attachment B).

**Table 4.1-10. Additional water temperature monitoring locations in 2015.**

Logger Location	RM	Water Temp.	Stream Stage <sup>1</sup>	Date Deployed	Summer Download	Fall Download	Status
<b>Tuolumne River</b>							
TR above North Fork	TR 81.3	X	X	4/29/2015	n/a	n/a	In Field
TR above Clavey River	TR 91.1	X	X	6/17/2015	n/a	n/a	In Field
TR above South Fork	TR 97.0	X	X	4/30/2015	n/a	10/28/2015	In Field
TR below Early Intake	TR 105.2	X	-	4/30/2015	8/11/2015	10/28/2015	In Field
<b>North Fork Tuolumne River</b>							
North Fork above TR	NF 0.1	X	X	4/29/2015	n/a	11/2/2015	In Field
North Fork at RM8 Bridge	NF 8.0	X	X	4/28/2015	n/a	10/27/2015	In Field
<b>Clavey River</b>							
Clavey River above TR	CR 0.1	X	X	4/29/2015	6/17/2015 8/2/2015	10/27/2015	In Field
Clavey River at USFS Bridge (1N01)	CR 8.4	X	X	4/28/2015	6/18/2015 8/11/2015	10/27/2015	In Field
Clavey River at USFS Bridge (1N04)	CR 16.9	X	X	6/16/2015	8/11/2015	10/27/2015	In Field
<b>South Fork Tuolumne River</b>							
South Fork above TR	SF 0.1	X	X	4/30/2015	8/12/2015	10/28/2015	In Field
<b>Cherry Creek</b>							
Cherry Creek above TR (bel PH)	CC 0.6	X	-	4/30/2015	6/17/2015	n/a	In Field



Logger Location	RM	Water Temp.	Stream Stage <sup>1</sup>	Date Deployed	Summer Download	Fall Download	Status
Cherry Creek above HPH	CC 2.0	X	-	4/29/2015	6/17/2015 8/12/2015	10/27/2015	In Field

<sup>1</sup> "X" = Data collection is underway; "-" = Data is not being collected at this location.

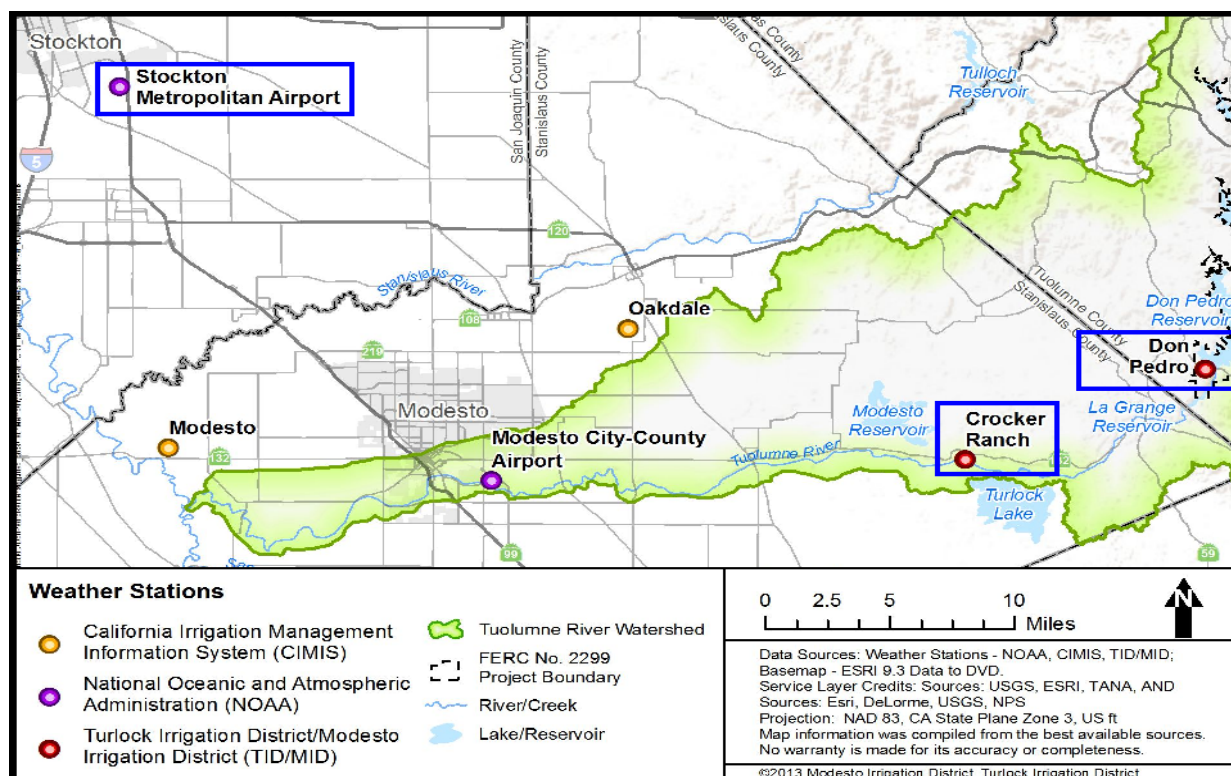
#### 4.1.4 Meteorology Data

##### 4.1.4.1 General Meteorological Data Requirements

To effectively model sub-daily water temperatures, hourly meteorological data are necessary. Meteorological data required for temperature modeling includes air temperature, dew point or wet bulb temperature, wind speed and direction, precipitation, solar radiation, cloud cover, and barometric pressure.

##### 4.1.4.2 Available Meteorological Data

Hourly meteorological data for the study area, from 1971 through 2013, have been developed by TID/MID (2013b). The meteorology dataset was developed using data from nine weather stations (Figure 4.1-8). The weather stations and types of data collected at each station are listed in Table 4.1-11. This array of stations and data were necessary to address data gaps at various stations to form the continuous time series of hourly meteorological data. The same approach was used recently by HDR to extend the meteorological dataset up to 2015. As with previous modeling work, air temperature data will be adjusted using a lapse rate to account for the elevation difference between Stockton (current location of air temperature data) and the study area. This adjusted air temperature will then be used to calculate the associated wet bulb temperatures for the study area. The application of lapse rate and wet bulb calculations are discussed below.



**Figure 4.1-8. Locations of meteorological data stations used to construct a meteorology dataset for this study (TID/MID 2013b).**

**Table 4.1-11. Weather stations, operating agencies, data types, and data availability (TID/MID 2013b).**

Weather Station	Operating Agency <sup>1</sup>	Period of Record	Data Type(s)
Don Pedro	TID/MID	11/30/2010 to 12/31/2012	air temperature; relative humidity; wind speed; barometric pressure; solar radiation
Crocker Ranch	TID/MID	11/30/2010 to 12/31/2012	air temperature; relative humidity; wind speed; barometric pressure; solar radiation
Stockton Metropolitan Airport	NOAA, NREL	10/1/1970 to 12/31/2012	air temperature; relative humidity; wind speed; barometric pressure
Modesto City-County Airport	NOAA, NREL	1/1/1973 to 12/31/2012	air temperature; relative humidity; wind speed; barometric pressure; modeled solar radiation
Castle Air Force Base	NOAA, NREL	1/1/1973 to 12/31/2012	air temperature; relative humidity; wind speed; barometric pressure
Modesto	CIMIS	1/1/2010 to 12/31/2012	air temperature; relative humidity; wind speed; barometric pressure; solar radiation
Denair II	CIMIS	1/1/2010 to 12/31/2012	solar radiation
Oakdale	CIMIS	1/1/2010 to 12/31/2012	solar radiation
Sacramento Executive Airport	NOAA, NREL	10/1/1970 to 12/31/1991	modeled solar radiation

<sup>1</sup> NOAA = National Oceanic and Atmospheric Administration; NREL = National Renewable Energy Laboratory (a laboratory of the United States Department of Energy); CIMIS = California Irrigation Management System.

## Lapse Rate

Lapse rate describes air temperature changes with respect to elevation. Air temperature generally decreases with increasing elevation (Linacre 1992). Air temperature in the upper reaches of the study area will be estimated based on adjustments for the altitude change (lapse rate) between Stockton station (elevation of approximately 30 feet) and the study area (elevations range from approximately 800 feet at Wards Ferry Bridge to approximately 4,550 feet just below Eleanor Dam). Sub-reaches will be delineated based on results of the fish barrier assessment. A lapse rate of 6°C per 3,128 feet of elevation change will be applied (Linacre 1992).

## Wet Bulb Temperature

Wet bulb temperature ( $T_{wb}$ ) is the temperature of the air if cooled to saturation (or 100 percent relative humidity) (Martin and McCutcheon 1999). With the assumed elevation and barometric pressure ( $P$ ), air temperature ( $T_a$ ), and relative humidity, the wet bulb temperature can be calculated through the iterative process presented in Equation 4-1. Wet bulb temperatures are calculated to accommodate changes in air temperature (based on the aforementioned lapse rates) and barometric pressure with elevation.

$$e(T_{wb}, T_a, P) = \left( 6.108 \exp \left( \begin{cases} \frac{17.27 T_{wb}}{T_{wb} + 237.3} & T_{wb} \geq 0 \\ \frac{21.875 T_{wb}}{T_{wb} + 265.5} & T_{wb} < 0 \end{cases} \right) \right) - 0.00066(1 + 0.00115 T_{wb})(T_a - T_{wb})P \quad \text{Equation 4-1.}$$

## **5.0 RESULTS**

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This section provides a summary of the collaborative process with LPs and an initial assessment of thermal conditions in the study area based on review and analysis of the historical data only (through 2014). Analysis of the 2015 year dataset is pending completion of data QA/QC and data assessment. This initial assessment will be updated with findings from the 2015 data and presented in Updated Study Report (USR).

### **5.1 Collaboration with Licensing Participants**

As defined in the FERC-approved RSP, the Districts held a Flow and Temperature Monitoring and Modeling Workshop with LPs on May 19, 2015. The objectives of Workshop were to: (1) present an overview of the Water Temperature Monitoring and Modeling Study; (2) review and confirm with LPs proposed temperature and flow monitoring locations; and (3) review and confirm with LPs the modeling approach. After a brief review of the Water Temperature Monitoring and Modeling Study's goal, objectives, scope, and study area, the Districts summarized their findings of the existing data analysis. Data parameters evaluated included flow, water temperature, and meteorology, and data review consisted of location of sources, frequency, and period assessments. Findings included general characterizations of hydrology and thermal conditions, potential modeling periods, identification of data gaps, and recommendations for additional monitoring to support modeling objectives. Multiple mainstem and tributary locations within the study area were recommended for additional monitoring of water temperature and/or stage. The Districts concluded the Workshop by summarizing the proposed water temperature modeling approach. Topics discussed included model selection considerations, data development, and model calibration and application. For the study, the Districts' consultant proposed the use a suite of RMA models for hydrodynamics, water temperature and stream geometry. LPs present at the Workshop supported the additional monitoring locations and the modeling approach as proposed by the Districts. Additional information from the Workshop is available in Attachment E.

### **5.2 Flow and Water Temperature Conditions in the Upper Tuolumne River Study Area**

Historic flow and water temperature data were available for the upper Tuolumne River and tributary locations through the end of 2014 when this study commenced (Tables 4.1-3 and 4.1-8). This historical data was used to characterize the general thermal regime of the upper Tuolumne River and its principal tributaries from Early Intake to the upstream end of the Don Pedro Project Boundary (approximately Wards Ferry), including Cherry Creek, South Fork Tuolumne River, Clavey River, and North Fork Tuolumne River. However, flow and water temperature data were limited for the South Fork Tuolumne, Clavey, and North Fork Tuolumne rivers and the Districts implemented a monitoring program to address data gaps in 2015 (Tables 4.1-4 and 4.1-9).

To effectively assess thermal conditions in the upper Tuolumne River watershed, a basic understanding of flow conditions is useful. Flow can impact temperature by changing the stream surface area and volume, thus affecting the rate of heat transfer with the atmosphere. Further, flow changes can convey thermal energy downstream, impacting temperature signals for

considerable distances. Tributary inflows can contribute warmer or cooler water to mainstem flows and, as noted above, releases from reservoirs can introduce cold water to reaches downstream of dams or powerhouses. As such, flow conditions in the study area will be discussed initially, followed by a discussion of thermal conditions.

### 5.2.1 Flow

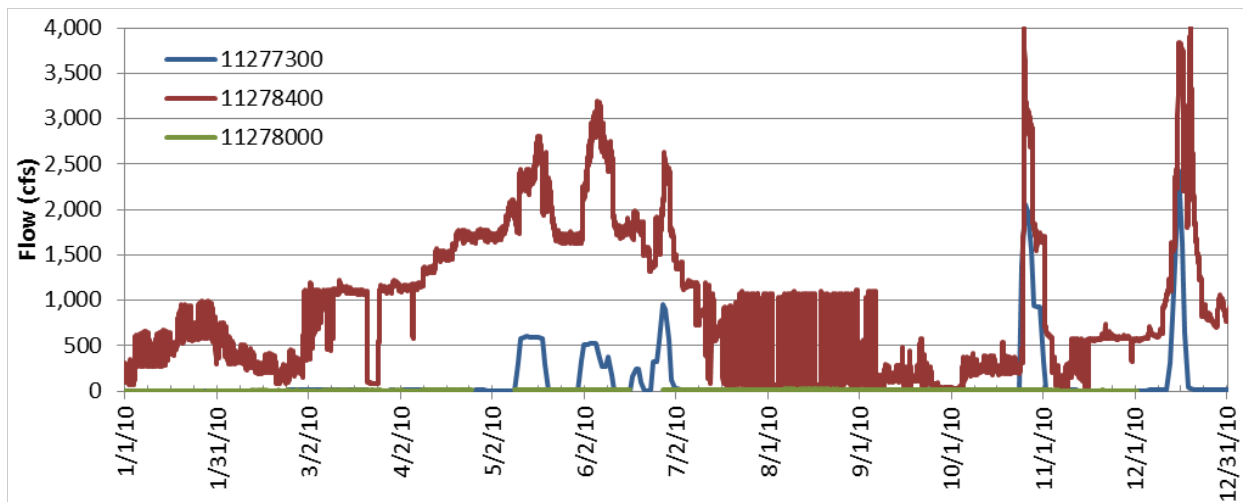
The Tuolumne River is the largest tributary watershed to the San Joaquin River system, with an area in excess of 1,900 square miles (<http://streamstatsags.cr.usgs.gov>). The elevation with the Tuolumne River watershed ranges from over 13,000 feet at Mt. Lyell in Yosemite National Park to approximately 30 feet at the confluence with the San Joaquin River (Mount 1995; Epke et al. 2010). Mean annual runoff increases in the downstream direction, ranging from 280 thousand acre-feet (TAF) below O'Shaughnessy Dam near Hetch Hetchy, to 757 TAF below La Grange Dam, to 938 TAF at Modesto (Table 5.2-1). Average annual watershed precipitation is 38 inches (source: <http://waterdata.usgs.gov>). The Tuolumne River and its principal tributaries all exhibit a seasonal rainfall and snowmelt hydrograph typical of a Mediterranean climate, where summers are typically warm and dry, and winters cool and wet. Winter rainfall that takes place below the snowline is prone to runoff, increasing stream flows. Winter precipitation that falls as snow typically runs off in the spring and early summer, in response to seasonal meteorological conditions. Flows subsequently diminish through the drier summer and fall months. The flow regime in certain stream reaches of the study area are regulated by reservoirs.

**Table 5.2-1. Tuolumne River mean annual flow at Modesto, La Grange, and Hetch Hetchy for the period 1971-2011 (source: <http://waterdata.usgs.gov>).**

Name	USGS Gage	Mean annual flow (cfs)	Mean annual flow (TAF)
Tuolumne River Near Hetch Hetchy, CA	11276500	387	280
Tuolumne River below La Grange Dam near La Grange, CA	11289650	1,045	757
Tuolumne River at Modesto, CA	11290000	1,296	938

<sup>†</sup> Source: <http://waterdata.usgs.gov>.

The Tuolumne River and Cherry Creek are both regulated streams and thus have modified flow regimes in response to storage and water management operations. An example of Cherry Creek flows below Cherry Valley Dam and below Holm Powerhouse is shown in Figure 5.2-1 for 2010. Releases to Cherry Creek are modest and generally associated with high flow conditions and reservoir spill or storage management operations. Releases from Eleanor Dam are likewise small; for 2010 maximum release was less than 10 cfs (Figure 5.2-1).



**Figure 5.2-1. Cherry Creek flow below Cherry Valley Dam (USGS Gage 11277300) and below Holm Powerhouse (USGS Gage 11278400), and Eleanor Creek flow below Eleanor Dam (USGS Gage 11278000), 2010.**

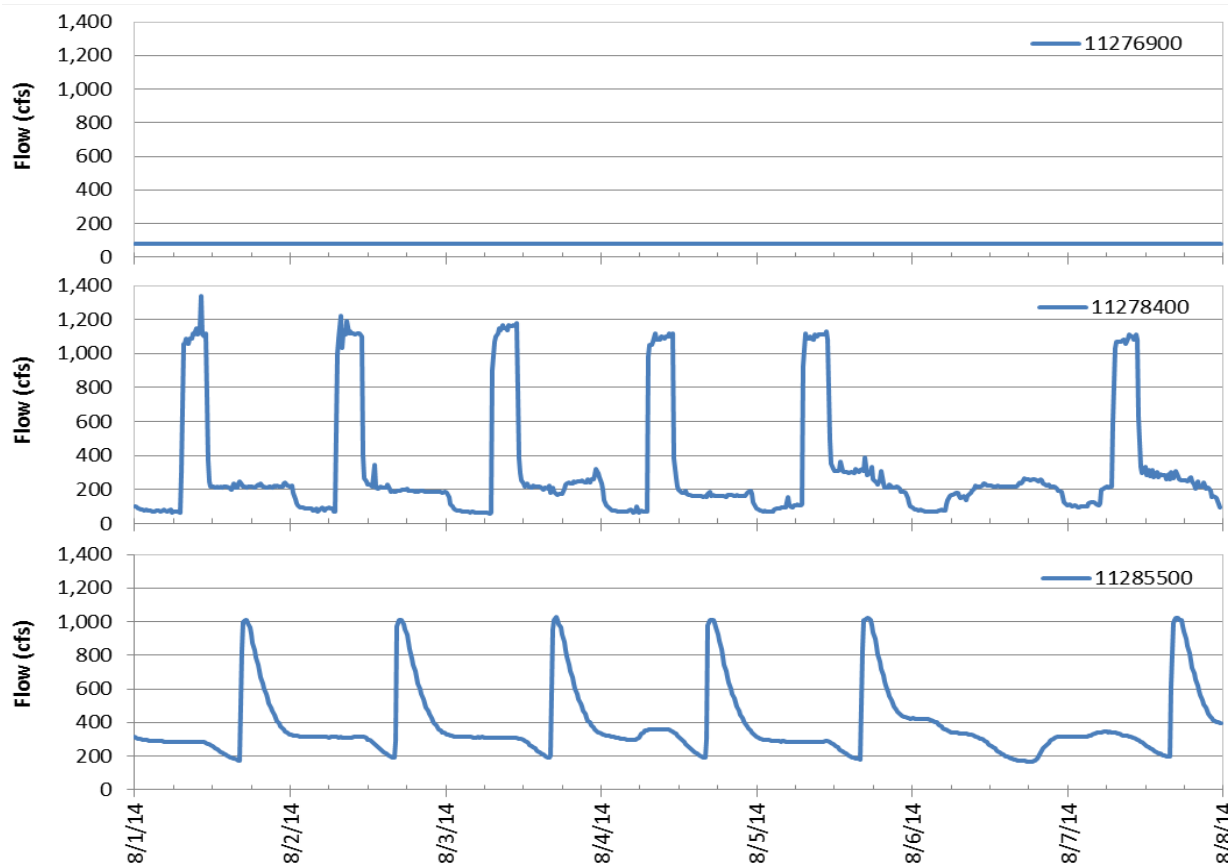
The mainstem Tuolumne River exhibits a similar hydrograph as Hetch Hetchy Reservoir captures winter rainfall flow events and spring and summer snowmelt runoff for storage during drier periods of the year. Examining flows for a typical summer week at the Tuolumne River below Early Intake, Cherry Creek below Holm Powerhouse, and Tuolumne River near Wards Ferry illustrates how relatively low, stable flows at Early Intake are over shadowed by the signature of dynamic peaking flows from Holm Powerhouse, and that these conditions persist some 26 miles downstream to Wards Ferry (Figure 5.2-2). Travel time, peak attenuation, and the contribution of other tributaries are all apparent in this figure.

The tributaries downstream of Cherry Creek exhibit a largely unimpaired flow regime. Using the proration flows (TID/MID 2013a) for the Clavey and North Fork Tuolumne rivers for water year 2011 (October 1, 2010 to September 30, 2012), the flow signatures of winter rainfall events are clearly indicated, as is the snowmelt signature of the winters accumulation of snowpack (Figure 5.2-3). The North Fork Tuolumne River has both a smaller basin area and a lower headwater elevation than the Clavey River, indicating a smaller hydrologic response to these runoff events, and a snowmelt signature that terminates earlier than the Clavey River. The South Fork Tuolumne River exhibits a hydrology similar to the Clavey River.

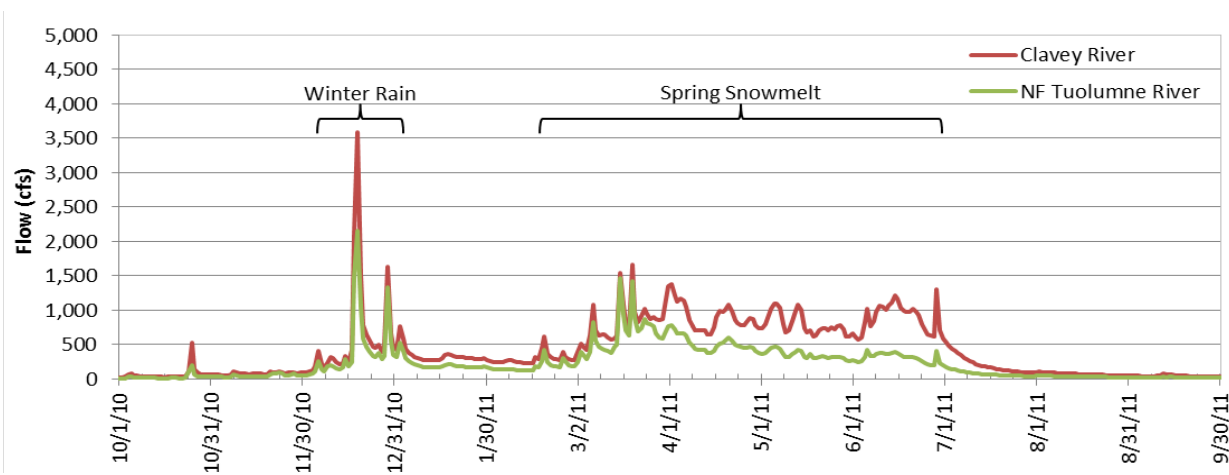
Comparing flows at Cherry Creek above Holm Powerhouse with flows in the Clavey River illustrates that Cherry Creek flows are notably moderated during the winter rainfall events. The seasonal snowmelt signal is likewise remarkably moderated, as winter and spring runoff waters from above Cherry and Eleanor Lakes are stored for summer hydropower production and downstream water supply (Figure 5.2-4).

These flow conditions illustrate both intra- and inter-annual variability in response to hydrologic (e.g., wet or dry years), meteorological (cool or warm springtime periods), and operating conditions (on the mainstem Tuolumne River and Cherry Creek). Nevertheless, the basic

hydrologic elements are typically present in all year types. Further, these conditions have direct implications on water temperature regimes in the Tuolumne River and its tributaries.

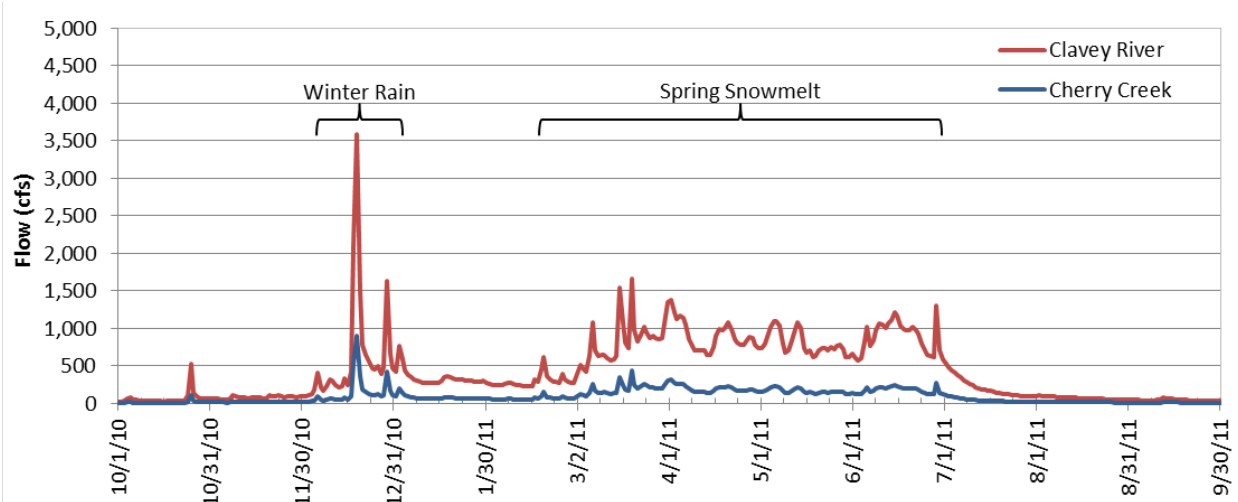


**Figure 5.2-2.** Flow in the Tuolumne River below Early Intake (USGS Gage 11276900) - top, Cherry Creek below Holm Powerhouse (USGS Gage 11278400) - middle, and Tuolumne River near Wards Ferry (USGS Gage 11285500) – bottom, August 1-8, 2014.



**Figure 5.2-3.** Clavey and North Fork Tuolumne rivers near mouth, daily flows for water year 2011 (October 1, 2010 to September 30, 2012) (TID/MID 2013a).





**Figure 5.2-4. Clavey River near mouth and Cherry Creek (above Holm Powerhouse): daily flows for water year 2011 (October 1, 2010 to September 30, 2012) (TID/MID 2013a).**

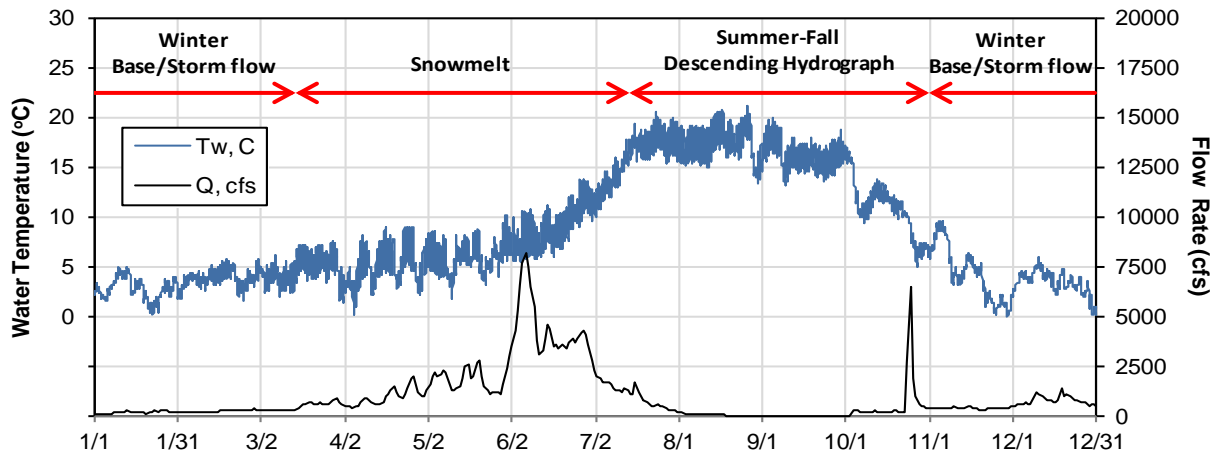
### 5.2.2 Water Temperature: Historic Data

As with flow, water temperature also exhibits a seasonal pattern in the study area. A useful concept in exploring thermal regimes of streams is to recognize that for much of the year, the river is in equilibrium with meteorological conditions. However, there are deviations from this equilibrium condition due to the imposition of warm and cold water flows on the mainstem. As noted previously, the hydrology of the system is driven by winter precipitation that yields rainfall runoff at lower elevations and accumulations of snow at higher elevations. Spring runoff associated with snowmelt leads to increased flows during a period of increasing solar insolation and increasing thermal loading. Through the summer period, flows diminish in response to depleted snowpack and lack of appreciable precipitation, while atmospheric thermal loading remains high. The result is that annual water temperature maxima typically occur in mid-summer. Flows continue to diminish through the fall, as do thermal loading rates and water temperatures. Water temperature responses to these conditions above Hetch Hetchy are shown in Figure 5.2-5. Modest to high flows occur in winter during a period termed “winter base/storm flow” and water temperatures are cool. During spring, large flows associated with snowmelt water yield cold waters that are transported from higher elevation tributary headwaters to the mainstem in relatively short periods – periods sufficiently short that these tributary inflows reach the mainstem Tuolumne River prior to heating appreciably (Figure 5.2-5). These contributions are often markedly colder than the mainstem, and can also be of considerable magnitude, thus have a marked effect on downstream water temperatures. As the snowmelt hydrograph abates and summer sets in, lower flows lead to a notable increase in stream temperatures, in some cases exceeding 20°C.

During mid-summer into early fall, certain tributaries may yield notably warmer water inputs to the mainstem Tuolumne River, particularly in the lower reaches of the system. However, these smaller tributary contributions may have only minor, local effects on the notably larger Tuolumne River. As stream flows continue to decrease or stabilize into the fall period, water



temperatures are reduced due to shorter day length, lower solar altitude, and overall meteorological conditions that favor cooler water temperatures.

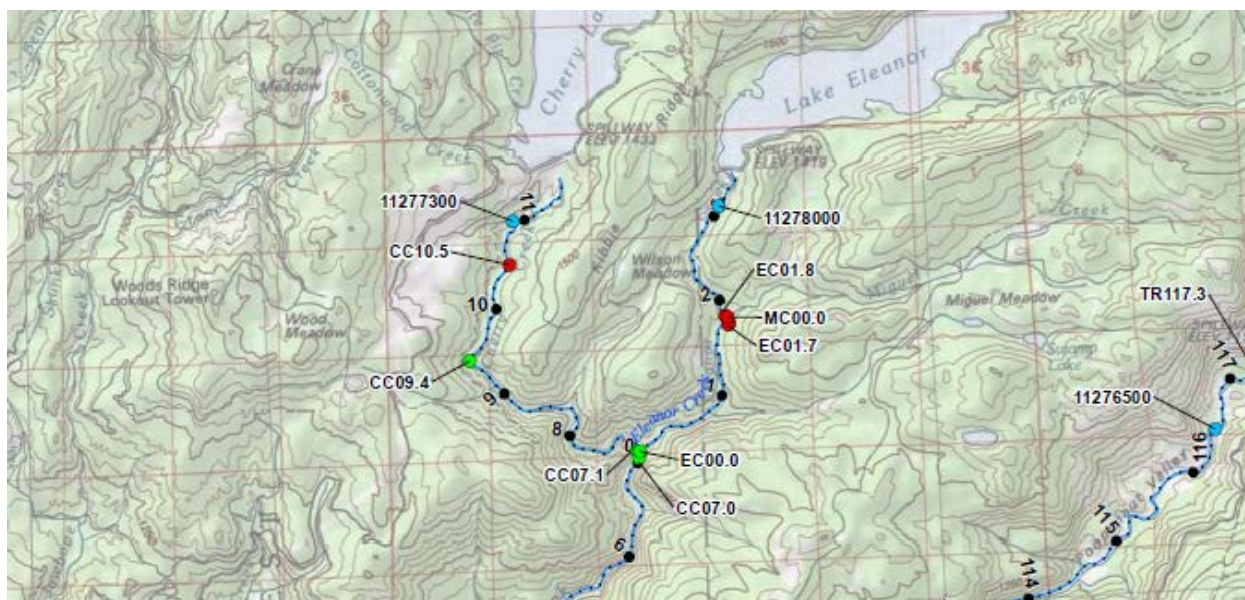


**Figure 5.2-5.** Flow and water temperature, Tuolumne River above Hetch Hetchy (USGS Gage 11274790) showing representative seasonal hydrograph elements. Flow data from TID/MID (2013b) water temperature data from <http://waterdata.usgs.gov/ca/nwis> (2010).

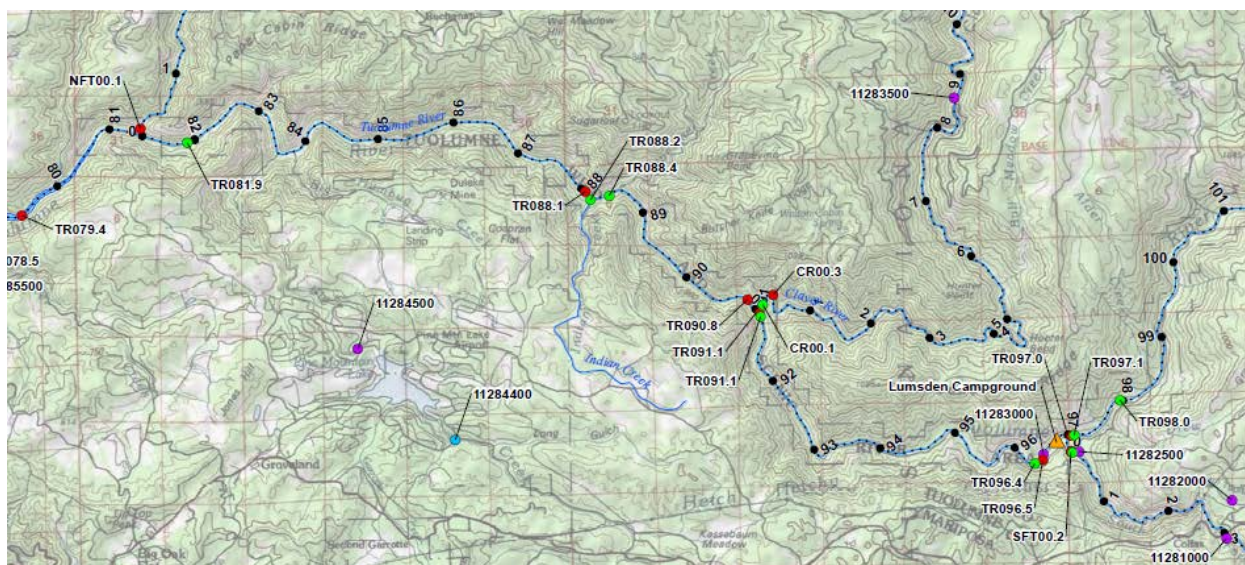
For the Tuolumne River below Hetch Hetchy and Cherry Creek, impoundment of winter water for release later in the year has a marked effect on water temperature in downstream reaches. For both the Cherry Creek (including Eleanor Creek) and Tuolumne River below Hetch Hetchy, the respective reservoirs effectively “reset” the thermal regime below the dams (including any delivery of water via penstocks to downstream reaches) to headwater conditions (Ward and Stanford 1983). The storage of winter water in the reservoir and subsequent deep-water release through the summer maintains cool water temperatures in downstream river reaches throughout the year. For the Tuolumne River, these cool waters emanate from O’Shaughnessy Dam, or occasionally from Kirkwood Tunnel releases to the Tuolumne River near Early Intake (see 4.1.2.3). For Cherry Creek, waters from Cherry Lake are conveyed via tunnels, pipelines, and penstocks to the Holm Powerhouse, bypassing approximately 10 stream miles. These waters are discharged just over one mile above the confluence with the Tuolumne, and during summer months are effectively conveying higher elevation, stored cold winter water to the lowest portion of Cherry Creek. These waters are notably colder than local (lower elevation, summer period) meteorological conditions would yield. Thus, releases from both O’Shaughnessy Dam and Holm Powerhouse on Cherry Creek begin to heat in the downstream direction in response to local meteorological conditions.

As with flow conditions, intra- and inter-annual variations in water temperature conditions can occur. Warmer summers or winters, lower flows due to drought, cooler spring conditions that reduce the rate of snowmelt, and other factors lead to widely variable conditions. However, the general seasonal patterns are largely consistent within or among years, perhaps shifting early or later, with larger or smaller magnitudes, but are nonetheless present in most years. The Cherry Creek watershed is discussed first due to the complex operations (Figure 5.2-6). Subsequently the streams with no appreciable storage – South Fork Tuolumne, Clavey, and North Fork Tuolumne Rivers – are presented (Figure 5.2-7). Finally, the mainstem Tuolumne River will be

discussed at the end of this section because it is influenced by the principal tributary streams below Early Intake.



**Figure 5.2-6. Water temperature data collection sites in upper Eleanor and Cherry creeks.**



**Figure 5.2-7. Water temperature data collection sites in the Tuolumne River and principal tributaries below Cherry Creek.**

#### 5.2.2.1 Cherry Creek Watershed

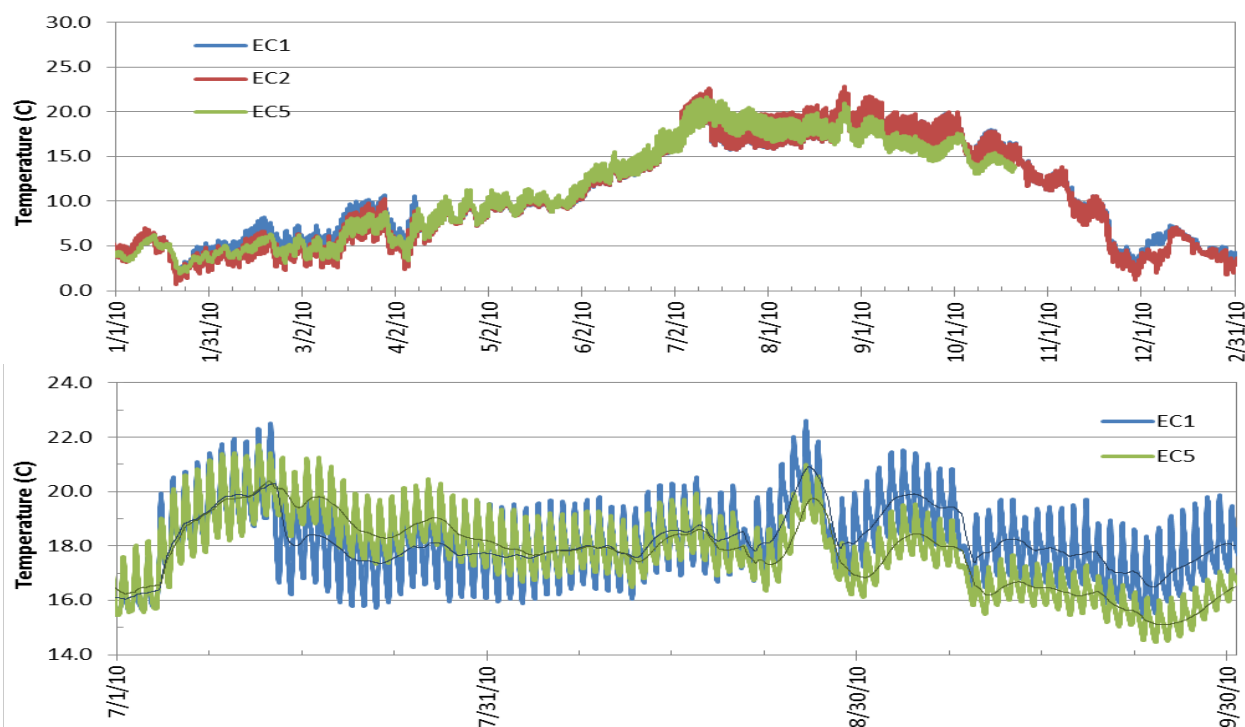
The Cherry Creek watershed includes Cherry and Eleanor creeks and their respective reservoirs. Eleanor Creek is a tributary to Cherry Creek, entering at approximately RM 7 on Cherry Creek. Water temperature data is available at four sites on Eleanor Creek and at one site on Miguel Creek, a tributary to Eleanor Creek (Table 5.2-2 and Figure 5.2-6).

**Table 5.2-2. Water temperature data sites on Eleanor Creek.**

Site Name	Site Label <sup>1</sup>	RM	Agency	Location Description
USGS Gage #11278000	11278000	3.1	USGS	Eleanor Creek near Hetch Hetchy, CA
EC1	EC01.8	1.8	CCSF	Eleanor Creek, upstream of Miguel Creek confluence
EC2	EC01.7	1.7	CCSF	Eleanor Creek, downstream of Miguel Creek confluence
EC5	EC00.0	0	CCSF	Eleanor Creek, upstream of Cherry Creek confluence
MC1	MC00.0	0	CCSF	Miguel Creek, upstream of Eleanor Creek confluence

<sup>1</sup> Label on map in Attachment D.

Water temperature conditions in Eleanor Creek exhibit the seasonal elements identified in Figure 5.2-5 – cold winter temperatures, with cool conditions persisting through the snowmelt, followed by heating summer period maxima and cooling in fall (Figure 5.2-8). Water temperatures above and below Miguel Creek (EC1 and EC2, respectively) are nearly identical throughout much of the year with the exception of winter and early spring, when downstream conditions slightly cooler, most likely to the contributions of cooler water from Miguel Creek. Throughout spring, water temperatures are similar throughout the creek, but starting in late-summer, temperatures in lower Eleanor Creek begin to cool more rapidly than those upstream (Figure 5.2-8). This may be in response to channel form, tributary inflows, topographic shading, or releases from upstream Eleanor Lake, where seasonal heating in the reservoir has led to release temperatures that are higher than what ambient meteorological conditions will support, resulting in cooler water temperatures as waters flow downstream.



**Figure 5.2-8. Eleanor Creek water temperature (top) above Miguel Creek (EC1), below Miguel Creek (EC2), and above the confluence with Cherry Creek (EC5) for January-December 2010, and (bottom) above Miguel Creek (EC1) and above the confluence with Cherry Creek (EC5) for July-September 2010. 24-hour moving average trace for each time series included.**

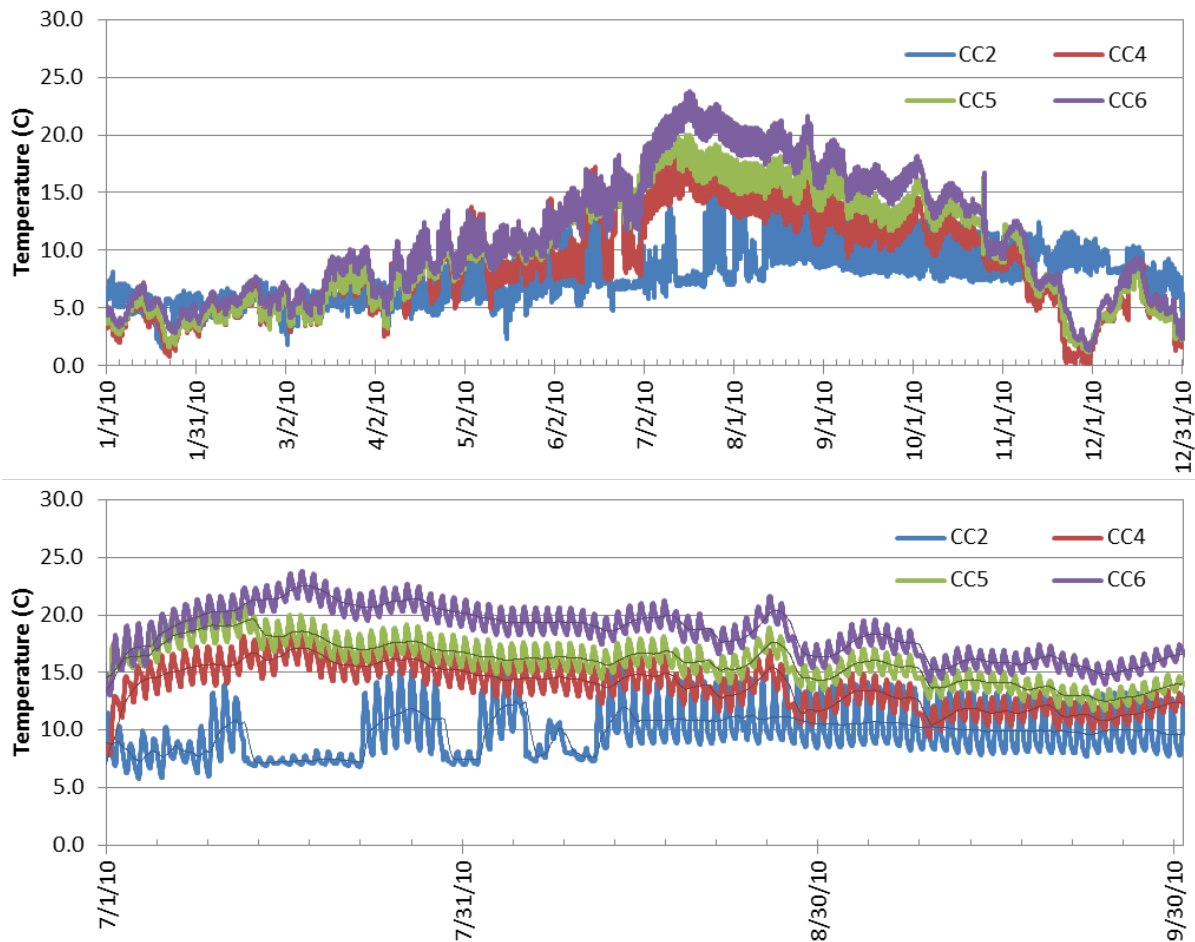


### 5.2.3 Cherry Creek

Water temperature data is available at ten sites on Cherry Creek (Table 5.2-3) (Figure 5.2-6, lower creek sites shown in Figure 5.2-7). As with Eleanor Creek, water temperature conditions in Cherry Creek exhibit the seasonal elements identified in Figure 5.2-5 (Figure 5.2-9). While winter temperatures are similar in the creek, water temperatures show a general increase in temperature downstream, starting in spring that persist well into fall. Water temperatures at CC2, near the dam, are coolest and there is systematic increase in water temperatures in the downstream direction that can lead to up to a 15°C increase from CC2 to CC6 during summer periods. During summer Eleanor Creek is typically warmer than Cherry Creek at their confluence, and contributes to longitudinal downstream heating in Cherry Creek.

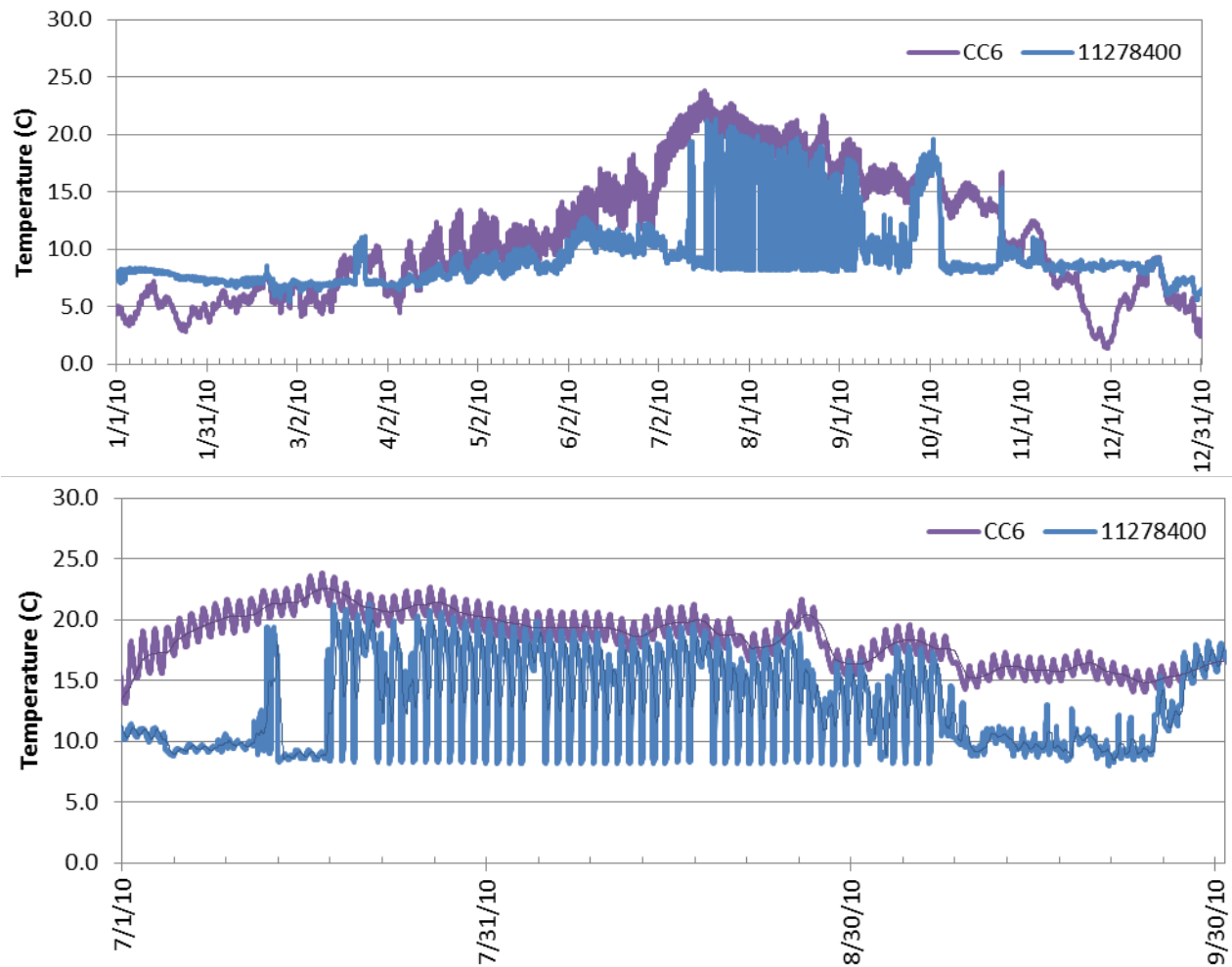
**Table 5.2-3. Water temperature data sites on Cherry Creek.**

Site Name	Site Label	RM	Agency	Location Description
CC1	CC16.1	16.1	CCSF	Upstream of Cherry Lake
USGS Gage 11277300	11277300	10.9	USGS	Cherry Creek below Valley Dam near Hetch Hetchy CA
CC2	CC10.5	10.5	CCSF	Cherry Creek, downstream of Cherry Dam
CC3	CC09.4	9.4	CCSF	Cherry Creek, downstream of Cherry Dam
CC4	CC07.1	7.1	CCSF	Cherry Creek, upstream of Eleanor Creek confluence
CC5	CC07.0	7.0	CCSF	Cherry Creek, downstream of confluence with Eleanor Creek
USGS Gage 11278300	11278300	1.2	USGS	Cherry Creek near Early Intake CA
CC6	CC01.2	1.2	CCSF	Cherry Creek, upstream of Dion Holm Powerhouse
TCKPH	CC00.6	0.6	CDFG	Cherry Creek Power House
USGS Gage 11278400	11278400	0.2	USGS	Cherry Creek below Dion R Holm Powerhouse, near Mather CA



**Figure 5.2-9. Cherry Creek water temperature (top) downstream of Cherry Valley Dam (CC2), above Eleanor Creek (CC4), below Eleanor Creek (CC5), above Holmes Powerhouse (CC6) for January-December 2010, and (bottom) July-September, 2010. 24-hour moving average trace for each time series included.**

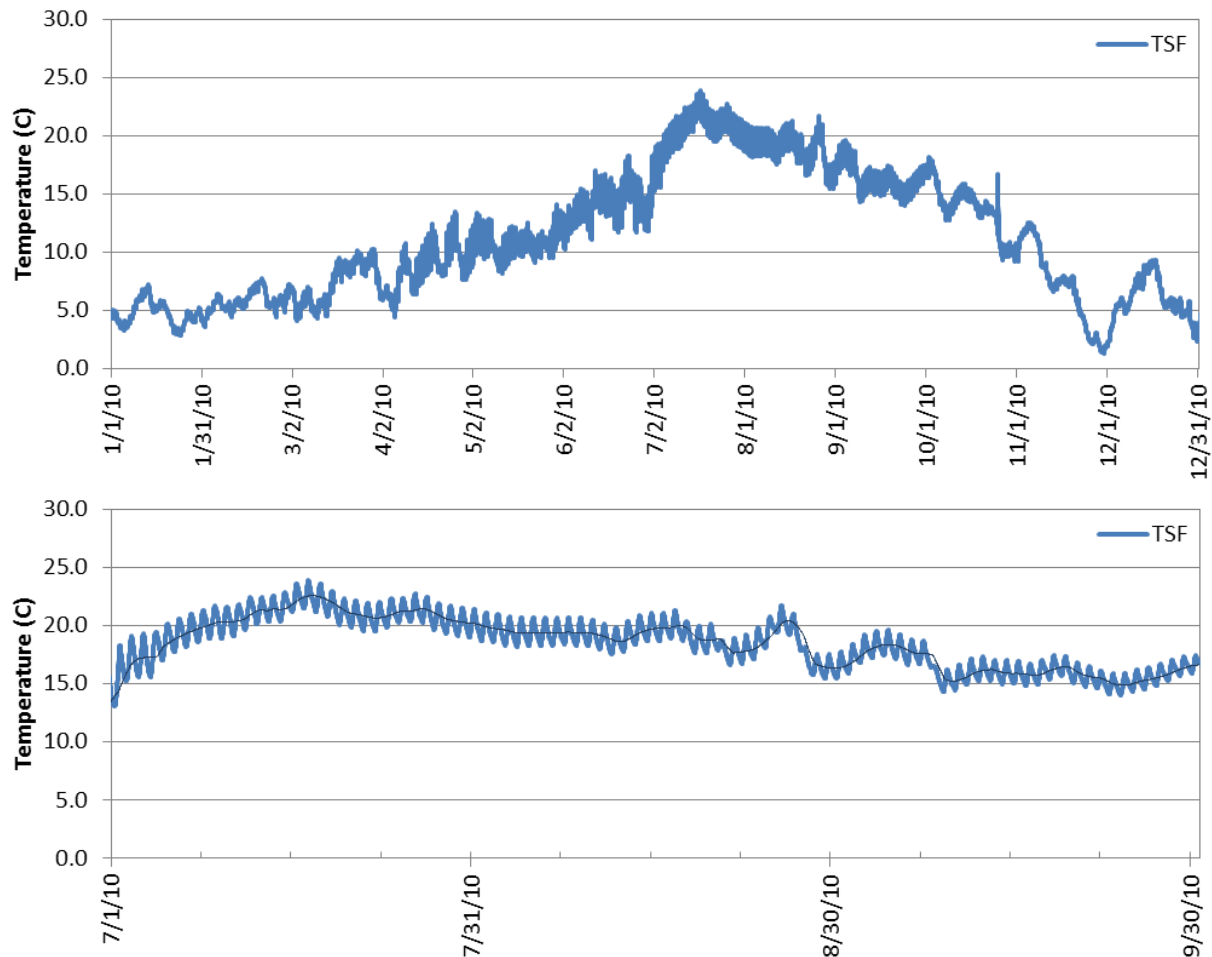
Below Holm Powerhouse, the temperature regime of the creek rapidly changes in response to hydropower operations. Cold waters from Cherry Lake are conveyed to the powerhouse, bypassing an approximately 10-mile natural stream channel and its associated heating or cooling. The volume of Cherry Lake is, by comparison, much greater than the stream channel. The smaller stream can gain and lose heat at a faster rate than the larger reservoir. Thus, in the winter, the Holm Powerhouse flows, which originate from Cherry Lake, are warmer than the creek immediately upstream of the powerhouse. In the summer the inverse is true (Figure 5.2-10, top). Summer temperatures are notably cooler below the powerhouse because creek flows are at seasonal lows. Even though temperatures may exceed 20°C, creek flows above the powerhouse are roughly two orders of magnitude smaller. When the powerhouse is off line, water temperatures downstream reflect upstream creek flows (CC6) and when the powerhouse is online, flows reflect Cherry Lake water temperatures (i.e., are more similar to temperatures at CC2) (Figure 5.2-10, bottom). Flow and temperature conditions below the powerhouse are conveyed with little change to the nearby Tuolumne River.



**Figure 5.2-10.** Cherry Creek water temperature (top) above Holm Powerhouse (CC6) and below Holm Powerhouse (USGS 11278400) January-December 2010, and (bottom) July-September, 2010. 24-hour moving average trace for each time series included.

#### 5.2.4 South Fork Tuolumne River

The South Fork Tuolumne River enters the Tuolumne River at approximately RM 97. Two water temperature monitoring sites are located at approximately RM 0.2 (Figure 5.2-7 and Attachment D). Site TSFRK is operated by California Department of Fish and Wildlife, while site TR6 is operated by CCSF. Water temperature data were unavailable at upstream locations. The South Fork Tuolumne River temperature regime is similar to Cherry Creek above Holm Powerhouse, with maximum summer temperatures in mid-July in excess of 20°C (Figure 5.2-11). However, consideration of South Fork Tuolumne River flows and temperature will be necessary for mainstem thermal assessment.

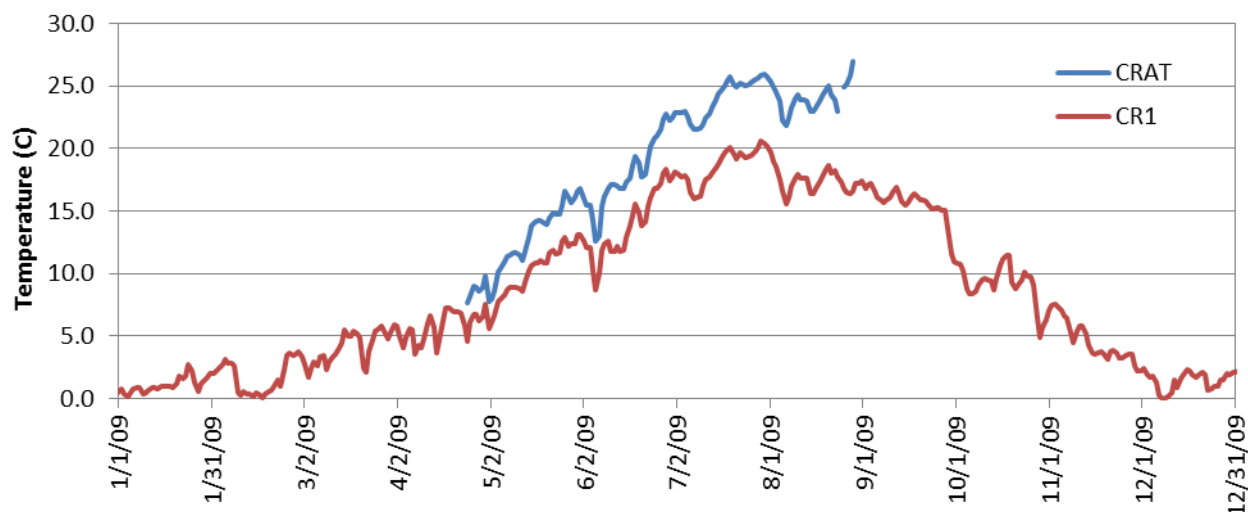


**Figure 5.2-11.** South Fork Tuolumne River water temperature (top) above Tuolumne River (RM 0.2) (TSFRK) January-December 2010, and (bottom) July-September, 2010. 24-hour moving average trace for each time series included.

### 5.2.5 Clavey River

The Clavey River enters the Tuolumne River at approximately RM 88.2. Two water temperature monitoring sites with limited data availability include CR1 (at RM 16.9 on the Clavey River near the 1N04 Bridge) and just above the confluence with the Tuolumne River (CRAT) (Figure 5.2-7 and Attachment D). Daily mean data are presented for 2009 where available data overlapped between the two Clavey River sites (Figure 5.2-12). Daily maximum temperatures at these sites exceeded 22°C at CR1 and 26°C at CRAT. Additional data has been acquired from U.C. Davis that will extend this record, and will be incorporated in to the final report after review and assessment. Additional data collected in 2015 will increase available data for the Clavey River.

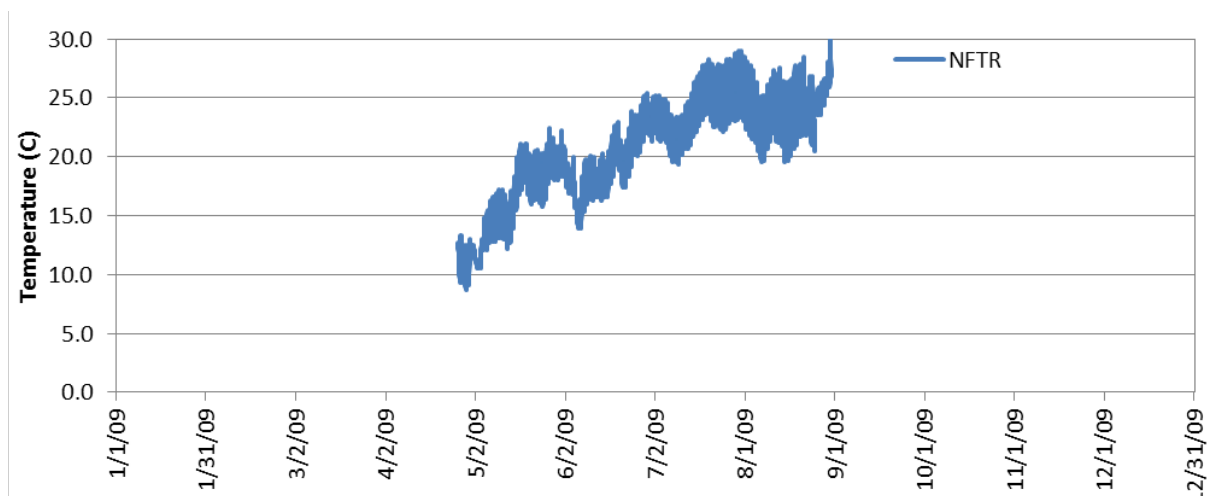




**Figure 5.2-12. Clavey River daily average water temperature at CRAT (RM 16.9) and above the confluence with the Tuolumne River (CR1), January-December 2009.**

### 5.2.6 North Fork Tuolumne River

The North Fork Tuolumne River enters the Tuolumne River at approximately RM 81.3. One water temperature monitoring site with limited data availability is NFTR located at approximately RM 0.1 (Figure 5.2-7 and Attachment D). Data was collected during spring and summer 2009 (Figure 5.2-13). During the summer months in 2009, the water temperature at the mouth of the North Fork of the Tuolumne River reached nearly 30 °C.



**Figure 5.2-13. North Fork Tuolumne River water temperature at NFTR (RM 0.1), available data between January-December 2009.**

### 5.2.7 Mainstem Tuolumne River

The study area includes the Tuolumne River from below Early Intake to Wards Ferry at the head of Don Pedro Reservoir. The aforementioned principal tributaries contribute flow and associated

thermal energy to the mainstem within this reach. All of the tributaries contribute notable flows during the winter and, in particular, during the spring snowmelt period. When these relatively high flow periods occur, water temperatures generally reflect the water temperatures of the tributary contributions (as well as flows from upstream of Early Intake). However, as flows begin to abate in the late spring and into summer, meteorological conditions produce some of the highest thermal loading rates of the year and water temperatures rapidly increase.

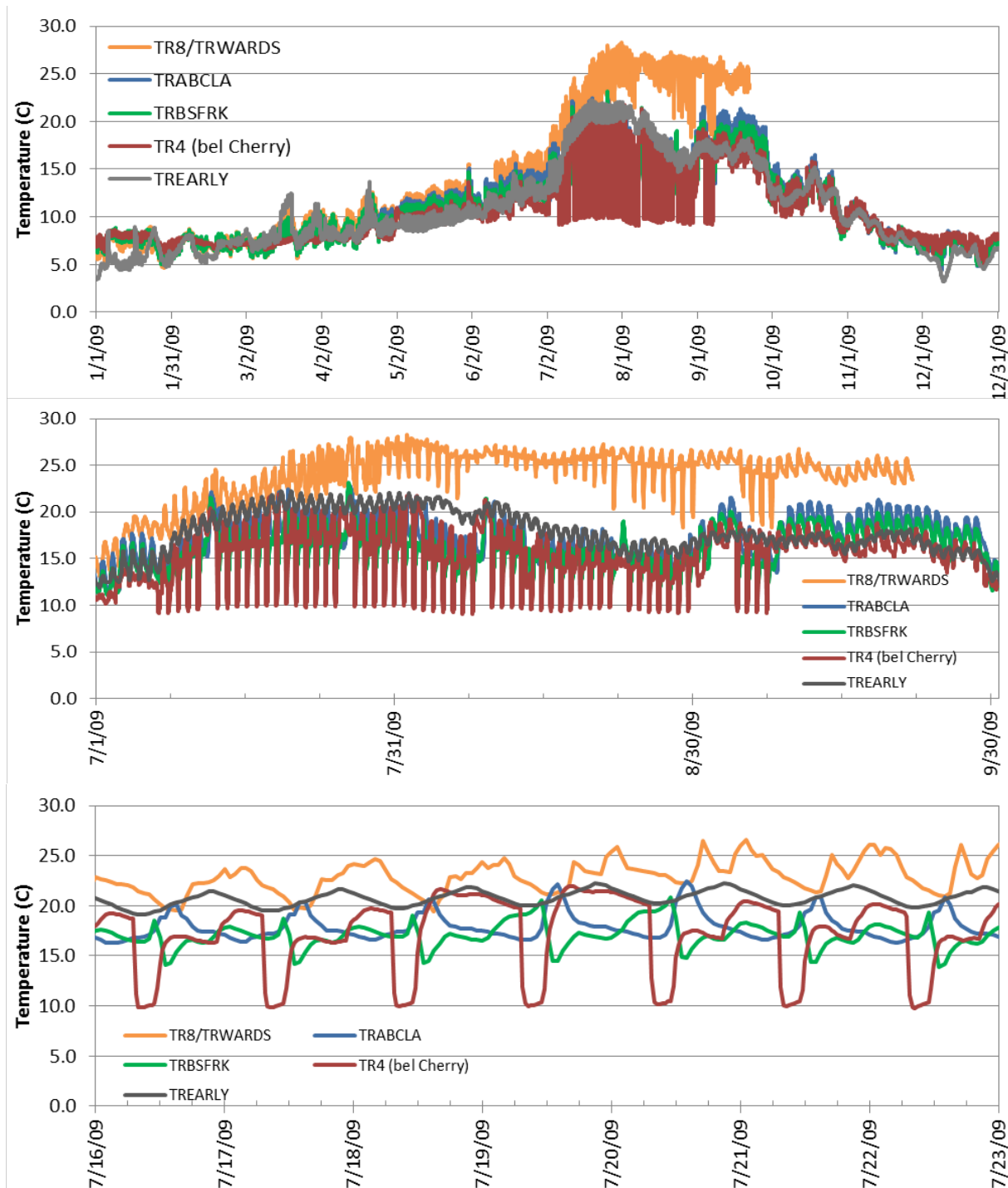
The Tuolumne River at Early Intake is regulated by operations at O'Shaughnessy Dam and Cherry Creek is regulated by operations at Cherry and Eleanor lakes and Holm Powerhouse. Both of these streams experience cool water releases at one or more locations below their respective dams, introducing cool water to downstream reaches through the year. Downstream tributaries are largely unimpaired and as flows diminish and temperatures increase, there is no temperature relief for the mainstem Tuolumne River. However, the relatively low flow in the tributaries, reduce the impact of their elevated temperatures on mainstem temperatures.

Examining temperatures through this reach identifies a complex thermal regime that is a function of mainstem and tributary hydrology and operations, snowpack, and meteorology. Winter temperatures are low in response to short days and low thermal loading. During the spring, cold snowmelt runoff is conveyed through tributaries from higher elevation headwaters to the mainstem. Water temperatures remain below 15°C through much of June throughout the study area (Figure 5.2-14, top). In July water temperatures begin to increase notably, and by mid-July temperatures at Wards Ferry surpass 25°C. Temperatures at Early Intake, though released from O'Shaughnessy Dam at roughly 15°C, exceed 20°C during this period due to the relatively low flow rates and adverse heating conditions.

All tributary flows are in excess of 20°C and sometimes 25°C by mid-summer. The exception is releases from Holm Powerhouse that originate in the high elevation, cool, stored water of Cherry Lake. These powerhouse releases have temperatures of less than 10°C during July and August (Figure 5.2-14, middle). These daily hydropower peaking operations result in flow increases from a baseflow of 100 or 200 cfs to a peaking flow of over 1,000 cfs for periods of four or five hours. The result is markedly colder waters being conveyed downstream during these periods, the impact of which can be seen at intermediate locations as well as at Wards Ferry. The complexity of these temperature signals is apparent in Figure 5.2-14 (bottom). Early Intake experiences a basic diurnal signal with a late afternoon maximum and an early morning minima. However, the imposition of Holm Powerhouse operations on the relatively small upstream Tuolumne River flows creates complicated signals that have single or double daily peaks occurring at various times of day or night.

When hydropower peaking operations cease in mid-September (Figure 5.2-14, middle), the Tuolumne River between Early Intake and Wards Ferry follows a more typical longitudinal heating profile, where water temperatures increase steadily from Early Intake, to below Cherry Creek, to below South Fork Tuolumne River, to above the Clavey River, to Wards Ferry. Minimal heating occurs between Early Intake and below Cherry Creek because the distance is short – only about two miles. There is considerable heating from above the Clavey River to Wards Ferry, and this may be a combination of the relatively long distance between these two points (Figure 5.2-7), contributions of warm waters from the Clavey River and North Fork

Tuolumne River (Figure 5.2-12 and Figure 5.2-13), and the lower gradient in this reach that leads to a longer transit time (Figure 4.1-2).



**Figure 5.2-14.** Tuolumne River water temperatures below Early Intake (TREARLY), below Cherry Creek (TR4), below South Fork Tuolumne River (TRBSFRK), above Clavey River (TRABCLA), and at Wards Ferry (TR8/TRWARDS), from (top) January 1 – December 31, (middle) July 1 – September 30, and (bottom) July 16 – July 23, 2009.

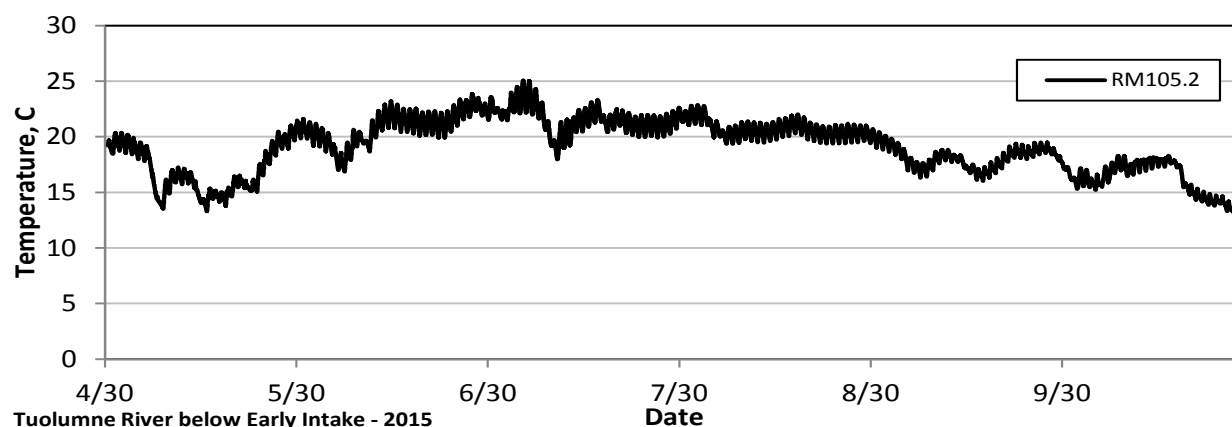
### 5.3 Temperature and Stage Monitoring and Data Collection: 2015

As noted above, water temperature loggers were deployed in April and May, 2015 at 12 sites in the Tuolumne River and its tributaries. Stage loggers were deployed with water temperature loggers at nine of the 12 sites. Data loggers that could be safely reached were downloaded in August and October 2015. Some devices are still in the field collecting data and have not been downloaded since the last deployment due to accessibility issues. All loggers remain in the field to collect winter data, and will be downloaded when conditions allow safe retrieval. All 2015 water temperature data presented herein are provisional. Stage data continue to be processed and were not available for inclusion in this progress report.

#### 5.3.1 Mainstem Tuolumne River

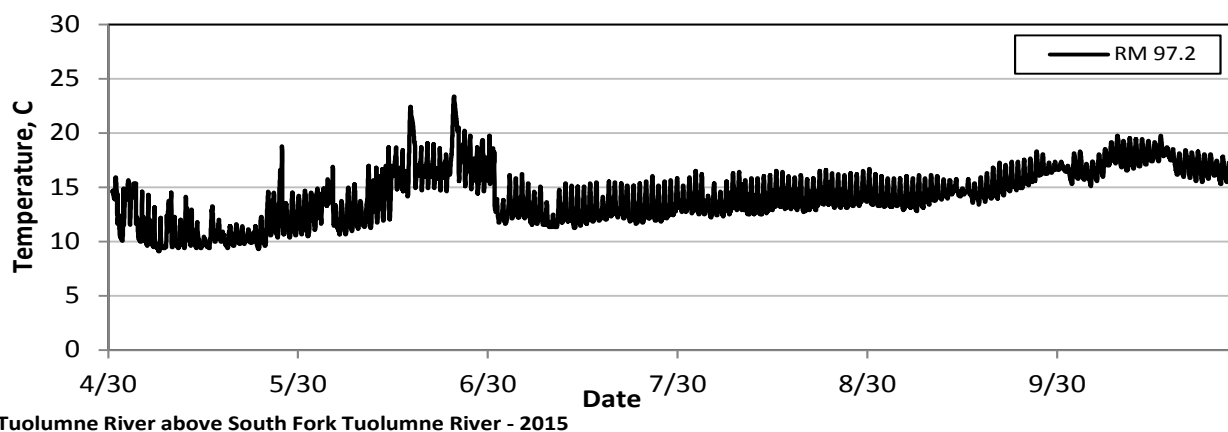
Temperature loggers have been downloaded from two sites in the mainstem: Tuolumne River below Early Intake and Tuolumne River above South Fork Tuolumne River. High flow prevented access to loggers installed in the Tuolumne River above North Fork Tuolumne River and above Clavey River.

Water temperatures in the Tuolumne River below Early Intake (RM 105.2) were collected from April to October 2015 (Figure 5.3-1). Water temperatures in 2015 were generally consistent with historical data collected through the end of 2014, indicating warming through spring and remaining above 20°C for most of summer, followed by fall cooling.



**Figure 5.3-1. Water temperature data collected in 2015 in the Tuolumne River below Early Intake.**

Water temperatures in the Tuolumne River above South Fork Tuolumne River (RM 97.0) were collected from April to October 2015 (Figure 5.3-2). Water temperatures in 2015 were likewise consistent with historical data collected through the end of 2014. As with historical data presented previously, Holm Powerhouse operations are notable in the larger diurnal signal (hydropower peaking) and cooler waters introduced from Cherry Reservoir storage during summer.



**Figure 5.3-2.** Water temperature data collected in 2015 in the mainstem Tuolumne River above South Fork Tuolumne.

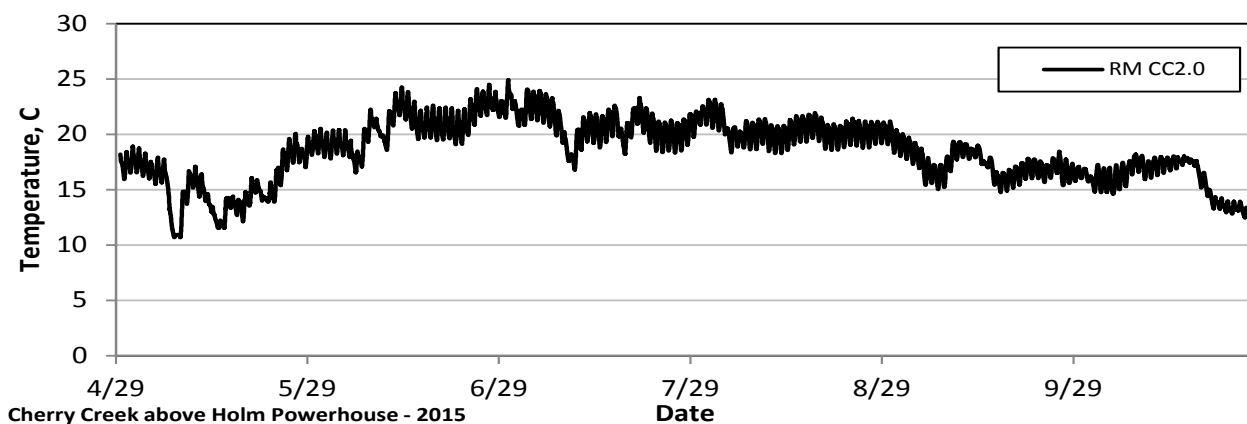
### 5.3.2 Tuolumne River Tributaries

Tuolumne River tributaries include Cherry Creek, South Fork Tuolumne River, Clavey River and North Fork Tuolumne River. With the exception of Cherry Creek, little historical data were available for the tributaries. Thus, the 2015 data provide useful information in further characterizing these systems.

#### 5.3.2.1 Cherry Creek

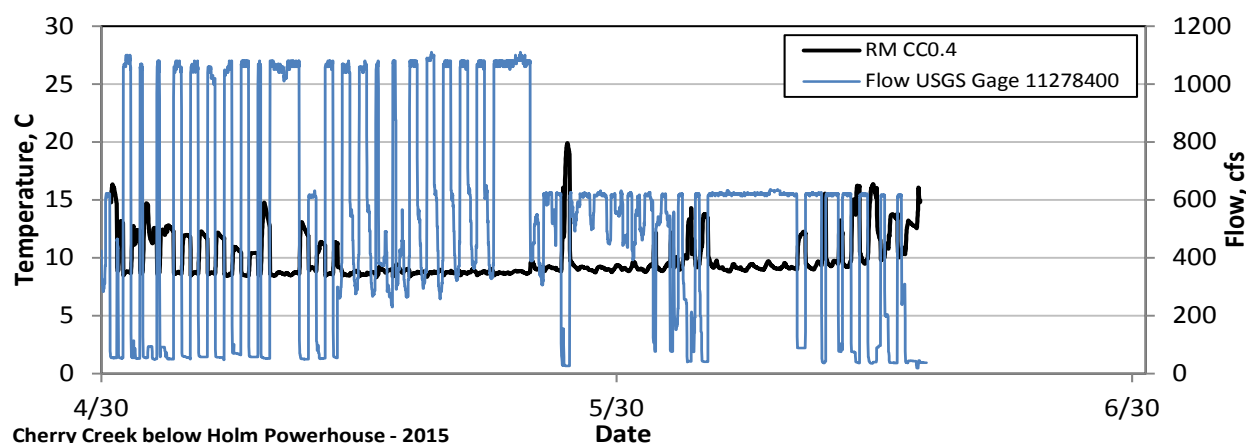
Two locations on Cherry Creek were monitored by the Districts in 2015: above and below Holm Powerhouse.

Water temperatures in Cherry Creek at RM 2.0, above Holm Powerhouse, were available from April through October 2015 (Figure 5.3-3). Temperatures in 2015 were consistent with historical data, illustrating a trend of warming through spring and remaining above 20°C for most of summer in response to seasonally low stream flows above the powerhouse.



**Figure 5.3-3.** Water temperature data collected in 2015 in Cherry Creek above Holm Powerhouse.

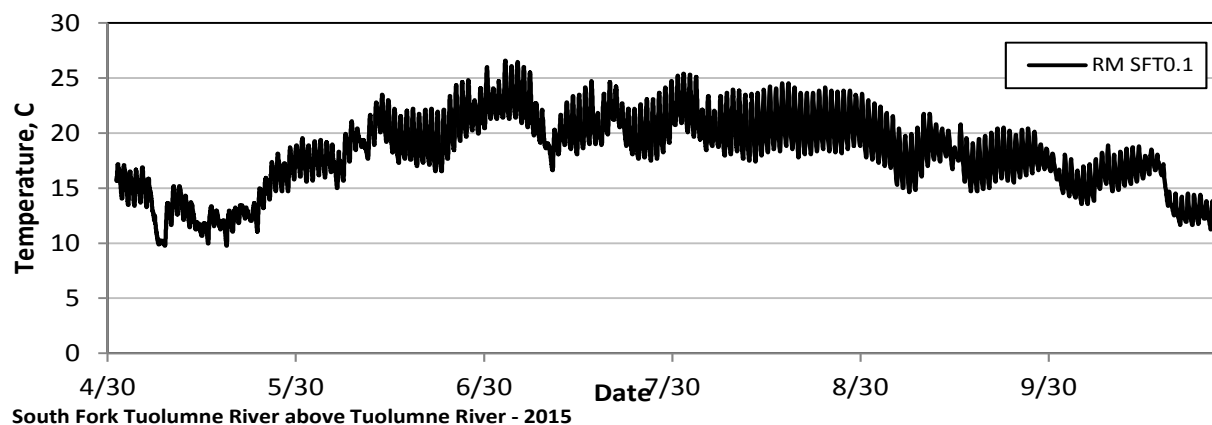
Water temperature in Cherry Creek below Holm Powerhouse, at RM 0.6, were available from April into June, 2015 (Figure 5.3-4, including flow from USGS gage 11278400). Peaking hydropower flows through the powerhouse represent deep, cool water releases from Cherry Reservoir resulting in variable flows associated lower water temperatures. The influence of the powerhouse flows is consistent with the historic data (Figure 5.2-10).



**Figure 5.3-4. Water temperature and flow data collected in 2015 in Cherry Creek below Holm Powerhouse.**

#### 5.3.2.2 South Fork Tuolumne River

Water temperatures in the South Fork Tuolumne River above the confluence with the Tuolumne River were available from April through October, 2015 (Figure 5.3-5). 2015 data were similar to historic data where temperatures warm in the spring and remain warm throughout the summer, followed by fall cooling.

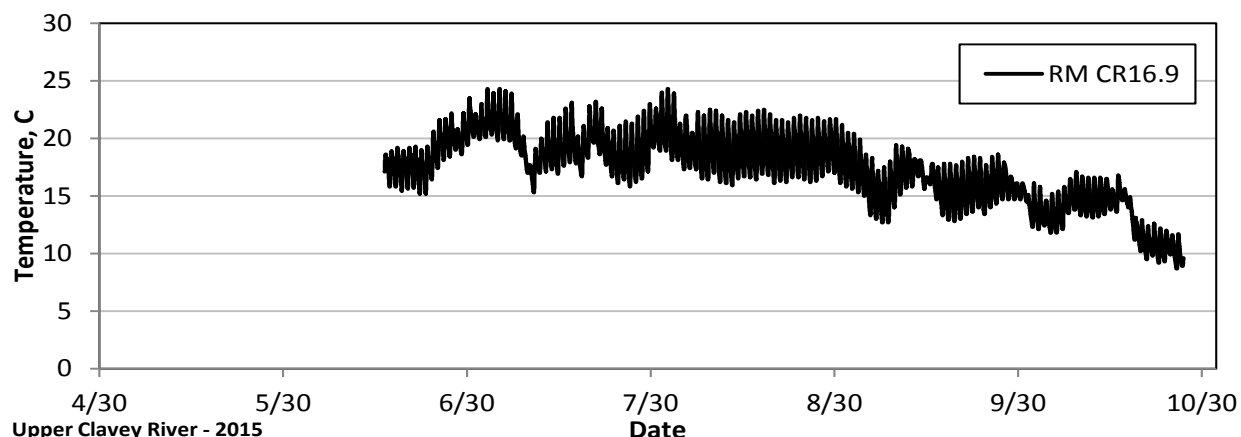


**Figure 5.3-5. Water temperature data collected in 2015 in the South Fork Tuolumne River water.**

### 5.3.2.3 Clavey River

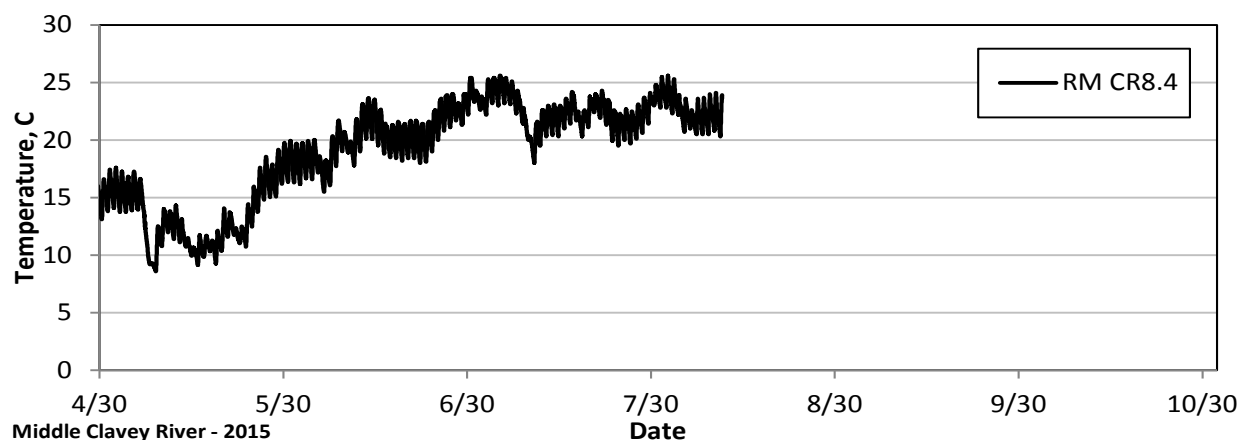
Water temperatures were collected at three sites on the Clavey River in 2015, the upper Clavey River (RM 16.9), middle Clavey River (RM 8.4), and lower Clavey River (RM 0.1).

Water temperatures in the upper Clavey River were monitored at the USFS Bridge 1N04 at RM 16.9 from June to October, 2015 (Figure 5.3-6). Data collected in 2015 are generally consistent with data collected through the end of 2014, recording warming through spring and remaining at or just below 20°C for most of summer at this most upstream site.



**Figure 5.3-6. Water temperature data collected in 2015 in the upper Clavey River.**

Water temperatures in the middle Clavey River were collected at the USFS Bridge 1N01 at RM 8.4 from May 1 into August, 2015 (Figure 5.3-7). While there are still loggers in the field, the last download was in summer. Temperatures typically exceeded 20°C in summer.

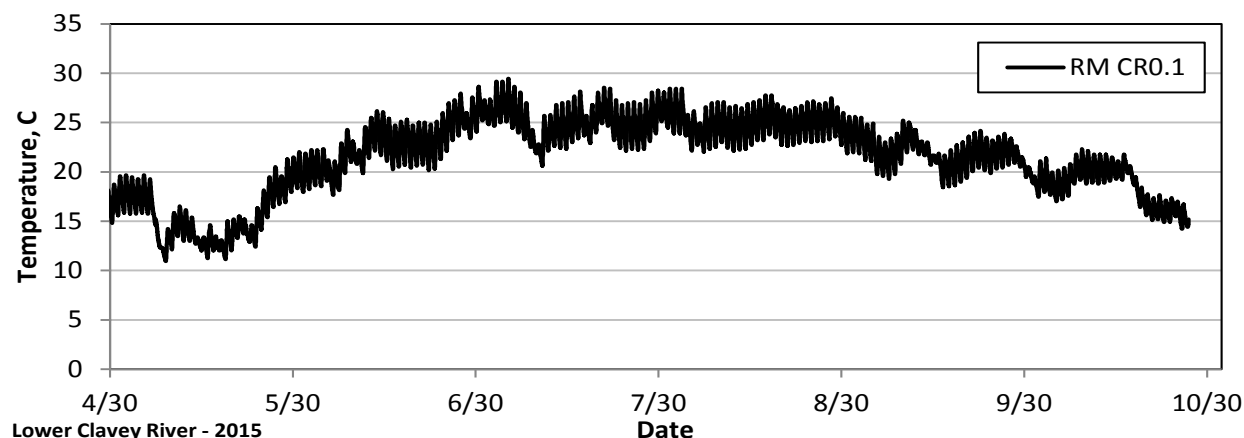


**Figure 5.3-7. Water temperature data collected in 2015 in the middle Clavey River.**

Water temperatures in the lower Clavey River were monitored above the confluence with the Tuolumne River (RM 0.1) from April to October, 2015 (Figure 5.3-8). Data collected in 2015



are generally consistent with historic data, recording warming through spring and remaining above 20°C (and at times 25°C) for most of summer followed by fall cooling.



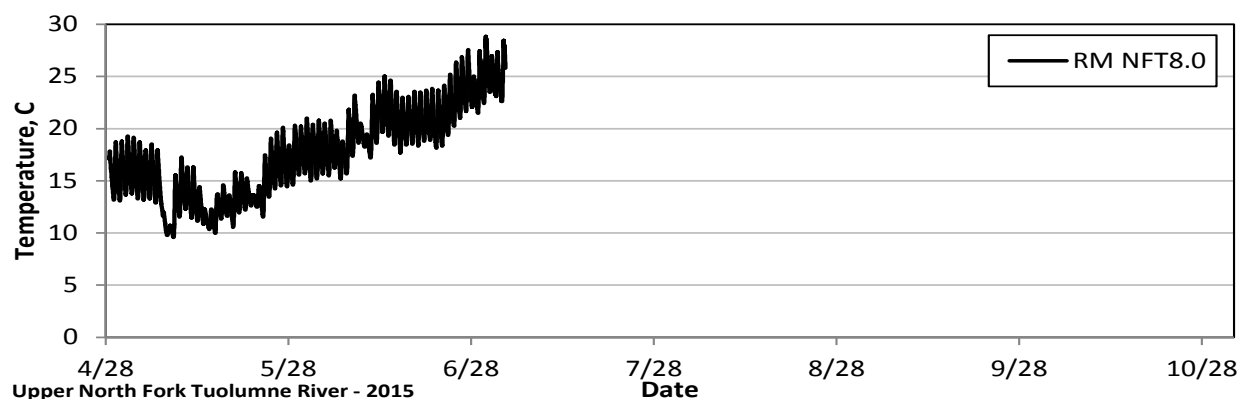
**Figure 5.3-8. Water temperature data collected in 2015 in the lower Clavey River.**

The three Clavey River water temperature time series illustrate seasonal heating dynamics consistent with the other tributaries. Further, longitudinal heating conditions are well represented, with cooler summer temperatures at RM 16.9 and warmer near the mouth at RM 0.1. As with the limited 2009 data, maximum summer temperatures at the confluence were well in excess of 25°C.

#### 5.3.2.4 North Fork Tuolumne River

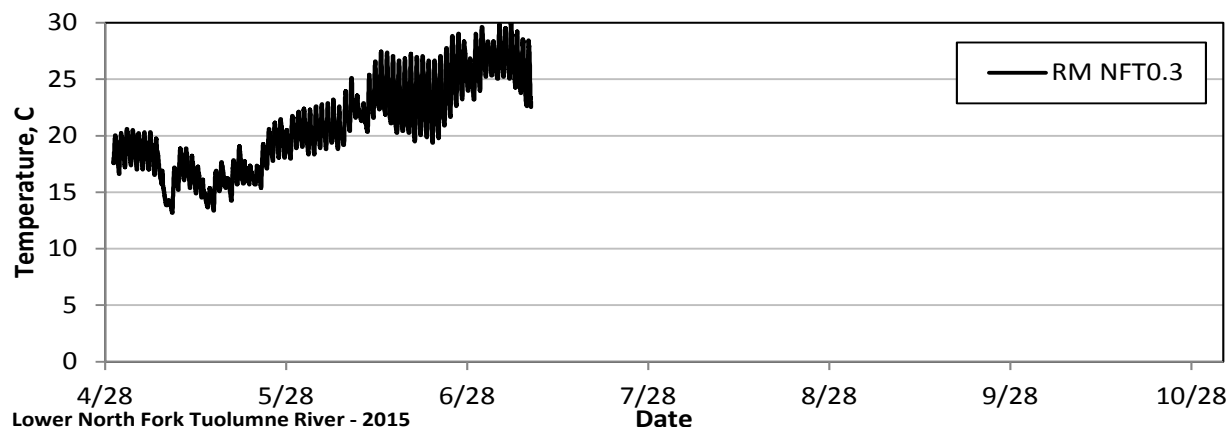
Water temperatures were collected at two sites on the North Fork Tuolumne River, at USFS Bridge (RM 8.0) and above the confluence with the Tuolumne River (RM 0.3).

Water temperature monitoring in the upper North Fork Tuolumne River, at the bridge at RM 8.0, commenced in April, but was terminated in early July when flows dropped to low levels (Figure 5.3-9).



**Figure 5.3-9. Water temperature data collected in 2015 in the upper North Fork Tuolumne River.**

Water temperatures in the lower North Fork Tuolumne River above the confluence with the Tuolumne River (RM 0.3), were monitored from late April into early July, when the stream ran dry (Figure 5.3-10).



**Figure 5.3-10. Water temperature data collected in 2015 in the lower North Fork Tuolumne River.**

While limited in duration, due to extremely low flows experienced in the summer of 2015, the temperatures in the North Fork Tuolumne River are similar to the limited record in 2009, where maximum summer temperatures reached approximately 30°C.

### 5.3.3 Summary

Water temperature data collected throughout the study area during 2015 are consistent with historical datasets collected through up to and including 2014. The 2015 data at all sites follows trends of seasonal warming and cooling similar to historically available information. In addition, water temperature data from individual sites exhibit maximum and minimum values comparable to previous years. The additional tributary locations have provided useful information on the longitudinal thermal regimes of these systems. The extension of this dataset through the winter and into the summer of 2016 will provide additional information to assist in characterizing and assessing thermal conditions in the study area.

## 6.0 DISCUSSION AND FINDINGS

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This report aims to address the interim status of the Water Temperature Monitoring and Modeling Study. Specifically, this report addresses the first five of the seven elements of the overall study plan:

- Synthesize and interpret existing information including geometric, flow and stage, meteorological, and water temperature data to characterize existing thermal conditions in the study area,
- Identify locations where existing data is inadequate,
- Install data loggers to obtain additional information at locations for which existing data are inadequate,
- Conduct a QA/QC assessment of collected data,
- Provide an initial study report,
- Develop a water temperature model, and
- Provide an updated study report.

Some of these elements are in progress, including the continuing collection and QA/QC assessment of field data. Completion of QA/QC will expand the existing dataset, which is particularly important in tributaries where little information has been collected, such as the Clavey and North Fork Tuolumne rivers. Subsequently, this information will be used to update the historical dataset, and any findings or assumptions on the identified thermal conditions of the Tuolumne River and the principal tributaries in the study area will be updated accordingly.

These data will form important time series information to support the development of a flow and temperature model to assess the potential for reintroduction of Chinook salmon and steelhead trout. A model will be a valuable tool to assist in a reintroduction analysis, especially given the size of the study area and the overall complexity associated with hydrology, meteorology, and operations.

These data will also inform discussions with fisheries biologists on appropriate temperature metrics to assess reintroduction conditions (e.g., thermal suitability of habitat, etc.) and potential strategies. There are a wide range of metrics that use daily maximum, minimum, and average temperatures in fisheries assessments. The data monitoring program and simulation models have been designed/selected to provide sub-daily (e.g., hourly) information to support the development and application of such metrics.

As part of the biological review, development, and application of applicable temperature metrics for anadromous fish species, consideration of fish passage barriers, and other considerations will be required to define the spatial and temporal aspects of flow and temperature model development. It is expected that specific reaches and specific time frames will be identified based on flow, temperature, fish access, and other attributes that will guide model application.

Outlined below are several activities that are ongoing in light of the study plan objectives.

## **6.1 Updates to Field Data**

The current monitoring program will be updated to include data collected for the remainder of 2015 and into 2016. These data can be used to support anadromous fisheries reintroduction analysis, including model application. Flow, stage and water temperature data collected by USGS, CCFS, NMFS, and other agencies/entities will continue to be incorporated into the master database as data come available. District data loggers that are still collecting stage and water temperature will be downloaded and QA/QC applied.

### **6.1.1 Geometry Data**

Updates to geometry datasets will be made as data becomes available. The existing mainstem geometry data (Jayasundara et al. 2014) will be updated to include tributaries. Updates will include planform, gradient, and cross section data from Cherry and Eleanor creeks, Clavey River, and the North and South Fork Tuolumne rivers. Data will include LiDAR data supplied by NMFS, as well as measured cross sections and information from recent field observations and examination of aerial photos. An assessment of topographic or riparian shade attributed will be completed on a reach-by-reach basis.

### **6.1.2 Flow and Stage Data**

Flow and stage data will be reviewed and formatted for model input and testing as part of the ongoing model development and application process.

### **6.1.3 Water Temperature Data**

Water temperature data will be reviewed and formatted for model input and testing as part of the ongoing model development and application process.

### **6.1.4 Meteorology Data**

Meteorology data has been extended to 2015. Following the same dataset development procedures outlined in Section 4.1.4.2. These data will be formatted for model input and testing as part of the ongoing model development and application process.

## **6.2 Model Selection and Development Process**

Model selection was based on previous upper Tuolumne River system conceptualization wherein appropriate models were evaluated for use (Jayasundara et al. 2014).

In selecting a model, the following attributes were considered:

- Robust hydrodynamics: A model must be able to replicate variable flow conditions on a short time step (e.g., hourly) to assess potential implications of dynamic flow conditions in steep river reaches.
- Longitudinal temperature gradients: Longitudinal temperature gradients are important in assessing temperature via the fate and transport of heat energy.
- Sub-daily temperatures: Sub-daily temperatures are desirable to identify not only mean daily conditions, but also minimum and maximum daily temperatures to develop metrics for anadromous fish assessment and regulatory considerations.
- Shade: Topographic and riparian shade may both be important factors in estimating water temperature response.

Only models with open-source code (i.e., code that is accessible for user review and modification) that is actively supported by the model developer or sponsor were included in this previous evaluation.

The RMA suite of models is a robust modeling system, capable of meeting study needs and schedule. These models have been applied successfully to the Tuolumne River in simulations below Hetch Hetchy over a wide range of flows (Jayasundara et al. 2010). The RMA models were chosen for this study because of their ability to model both flow and temperature in this extremely steep reach, the relatively short run times required, their capacity to report sub-daily water temperature, and the relatively minor modifications needed to represent the river system.

The RMA models, RMA-2 (v8.0) for hydrodynamics and RMA-11 (v8.0) for water temperature, will be used to represent the Tuolumne River and tributaries in a one-dimensional, depth-averaged, finite element scheme. The models will employ a common geometry file that will be used by both the hydrodynamic and water temperature models. Model development generally includes several elements: data development; model implementation; model calibration; and sensitivity testing. The current focus of the study to date has been on data development. Model construction and application will occur in the next phase of the study.

All activities will be documented in the USR.

## **7.0                    STUDY VARIANCES AND MODIFICATIONS**

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There were no variances or modifications to the original study plan. Adjustments were made to accommodate access, timing, and other factors typical of field work. Overall, the intent of the study to characterize mainstem and tributary conditions was met.

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**UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE  
MONITORING AND MODELING STUDY  
PROGRESS REPORT**

**ATTACHMENT A**

**SAMPLING PLAN: WATER TEMPERATURE, FLOW, STAGE**

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# SAMPLING PLAN: WATER TEMPERATURE, FLOW, STAGE

## Introduction

To support the development of a water temperature model, a network of water temperature and stage recorders were deployed in the spring of 2015. Sampling locations were identified based on modeling needs and safe access to the installation locations. The specific installation points will be determined in the field and selected based on conditions that represent overall river conditions.

## Schedule and Access

Loggers are proposed to be installed at a total of 12 locations (Table 1) in spring 2015 if conditions allow (i.e., safe flows) and checked periodically throughout the monitoring period. Loggers will be removed or prepared to overwinter in late October or early November 2015. The same schedule will be repeated in 2016 (Table 2).

**Table 1. Locations where HDR will install and monitor water temperature and/or stage.**

Logger Location	River Mile	Latitude	Longitude	Temperature	Stage
<b>Tuolumne River</b>					
TR below Early Intake	TR 105.2	37.87582	-119.95970	X	
TR above South Fork	TR 97.0	37.84076	-120.04611	X	
TR above Clavey River	TR 91.1	37.862944	-120.11599	X	
TR above North Fork	TR 81.3	37.896630	-120.25286	X	
<b>Cherry Creek</b>					
Cherry above Holm PH	CC 1.2	37.89395	-119.94917	X	
Cherry above Tuolumne	CC 0.6	37.89253	-119.97121	X	
<b>South Fork Tuolumne River</b>					
South Fork above Tuolumne	SF 0.2	37.83870	-120.04852	X	X
<b>Clavey River</b>					
Clavey at USFS Bridge	CR 16.9	37.98623	-120.0532	X	X
Clavey at USFS Bridge	CR 8.4	37.89948	-120.07149	X	X
Clavey above Tuolumne	CR 0.1	37.864518	-120.11580	X	X
<b>North Fork Tuolumne River</b>					
North Fork at USFS Bridge	NF 8.0	37.985196	-120.20461	X	X
North Fork above Tuolumne	NF 0.1	37.897235	-120.25373	X	X

Access to logger installations will occur along existing U.S. Forest Service (USFS) or other public roads. Field personnel will park safely at a point nearest the desired location and navigate to the river channel. Care will be taken to use any existing trails or traverse areas that will cause little impact to the land. If areas are deemed too difficult to access on foot, they will be visited by white water boating. In the case of boating, HDR will hire a guide with all necessary USFS permits to navigate them to areas of the Tuolumne River. HDR will limit the visits to each location in order to provide the least impact while ensuring the collection of necessary data (Table 2).

**Table 2. Proposed schedule of field visits for 2015 and 2016 include general access.**

Month	Vehicle/Hike Access	WW Boat Access
<b>2015</b>		
March/April (installation)	X	X
May		
June	X	
July		X
August	X	
September		
October/November (removal)	X	X
<b>2016</b>		
March/April (installation)	X	X
May		
June	X	
July		
August	X	
September		
October/November (removal)	X	X

## Installation Equipment

### *Water Temperature*

HDR field personnel will install Onset ProV2 (<http://www.onsetcomp.com>) water temperature recorders in durable housings (Figure 1) at identified tributary and mainstem locations (Table 1). Duplicate loggers will be installed to provide the best chance for a continuous data set. Loggers will be installed during low flow (i.e., non-boating flows) to capture both high and low river flows. All monitoring locations will be documented with photographs and global positioning system (GPS) coordinates. Each recorder will be placed in the active channel and secured by a removable steel cable or chain tethered to a stable root mass, boulder, or man-made structure such that the recorder is secured in the channel during high-flow periods. The recorder will be installed in the channel thalweg, and the housing and cable will be disguised as much as possible while ensuring the ability to retrieve the unit for future downloads. Additional information described in Attachment A (QA/QC Approach) were also collected at each location.



**Figure 1.** Photograph of normal water temperature recorder housing. Approximate size is 4-6 inches with 2-8 feet of associated cabling.

### ***Water Stage (and Temperature)***

HDR field personnel will install Onset U20 Levelloggers (<http://www.onsetcomp.com>) in durable housings at identified tributary and mainstem locations (Table 1) to record stage. These loggers also record water temperature. Duplicate loggers will be installed in order provide the best chance for a continuous data set. Loggers will be installed during low flow (i.e., before or after spring run-off) to capture both high and low river flows. All monitoring locations will be documented with photographs and GPS coordinates. At locations where stage recorders are installed, semi-permanent housings will be affixed to large boulders or bedrock to ensure the levellogger does not move (Figure 2). Additional information described in Attachment A (QA/QC Approach) were also collected at each location. The water surface elevation and depth of the logger will be noted at the time of installation. A flow measurement will also be collected anytime a stage recorder is installed or downloaded using standard U.S. Geological Survey (USGS) methods.



**Figure 2. Example of level logger installation. Bolted (removable) to boulder or bedrock.**

## **Data Collection**

During each visit, HDR will download data into an optic shuttle or directly to a personal computer. Immediately after the data are safely downloaded, back-ups will be recorded on a portable flash drive or other suitable medium. Only after the raw water temperature data are safely backed-up will the optic shuttle be cleared and/or re-started. In addition, during each site visit, HDR will be prepared to replace or fix a recorder installation. Should a recorder need to be replaced because it is missing or has failed, HDR will be able to do so immediately to reduce the potential for additional data loss. Any recorder or optic shuttle that fails to download will be returned to the manufacturer for possible data recovery. During each visit, besides downloading data from the recorder, HDR will also check equipment operation/calibration, battery life, and calibrate the instrument to manufacturer's specifications. After the recorder is removed from the water, it will be cleaned and visually inspected. HDR will maintain a record of all recorder installations and data downloads including any problems that were encountered in the field.

Additionally, at locations where stage recorders are installed, field personnel will note the depth of the housing and the depth of the water at each location prior to download. After redeployment, staff will confirm the logger has been reset to the same depth or if movement is necessary the new depth will be recorded in order to apply an offset to the stage dataset during QA processes.



**UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE  
MONITORING AND MODELING STUDY  
PROGRESS REPORT**

**ATTACHMENT B**

**QA/QC APPROACH**

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# QA/QC APPROACH

## Introduction

The objective of the flow and temperature monitoring component of the Upper Tuolumne River Basin Habitat Assessment is to collect representative mainstem Tuolumne River and major tributary water temperatures for two purposes:

1. Characterize the existing thermal regime in the upper Tuolumne River.
2. Support a flow and temperature modeling effort.

The results of these two activities will be used to inform decision makers and resource managers to assess the suitability of conditions for anadromous fish reintroduction to the upper reaches of the Tuolumne River and its tributaries above Don Pedro Reservoir.

To ensure the collected data is representative of conditions in the river, the data collection methodology, as well as the data itself, is subject to a quality assurance/quality control (QA/QC) review. Variation from standard protocols may be reasonable under certain circumstances, but they may result in biases, therefore deviations from identified protocols are reviewed to ensure data collected under such conditions are representative. The fundamental premise of the QA/QC process is to review data collection procedures and field data to ensure it is representative of field conditions and is appropriate for the objectives of this study.

A field data collection protocol was developed by HDR regarding the site identification, deployment/installation of equipment, field visit frequency (schedule), retrieval of data and equipment, appropriate documentation and other activities (see Attachment D). Outlined below are the quality assurance steps external to the field data collection protocol.

## Quality Assurance Steps

Data quality assurance processes were assessed based on project objectives and include three principle activities:

- Pre-deployment activities
- Field activities
- Post-retrieval activities

### *Pre-Deployment Activities*

Prior to deployment the identified spatial and temporal frequency of data collection was determined, along with desired data accuracy. Spatial considerations and general monitoring site locations were identified to support thermal regime assessment and modeling. For the mainstem, sites were identified at the top and bottom of the reach and intermediate sites were assumed to be no more than approximately 6-10 miles apart. Three target sites per principle tributary were identified – “upper,” “middle,” and “lower” – to capture longitudinal characteristics. The upper and middle sites were not at fixed distances, but varied for each tributary. The lower site was above the confluence with the mainstem Tuolumne River. These general site locations were

modified during field deployment to accommodate access, safety, ensure representative data collection, and other conditions (see Attachment D). The temporal frequency of data collection was 30-minute intervals. This was deemed sufficient to capture diurnal changes in water temperature associated with meteorological conditions as well as the impact of management decisions in reaches where flow operations occurred (e.g., mainstem Tuolumne River and Cherry Creek). Desired data accuracy was  $\pm 0.5^{\circ}\text{C}$  as a maximum deviation from actual conditions. Logger manufacturer specifications were reviewed and included resolution and accuracy, operational temperature range, and deployment lifetime. HOBO Water Temp Pro v2 (Onset Computer Corporation: <http://www.onsetcomp.com>) met or exceeded the desired criteria, including an accuracy of  $\pm 0.2^{\circ}\text{C}$  over the range of temperatures expected in the study area. As part of the pre-deployment QA, each data logger was identified by logger number, checked for proper measurement frequency, correct start time of logging (on the computer), remaining battery life. Manufacturer calibration was assumed for all loggers.

### ***Field Activities***

QA activities associated with field deployment are included in Attachment D. From a data QA perspective, field notes/log sheets that include:

- Field crew;
- Date;
- Time;
- Location description (including latitude and longitude or UTM coordinates) ;
- Deployment method;
- Logger number deployed;
- Logger number retrieved (if appropriate);
- Depth;
- Distance from bank;
- Photograph #;
- Notable changes (or lack of changes) from previous site visits; and
- Other field notes as appropriate (including deviations and from defined protocols and reasons for a deviation).

This information was necessary not only to assure that field observations were collected in a consistent and dependable manner, but also to assist in the post-deployment QA process. For example, the deployment and retrieval times are necessary to ensure that air temperatures are removed from the final stream temperature data set.

### ***Post Deployment Activities***

Data retrieved from field loggers is in the form of a \*.dtf file, and can only be read by proprietary software from the Onset Computer Corporation (HOBOWare). While the logger data can be viewed in HOBOWare, this data cannot be modified in any manner. The \*.dtf data are then

exported to a text or MS Excel file format for review and analysis. Both the \*.dtf file and text file are archived, preserving the proprietary field logger file in case there are future questions regarding data integrity.

The QA process on the raw field data (which at this point in the process are residing in MS Excel) includes an initial graphical assessment to look for spurious data. Subsequently, the field logs are used to remove any data points prior to the deployment period or following retrieval time. At this point there are several other qualitative steps that are used to both assess and interpret the data. These may include:

- Plotting water temperature data and local air temperature on the same graph to ensure the logger is not wholly or partially exposed to the atmosphere;
- Plotting water temperature data at one site with nearby locations within the same system to determine if there are potentially anomalous conditions between locations (e.g., excessive heating, cooling, dampening of the diurnal range);
- Plotting water temperature data and local flow or stage on the same graph to assess potential differences in mean daily temperature or diurnal range with flow changes; and
- Review of field logs and photographs to determine if the thermal response is consistent with noted field conditions.

Once the aforementioned steps are completed the final data is included in a separate MS Excel workbook (or workbooks) with appropriate metadata. Metadata should include, but not necessarily be limited to

- Date of final dataset;
- Name of contact entity and person, with appropriate contact information;
- Purpose of dataset and/or project name;
- Equipment used to collect the data (e.g., HOBO Water Temp Pro v2);
- Location of each logger (latitude/longitude), site name, and description;
- QA documentation or report that can support the meta data; and
- Other pertinent information to the dataset.

### ***Summary***

Through a comprehensive set of QA activities that spans the pre-deployment, field activities, and post-deployment period, the study team aims to produce reliable, representative data. These activities outlined herein can be applied to other monitoring programs (e.g., stage data, meteorological data, etc.).

**UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE  
MONITORING AND MODELING STUDY  
PROGRESS REPORT**

**ATTACHMENT C**

**DATA INVENTORY**

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## DATA INVENTORY

**Table 3. Upper Tuolumne River and tributaries flow data inventory, 2005 - 2009.**

[illegible]

**Table 4. Upper Tuolumne River and tributaries flow data inventory, 2010 - 2015.**

River Mile	Site Name	Agency	Land Owner	Active	Site_Locations
CC00.2	11278400	USGS	USFS*	YES	Cherry Creek below Dion R Holm PH, near Mather CA
CC01.2	11278300	USGS	USFS*	YES	Cherry Creek near Early Intake CA
CC10.9	11277300	USGS	USFS	YES	Cherry Creek below Valley Dam near Hetch Hetchy CA
EC03.1	11278000	USGS	NPS	YES	Eleanor Creek near Hetch Hetchy CA
SFT00.1		TID/MID	USFS*	YES	South Fork Tuolumne River above Tuolumne River confluence
CR00.1		TID/MID	USFS*	YES	Clavey River, upstream of Tuolumne River confluence
CR08.4		TID/MID	USFS	YES	Clavey River at 1N01 Bridge
CR16.9		TID/MID	USFS	YES	Clavey River at 1N04 Bridge
NF00.1		TID/MID	BLM*	YES	NF Tuolumne River upstream of Tuolumne River confluence
NF08.4		TID/MID	USFS	YES	NF Tuolumne River near 1N01 Bridge
TR78.5	11285500	USGS	BLM	YES	Tuolumne River at Wards Ferry Bridge nearr Groveland CA
TR104.4	11276900	USGS	USFS*	YES	Tuolumne River below Early Intake near Mather CA
TR105.9	11276600	USGS	USFS	YES	Tuolumne River above Early Intake near Mather CA
TR116.5	11276500	USGS	NPS	YES	Tuolumne River near Hetch Hetchy CA
TR125.5	11274790	USGS	NPS	YES	Tuolumne River at Grand Canyon of Tuolumne above Hetch Hetchy
*managed under Wild and Scenic River designation					



Table 5. Upper Tuolumne River and tributaries stage data inventory, 2005 - 2009.

						<div><div></div> daily median<div></div> 1 hour data<div></div> 30 minute data<div></div> 15 minute data</div> <div>Solid box indicates data is available for entire month. Otherwise, number in box indicates number of days in month for which data is available.</div>																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
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Table 6. Upper Tuolumne River and tributaries stage data inventory, 2010 - 2015.

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**Table 7.**[illegible]

**Table 8. Water temperature data inventory, Upper Tuolumne River and tributaries, 2010 - 2015.**

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**UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE  
MONITORING AND MODELING STUDY  
PROGRESS REPORT**

**ATTACHMENT D**

**MAPS OF STUDY AREA INCLUDING LOCATIONS OF DATA  
COLLECTION SITES**

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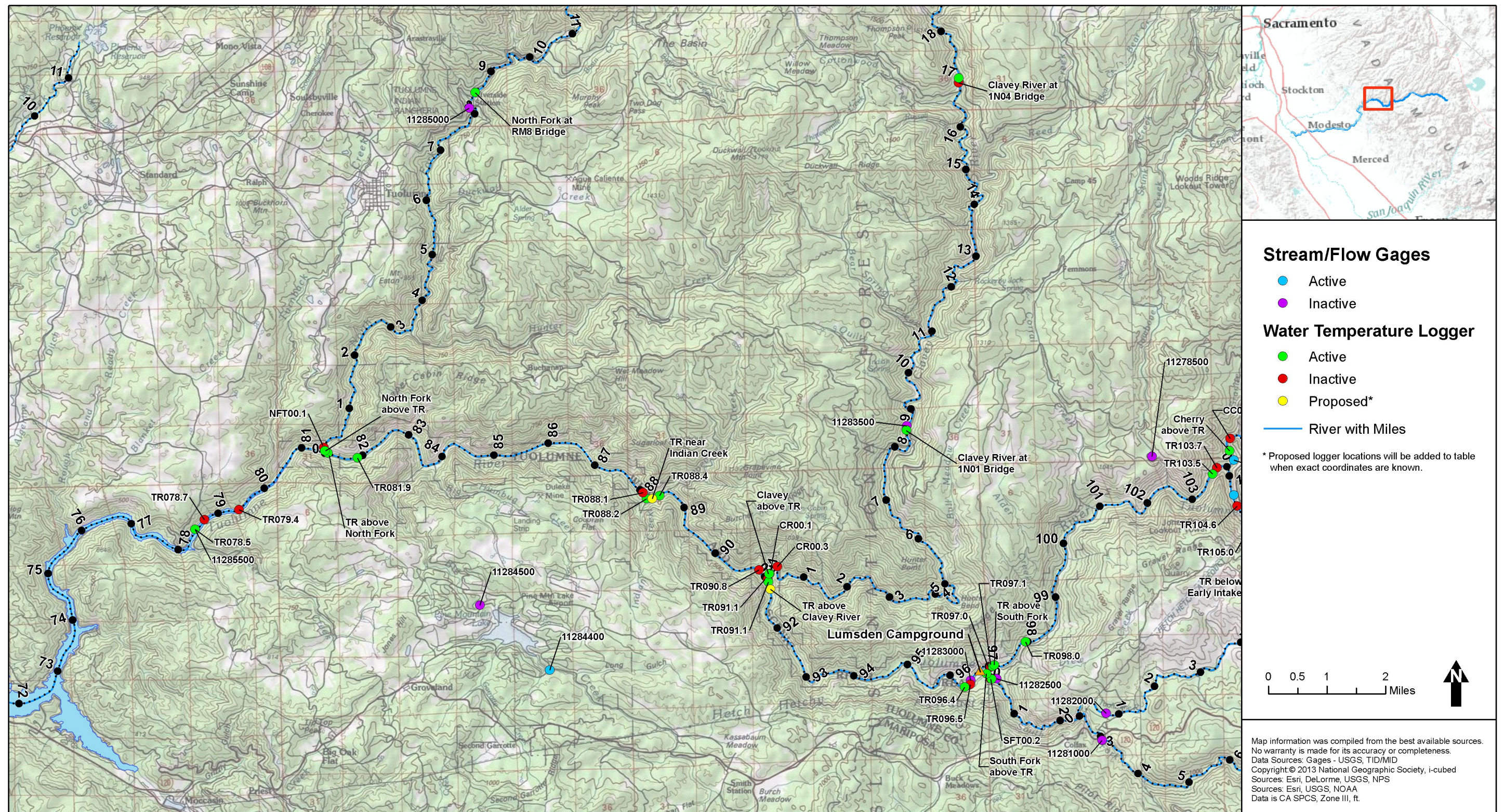


Figure 1 Study area including locations of data collection sites, 1 of 2.



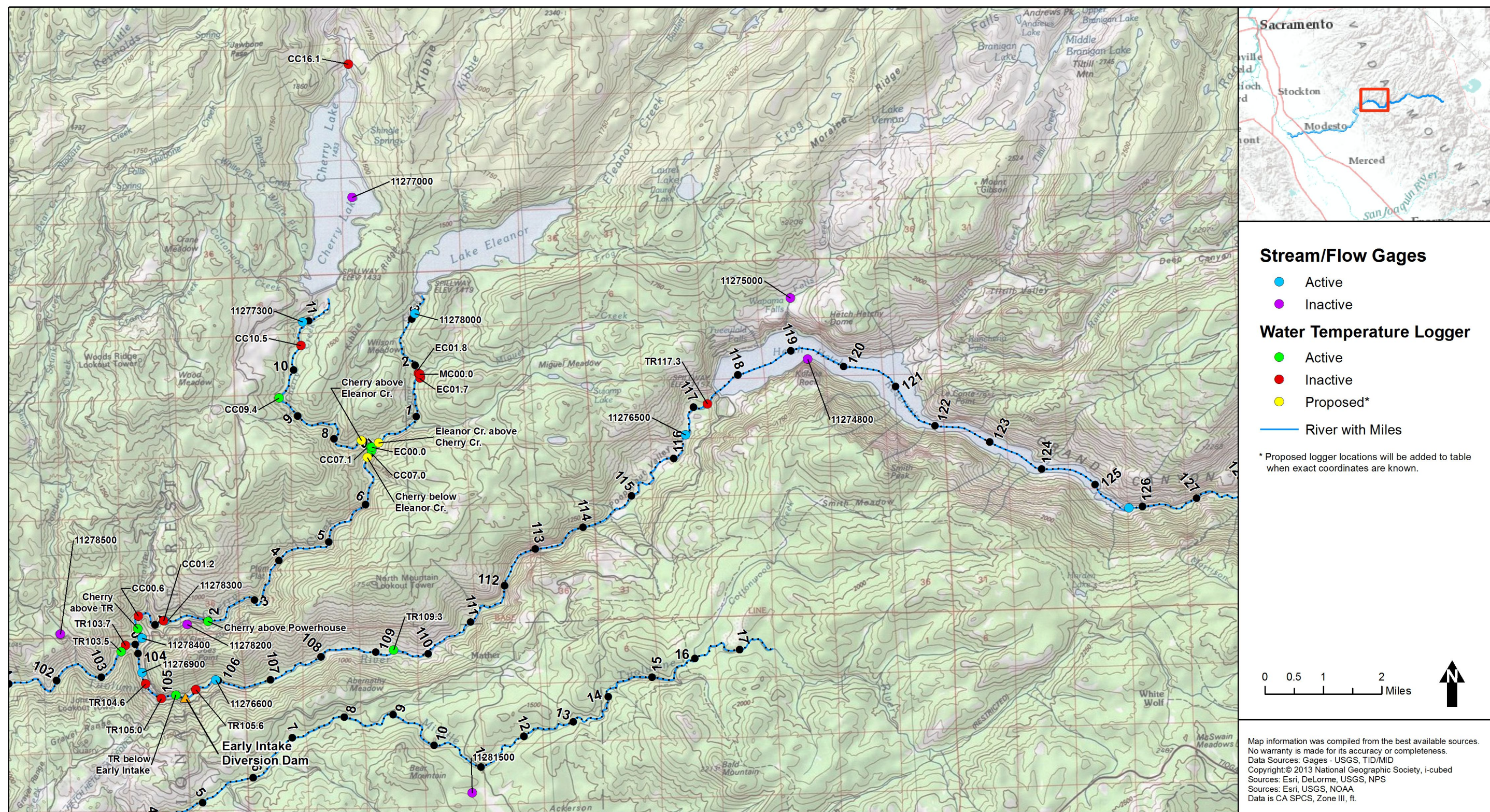


Figure 2 Study area including locations of data collection sites, 2 of 2.



**UPPER TUOLUMNE RIVER BASIN WATER TEMPERATURE  
MONITORING AND MODELING STUDY  
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**ATTACHMENT E**

**WORKSHOP MEETING NOTES AND MATERIALS**

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**La Grange Hydroelectric Project Licensing (FERC No. 14581)**  
**Flow and Temperature Monitoring/Modeling Workshop**  
**HDR Office**  
**2379 Gateway Oaks Drive, Suite 200, Sacramento, CA**

**Tuesday, May 19, 2015**  
**1:30 pm to 4:30 pm**

**Meeting Notes**

On May 19, 2015, Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) hosted a workshop about the flow and temperature monitoring and modeling component of the La Grange Hydroelectric Project Fish Passage Assessment. This document summarizes discussion during the meeting. It is not intended to be a transcript of the meeting. Attachment A to this document includes the following meeting documents: agenda, sign-in sheet, presentations, and handouts.

Mr. John Devine of HDR, Inc. (HDR), consultant to the Districts, welcomed participants to the meeting. Attendees went around the room and introduced themselves. Attendees on the phone introduced themselves: Mr. John Shelton and Ms. Gretchen Murphy of the California Department of Fish and Wildlife (CDFW) and Messrs. Tom Holly and John Wooster of the National Marine Fisheries Service (NMFS) participated in the meeting remotely.

Mr. Devine reviewed the meeting agenda and presented introductory slides. Mr. Devine described the La Grange Project and gave an overview of the La Grange Project Integrated Licensing Process (ILP). The flow and temperature monitoring and modeling is one part of a larger study of fish passage and reintroducing fish to the Upper Tuolumne River above Don Pedro Reservoir. Mr. Devine reviewed the objectives of the flow and temperature monitoring and modeling as well as the study area and schedule for reporting.

Mr. Chris Shutes (California Sportfishing Protecting Alliance) asked if there would be consultation for other components of the study request, in addition to the workshops for the flow and temperature modeling component and the fish passage feasibility component. Mr. Devine replied that for the upstream barrier study component, the Districts would be developing a criteria document, and would send the document out to licensing participants for review. The Districts will keep licensing participants apprised of the schedule and licensing participants are welcome to attend the fieldwork. Mr. Devine noted that this is a two-year study, and fieldwork will be completed this August and next spring/summer. The schedule for fieldwork in 2016 will be dependent on runoff; however, fieldwork will likely be scheduled to begin during high flows in May/June.

Mr. Shutes asked about the upper habitat characterization component of the study. Mr. Devine noted that similar to the temperature monitoring and modeling, the Districts would be voluntarily conducting a barriers assessment and summarized the study component. Mr. Devine also stated that NMFS was conducting LIDAR/hyperspectral remote sensing work to support additional upper habitat characterization objectives. Mr. Devine asked that NMFS provide the time frame

for completion of this work and its availability to interested parties as the Districts would like to wait and see what the results of that work are and then come together as a group with licensing participants to discuss the data gaps. Mr. Devine noted that it would be helpful if NMFS could provide an updated schedule for completing the LIDAR/hyperspectral work and when it would be available.

Mr. Devine finished his slide presentation and noted that the meeting handouts would be made available on the La Grange Hydroelectric Project licensing website after the meeting. He then introduced Mr. Mike Deas (Watercourse Engineering) as the modeling and monitoring lead for this effort. Mr. Deas began his presentation. Mr. Deas provided additional details about the objectives of the modeling and monitoring, scope of the work, and the study area. Referring to the map of the study area, Mr. Shutes asked if RM 81 was the extent of Don Pedro Reservoir at full pool. Mr. Devine replied that RM 81 is roughly the Don Pedro Project Boundary at elevation 845 ft.

Mr. Deas resumed his presentation. Mr. Deas provided details about the availability and sources of existing flow and temperature data. He described the rationale for choosing the locations and periods to be monitored for flow and temperature and the equipment that would be used for the study. Mr. Peter Drekmeier (Tuolumne River Trust) asked if a temperature gage was installed on the North Fork Tuolumne River, as he had seen similar equipment on a recent float trip. Mr. Devine replied that it may have been a gage as both the Districts and NMFS have monitoring equipment deployed in that area.

Mr. Deas resumed his presentation. Referring to the slide summarizing the locations of currently installed loggers, Mr. Bao Le (HDR) noted that stage loggers collect both stage data and temperature data.

Mr. Drekmeier asked why data was being collected at Cherry and Eleanor, upstream of Holm Powerhouse, as Mr. Drekmeier believed Holm to be a barrier to fish passage. Mr. Deas replied that there may be suitable habitat upstream of Holm. Mr. Devine added that because the Districts had not yet completed the barrier work, Holm was not yet confirmed to be a barrier to fish passage.

Referring to the table summarizing the available water temperature data, Mr. Bill Sears (City and County of San Francisco) noted that U.S. Geological Survey (USGS) temperature gage data was not included in the table. Mr. Sears asked if the Districts were only using data that came from standardized equipment, and were thus excluding the USGS data. Mr. Deas replied that the Districts would be using USGS temp gage data, but because the team had not yet processed the USGS temp data, it had not been included in the table.

Mr. Mark Gard (U.S. Fish and Wildlife Service) asked if the Districts would be collecting seasonal flow data in the South Fork Tuolumne River, or alternatively use mass balance to calculate the flow. Mr. Deas replied that the Districts would be collecting stage data on the South Fork.

Mike Deas resumed the presentation. Mr. Deas noted that the Districts would like access to the NMFS LIDAR data as soon as possible and asked what the schedule was for data availability. Mr. John Wooster (NMFS) replied that he had not been in touch recently with the research team completing the work, but he would look into it.

Mike Deas concluded the slide presentation. Mr. Deas said anyone wanting more information about the study was welcome to contact the Districts or HDR.

Mr. Devine asked Mr. Wooster to give an update on the status of the NMFS logger deployments. Mr. Wooster replied that during the prior week, NMFS had installed a logger on the Clavey around RM 16. Referring to the three downstream Tuolumne River locations where the Districts had installed loggers, Mr. Wooster noted that last July NMFS had deployed loggers in nearly identical locations, except that the NMFS logger above the North Fork is a bit further upstream than the Districts' logger. Mr. Wooster said that the NMFS logger near the South Fork is downstream of the confluence and close to Merals Pool. Given that loggers are installed both upstream and downstream of the South Fork, there may be an opportunity to evaluate mixing in the area. Mr. Wooster said NMFS had South Fork and Clavey loggers at almost identical river miles to the locations of the Districts' loggers. Mr. Wooster noted that data from the NMFS loggers may be helpful for extending the Districts' data set.

Mr. Devine asked if there was any data available from the loggers that NMFS had installed in July. Mr. Wooster replied that so far there had been only one data download, and that download was from the loggers on the Tuolumne River below South Fork. He said NMFS would be back in the field the first week of June to revisit some of the other loggers. Mr. Devine asked if NMFS has another download visit scheduled for later in the summer. Mr. Wooster replied that NMFS has summer fieldwork scheduled throughout the watershed for the genetics sampling, and will be downloading data opportunistically as NMFS staff are in the vicinity for other fieldwork. After the summer fieldwork is complete, NMFS will try to revisit all the loggers in the fall to complete another download.

Mr. Deas asked if NMFS planned to leave the loggers deployed over the winter. Mr. Wooster said yes, the loggers would be left out over the winter.

Mr. Bob Hughes (CDFW) asked if the Districts had a written study plan. Mr. Devine replied that the study plan is available in the La Grange Revised Study Plan document filed with licensing participants and FERC. Mr. Hughes asked if the study plan includes collaboration with interested parties, such as collaboration during model development and to review the data once it is available. Mr. Devine replied that the study plan does include future collaboration. Although there are no other workshops planned at this date, the Districts would certainly consider hosting an additional meeting(s) if licensing participants were interested. Mr. Hughes said that as long as everyone is kept up to speed on the progress, a formal workshop would not necessarily be needed. Mr. Shutes added that the Don Pedro Project hydrology workshop had been helpful. He noted that prior to the workshop, there had been considerable concern about the model. However, after the workshop, people had been satisfied that the study was in good shape.

Mr. Devine said that the availability of the Districts' logger data would depend on when the data could be downloaded and the schedule for QA/QC. Preliminary results are expected this fall.

Mr. Hughes said he thought the presentation was very thorough and that all the bases had been covered.

Mr. Wooster noted that the Districts planned to model the months June through October, but thought he heard the potential to model all months. Mr. Wooster asked how and when a decision would be made about the months to be modeled. Mr. Deas replied that the Districts had identified June through October as the critical period, and as the study proceeds and identifies additional information, the time period may be adjusted. Mr. Deas clarified that the reference to modeling all months was simply to illustrate that data would be collected year-round and thus all months could be modeled. Mr. Devine added that the months included in the model would be driven by life history of the species of interest (the timing of spawning, egg incubation, fry rearing, etc.). The end of the critical period is October because that is when temperatures start to get cold. However, the time period used in the model is up for discussion.

Mr. Wooster replied that to cover steelhead migration, NMFS would be interested in including some of the spring months prior to June. Mr. Wooster asked for clarification on the significance of the June to October period for the model. Would the model be built to cover all 12 months, but only be calibrated using the months of June through October? Mr. Deas replied that the months covered in the model will be dependent on the availability of data. The Districts will have year-round data for much of the system. However, the Districts anticipate that loggers will not be able to be maintained in some places over the winter, so there will be data gaps for some places. Mr. Deas said it was important to have confidence in the period of focus. Mr. Devine added that life history of target species would inform the modeling time period, and that discussions on that topic would start the next day (May 20) at the first La Grange Fish Passage Facilities Assessment Workshop.

Mr. Hughes requested that materials for the May 20 Fish Passage Facilities Assessment Workshop be posted online prior to the start of the workshop. Mr. Devine said that the Districts would do that. Mr. Wooster requested that a set of handouts from today's workshop be brought to the May 20 workshop for NMFS, as no NMFS representatives were able to attend today's meeting in-person. Mr. Devine said that a set of handouts would be brought for NMFS.

The meeting adjourned at 3:00 pm.

## **ACTION ITEMS**

1. The Districts will post the meeting handouts to the La Grange Hydroelectric Project Licensing Website.
2. NMFS will provide a schedule for the LIDAR/hyperspectral study report and availability of the data.

3. Regarding meeting materials for the May 20 La Grange Fish Passage Facilities Assessment Workshop, the Districts will post the meeting materials to the licensing website prior to the start of the workshop.
4. The Districts will bring a set of handouts from this meeting to the May 20 Workshop and give the handouts to NMFS.



# **ATTACHMENT A**

**La Grange Hydroelectric Project**  
**Flow and Temperature Monitoring/Modeling Workshop**  
**Tuesday, May 19, 1:30 pm – 4:30 pm**  
**HDR Office, 2379 Gateway Oaks Drive, Suite 200, Sacramento, CA**  
**Conference Line: 1-866-994-6437, Passcode: 8140607**  
**Join Lync Meeting <https://meet.hdrinc.com/jesse.deason/8DZ4NVN>**

**Meeting Objectives:**

1. Present an overview of the La Grange Hydroelectric Project Temperature Study.
2. Review and confirm proposed temperature and flow monitoring locations.
3. Review and confirm modeling approach.
4. Confirm schedule/tasks and opportunities for collaboration.

TIME	TOPIC
1:30 pm – 1:40 pm	Introduction of Participants (All)
1:40 pm – 2:00 pm	Background/Overview of the La Grange Project Temperature Study (Districts)
2:00 pm – 4:00 pm	<p>Temperature Study Introduction (Districts)</p> <ol style="list-style-type: none"> <li>a. Study goal and objectives, scope, and study area</li> </ol> <p>Review and Discussion of Existing Information</p> <ol style="list-style-type: none"> <li>a. Parameters and sources</li> <li>b. Review process summary</li> <li>c. Results, findings and recommendations</li> </ol> <p>Proposed Monitoring Program – Presentation and Discussion</p> <ol style="list-style-type: none"> <li>a. Rationale <ol style="list-style-type: none"> <li>i. Space (locations)</li> <li>ii. Time (periods of interest)</li> <li>iii. Equipment</li> </ol> </li> </ol> <p>Temperature Modeling – Presentation and Discussion</p> <ol style="list-style-type: none"> <li>a. Approach (including spatial and temporal resolution)</li> <li>b. Data needs</li> <li>c. Model information/output</li> </ol> <p>Schedule and Reporting</p>
4:00 pm – 4:30 pm	<p>Meeting Wrap-up (All)</p> <ol style="list-style-type: none"> <li>a. Confirm study approach and methods</li> <li>b. Agreements, action items and next steps</li> </ol>

**La Grange Hydroelectric Project  
Flow and Temperature Monitoring/Modeling Workshop  
Tuesday, May 19, 1:30 pm to 4:30 pm**

**Sign-In Sheet**

No.	Name	Entity	Email Address
1	Bao Le	HDR	
2	Jesse Deason	HDR	
3	Bill Paris	MID	
4	Art Godwin	TID	
5	Mike Deas	Watercourse Engineering	
6	John Devine	HDR	
7	Steve Boyd	TID	
8	Ron Yoshiyama	San Francisco	
9	Peter Barnes	SWRCB	
10	Chris Shutes	CSPA	
11	Mark Gard	USFWS	
12	Bob Neglos	CDFW	
13	Bill Sears	SFPUC	
14	Peter Drehmire	TRT	

By Phone: John Shelton (CDFW)  
Gretchen Murphy (CDFW)  
John Wooster (NMFS)  
Tom Holley (NMFS)



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# **La Grange Hydroelectric Project FERC No. 14581**

## **Fish Passage Assessment - Temperature Monitoring/Modeling Scope**



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## La Grange Project History



La Grange Diversion Dam

- La Grange Diversion Dam was constructed from 1891 to 1893
- The dam is owned jointly by Turlock Irrigation District and Modesto Irrigation District
- Purpose is to divert irrigation and municipal and industrial (M&I) water
- La Grange powerhouse was constructed in 1924. The powerhouse is owned by TID



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## Overview of La Grange Project ILP

ILP Milestone	Schedule
Pre-Application Document (PAD)	January 2014
Scoping and study plan development	January 2015
FERC Study Plan Determination	February 2015
NMFS Request for Rehearing	April 2015
Study plan dispute resolution	May 2015
Study plan implementation	2015/2016
Initial Study Report	February 2016
Updated Study Report	February 2017
Final license application	June 2016





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# Revised Study Plan

## Study Components

**Fish Passage Facilities  
Assessment**

**Concept-Level Fish Passage  
Alternatives**

**La Grange Project Fish  
Barrier Assessment**

**Upper Tuolumne River  
Basin Habitat  
Assessment**

**Barriers to Upstream  
Anadromous Salmonid  
Migration**

**Water Temperature  
Monitoring and Modeling**

**Upstream Habitat  
Characterization**

**Habitat Assessment and  
Fish Stranding  
Observations below  
LGDD and Powerhouse**

**Develop Hydrologic Data for  
Flow Conduits at the La  
Grange Project**

**Collect Topographic, Depth,  
and Habitat Data in the  
Vicinity of the La Grange  
Project Facilities**

**Assess Fish Presence and  
Potential for Stranding**



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## **Water Temperature Monitoring and Modeling**

1. Originally a study request from NMFS. FERC determines Districts are not required to do the study. Study being conducted voluntarily by the Districts.
2. Study tasks include evaluating existing information, collecting additional information and developing a temperature model to simulate existing thermal conditions in the Upper Tuolumne River between Early Intake and Don Pedro Reservoir.
3. Primary objective is identifying where temperatures appear to be suitable for the various life stages of salmonids.





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## **Today's Temperature Workshop**

1. Districts' proposed a collaborative Workshop with LPs.
2. Core Study Team:
  - a) HDR – select and acquire monitoring equipment, deployment, maintenance, and download.
  - b) Watercourse Engineering, Inc. – water temperature modeling Lead Engineer.
3. Objectives include:
  - a) Review existing information and discuss additional information needs for temperature and river stage monitoring to support modeling.
  - b) Discuss and confirm modeling approach.
  - c) Discuss and confirm schedule/tasks and future collaboration.



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# **La Grange Hydroelectric Project FERC No. 14581**

## **Upper Tuolumne River Flow and Water Temperature Assessment**

**May 19, 2015**



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## Topics

- Temperature Study Overview:
  - Study Goal/Objectives, scope, and study area
- Review and Discussion of Existing Information
- Monitoring Program – Presentation and Discussion
- Temperature Modeling
- Meeting Wrap-up



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## Study Objectives

- Complete a water temperature investigation to characterize thermal conditions in Upper Tuolumne River basin below Early Intake.
- Monitoring Data
  - Existing Data
  - Additional Monitoring
- Develop a flow and temperature model
  - Mainstem Tuolumne River from Early Intake to Don Pedro Reservoir and major tributaries



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## Monitoring Objectives

- Identify existing data and monitoring locations
- Share current and proposed District monitoring sites
- Ensure locations, methods, need for additional monitoring are consistent/acceptable among parties
- Identify operations or conditions that may be anomalous during the proposed monitoring season (e.g., extreme drought, operational changes, etc.)



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## Temperature Modeling Objectives

- Develop a tool to assist in assessing a range of
  - Hydrology
  - Temperature
  - Meteorology
  - Thermal regimes and suitability for salmonid life stages on a reach scale basis.
- Model will produce data for suitability criteria at sub-daily time steps, allowing the development of a range of metrics (e.g., daily mean or maximum, 7-day average of the mean or maximum, etc.)





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## Study Scope

- Task 1: Identify, Synthesize, and Interpret Existing Water Temperature and Flow Data
- Task 2: Additional Monitoring -- Data Logger Deployment
- Task 3: Water Temperature Modeling and Reporting











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## Task 1: Existing Data Analysis

- Data sources
  - Flow
  - Water temperature
  - Meteorology
- Review
  - Location, frequency, period assessment
- Findings
  - Identify data gaps
  - Characterize hydrology and thermal conditions
  - Define potential modeling periods
  - Recommendations for additional monitoring



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## Flow – Data Sources

- USGS
  - 11276600 TUOLUMNE R AB EARLY INTAKE NR MATHER CA
  - 11276900 TUOLUMNE R BL EARLY INTAKE NR MATHER CA
  - 11285500 TUOLUMNE R A WARDS FERRY BR NR GROVELAND CA
  - 11277300 CHERRY C BL VALLEY DAM NR HETCH HETCHY CA
  - 11278300 CHERRY C NR EARLY INTAKE CA
  - 11278400 CHERRY C BL DION R HOLM PH, NR MATHER CA
  - 11278000 ELEANOR C NR HETCH HETCHY CA
- CCSF
  - Clavey River (historic data - CDEC)
  - Minimum flow schedule
    - Cherry Creek
    - Eleanor Creek
    - Tuolumne River at Early Intake
- HDR proration methodology (ungaged tributaries)



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## Flow - Summary

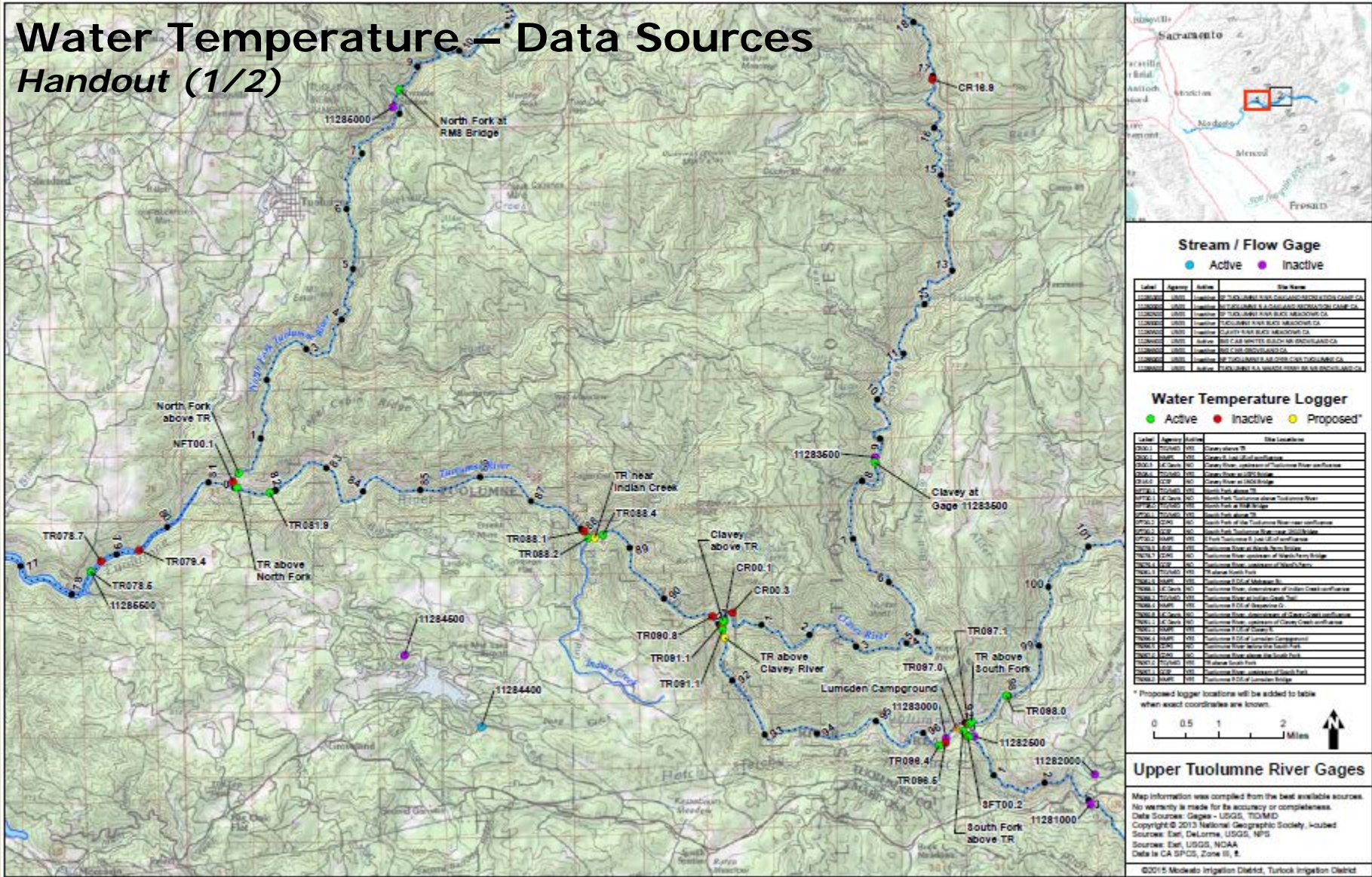
- Mainstem Tuolumne River
  - Early Intake – managed operation (and spill)
  - Cherry Creek to Don Pedro Reservoir – hydropower peaking with seasonal tributary contributions (e.g., spring snowmelt)
- Cherry/Eleanor Creeks
  - Above Dion R Holm PH – managed operation (and spill)
  - Below Dion R Holm PH – hydropower peaking
- SF Tuolumne, Clavey, and NF Tuolumne Rivers
  - Unregulated hydrograph
- Monitoring Recommendations
  - Additional seasonal flow data on Clavey and NF Tuolumne R.
  - Stage data on mainstem (travel time)





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## Water Temperature – Data Sources Handout (1/2)









# Water Temperature Data - Availability

Map Label	Agency	Active	Site Locations	2007												2008												2009												2010												2011												2012												2013												2014											
				J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D												
<b>Tuolumne River - Mainstem</b>																																																																																																			
TR078.5	USGS	YES	Tuolumne River at Wards Ferry Bridge	*																																																																																															
TR078.7	CDFG	NO	Tuolumne River upstream of Wards Ferry Bridge																																																																																																
TR078.4	CCSF	NO	Tuolumne River, upstream of Ward's Ferry																																																																																																
TR081.9	NMFS	YES	Tuolumne R DS of Mohican Br.	6 5 1 25 20 22 18 7 15 24 24 16 15 11 10 14 16 2																																																																																															
TR083.0	TRD/MID	YES	Tuolumne River at Indian Creek Trail																																																																																																
TR088.1	UC Davis	NO	Tuolumne River, downstream of Indian Creek confluence	26																																																																																															
TR088.4	NMFS	YES	Tuolumne R DS of Grapevine Cr.	*																																																																																															
TR090.8	UC Davis	NO	Tuolumne River, downstream of Clavey Creek confluence	*																																																																																															
TR091.1	NMFS	YES	Tuolumne R US of Clavey R.	*																																																																																															
TR091.1	UC Davis	NO	Tuolumne River, upstream of Clavey Creek confluence	6 28 7																																																																																															
TR096.4	NMFS	YES	Tuolumne R DS of Lumsden Campground																																																																																																
TR096.5	CDFG	NO	Tuolumne River below the South Fork	30 21 22 21 29 22 6 6 12																																																																																															
TR097.0	CDFG	NO	Tuolumne River above the South Fork	12																																																																																															
TR097.1	CCSF	NO	Tuolumne River, upstream of South Fork	6																																																																																															
TR098.0	NMFS	YES	Tuolumne R DS of Lumsden Bridge	5																																																																																															
TR103.5	CCSF	NO	Tuolumne River, ds of Cherry Ck confluence (TR4)	8 14 21 4 5 20																																																																																															
TR103.7	CCSF	NO	Tuolumne River, ds of Cherry Ck confluence (TR3)	8 13																																																																																															
TR104.6	CCSF	NO	Tuolumne River, ds of Early Intake Diversion Dam	8 13																																																																																															
TR105.0	CDFG	NO	Tuolumne River at Early Intake	29 23 23																																																																																															
TR105.6	CCSF	NO	Tailrace of Kirkwood Powerhouse	23																																																																																															
TR109.3	CCSF	NO	Tuolumne River, downstream of Preston Falls	5																																																																																															
TR117.3	CCSF	NO	Tuolumne River, downstream of O'Shaughnessy	14																																																																																															
<b>NF Tuolumne River</b>																																																																																																			
NFT00.1	UC Davis	NO	North Fork Tuolumne above Tuolumne River	*																																																																																															
<b>Clavey River</b>																																																																																																			
CR00.1	NMFS	YES	Clavey R. just US of confluence	*																																																																																															
CR00.3	UC Davis	NO	Clavey River, upstream of Tuolumne River confluence																																																																																																
CR14.9	CCSF	NO	Clavey River at 110th Bridge	8 6 28 20																																																																																															
<b>SF Tuolumne River</b>																																																																																																			
SFT00.2	CDFG	NO	South Fork of the Tuolumne River near confluence	7 18 16 27 19 27 22 25 16 17 29 26 1 12																																																																																															
SFT00.2	CCSF	NO	South Fork Tuolumne River near JN10 Bridge	6 4																																																																																															
SFT00.2	NMFS	YES	S Fork Tuolumne R. just US of confluence	*																																																																																															
<b>Cherry Creek</b>																																																																																																			
CC00.6	CDFG	NO	Cherry Creek Power House	16 20 22 3 18 23 7 9 27 15 25 19 26 23																																																																																															
CC01.2	CCSF	NO	Cherry Creek, upstream of Dion Holm Powerhouse	8 30 30 25 27 2 29 29 30 12 14																																																																																															
CC07.0	CCSF	NO	Cherry Creek, ds of confluence with Eleanor Creek	2 2 29 14																																																																																															
CC07.1	CCSF	NO	Cherry Creek, upstream of Eleanor Creek confluence	7 2 29 14																																																																																															
CC09.4	CCSF	NO	Cherry Creek, downstream of Cherry Dam	7 5 5																																																																																															
CC10.5	CCSF	NO	Cherry Creek, downstream of Cherry Dam	7 29																																																																																															
CC16.1	CCSF	NO	Upstream of Cherry Lake	7 25 30 4																																																																																															
<b>Eleanor Creek</b>																																																																																																			
EC00.0	CCSF	NO	Eleanor Creek, upstream of Cherry Creek confluence	7 3 30 21 1 25 5																																																																																															
EC01.7	CCSF	NO	Eleanor Creek, downstream of Miguel Creek confluence	7 27 10 29 5																																																																																															
EC01.7	CCSF	NO	Eleanor Creek, downstream of Miguel Creek confluence	7 27 10 29 5																																																																																															
EC01.7	CCSF	NO	Eleanor Creek, downstream of Miguel Creek confluence	7 27 10 29 5																																																																																															
EC01.8	CCSF	NO	Eleanor Creek, upstream of Miguel Creek confluence	7 27 10 29 5																																																																																															
MC00.0	CCSF	NO	Miguel Creek, upstream of Eleanor Creek confluence	7 1 2 25 5																																																																																															





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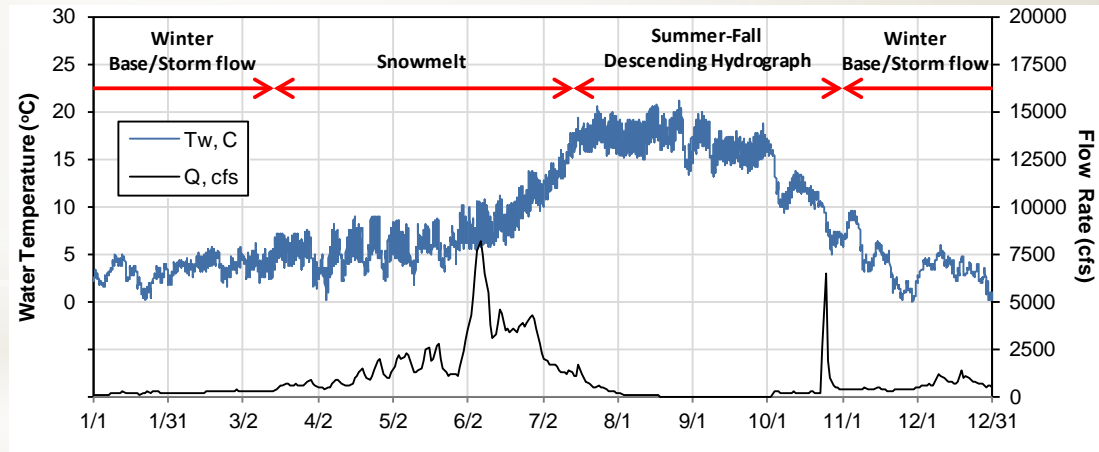
## Water Temperature - Summary

- Potential modeling periods

- June – October (critical)
- Year-round potential

- Analysis – in progress

- Key seasonal elements
- Flow-temperature nexus
- Critical periods



- Monitoring Recommendations

- Comprehensive data set at basin scale (including tributaries)
- Tributaries: two or three locations (initially two)
- Flow and temperature at key tributary locations



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## Meteorology

- Several stations available in project area (CDEC):
  - CVM: CHERRY VALLEY MET STATION
  - SEW: SMITH PEAK RAWS
  - DDL: DUDLEYS (MCDIARMID FIRE STATION)
  - GIN: GIN FLAT
  - BKM: BUCK MEADOWS
  - JFR: JAWBONE LAVA FLAT RAWS
- Rim Fire destroyed long-term Buck Meadows site
- Stations of various duration, for various periods, and measured parameters
- Adopting HDR method consistent with long term data set completed under previous modeling work





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## Meteorology

- HDR long-term data set determination (Don Pedro Reservoir)
- Adjusted vapor pressure terms a function of elevation and assumed lapse rate (6°C per 3,128 ft of elevation change)

Parameter	Unit	Source
Cloud Cover <sup>1</sup>	n/a	Calculated
Air Temperature <sup>2</sup>	deg C	Adjusted Stockton
Wet-Bulb Temperature <sup>3</sup>	deg C	Calculated
Barometric Pressure	mmHg	Adjusted Stockton
Wind Speed	m/s	Adjusted Stockton
Solar Radiation	w/m <sup>2</sup>	Sacramento 1973-1990 and Modesto City AP 1991-2010 (both NREL Solar radiation data), 2010 to present – Oakdale CIMIS

<sup>1</sup> Cloud cover was estimated based on solar radiation.

<sup>2</sup> Air temperature was only available from the Stockton meteorological station. Air temperature to be adjusted to representative elevation using a lapse rate.

<sup>3</sup> Wet-bulb temperatures are calculated based on adjusted air temperature and relative humidity from Stockton.



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## Task 2: Monitoring

- Rationale
  - Space (locations)
  - Time (periods of interest)
- Summary of deployment
  - USFS special use permit
  - Access – whitewater boating and helicopter
  - Installation schedule



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## Rationale

- System characterization – General
  - Thermal regime, flow conditions
  - Support modeling
- System characterization – Spatial/temporal
  - Spatial
    - Mainstem
    - Tributary
  - Temporal
    - Period of interest: late winter – late fall
    - Frequency: sub-daily (e.g., hourly)



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## Proposed Monitoring Locations

	Logger Location	River Mile
Mainstem	TR above North Fork	TR 81.3
	TR near Indian Creek	TR 88.2
	TR above Clavey River	TR 91.1
	TR above South Fork	TR 97.0
	TR below Early Intake	TR 105.2
Tributaries	North Fork TR above TR	NF 0.1
	North Fork TR at RM8 Bridge	NF 8.0
	Clavey R. above TR	CR 0.1
	Clavey R. at Gage 11283500	CR 8.4
	South Fork TR above TR	SF 0.1
	Cherry Ck. above TR	CC 0.6
	Cherry Ck. above Powerhouse	CC 1.2
	Cherry Ck. below Eleanor Ck.	CC 7.1
	Cherry Ck. above Eleanor Ck.	CC 7.2
	Eleanor Ck. Above Cherry Ck.	EC 0.1

- 15 proposed locations
- Mainstem locations to record water temperature at 30-minute intervals
- Tributary locations to record water temperature and stage at 30-minute intervals



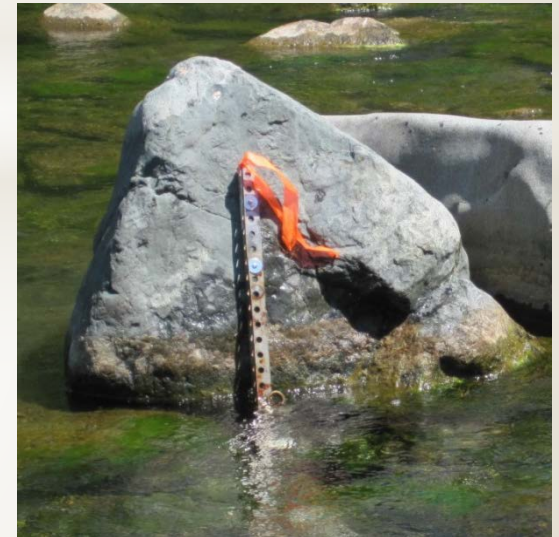
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## Monitoring Equipment



- Hobo Pro V2 or TidBit loggers ( $\pm 0.2$  °C) deployed at identified locations in a protective housing.
- Recorders are placed in the active channel and secured by a removable steel cable or chain tethered to a stable root mass, boulder, or man-made structure.

- Onset U20 level loggers installed to measure stage and temperature.
- Semi-permanent housings affixed to large boulders or bedrock to ensure the level logger does not move.
- A flow measurement will also be collected any location a stage recorder is installed or downloaded to develop a stage-discharge curve and continuous record.







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## Site Access and Monitoring

Month	Vehicle/Hike Access	Helicopter/Boat Access
<b>2015</b>		
<b>April/May (Installation)</b>	X	X
<b>June</b>	X	--
<b>July</b>	--	--
<b>August</b>	X	X
<b>September</b>	--	--
<b>October/November (removal or winter prep)</b>	X	X
<b>2016</b>		
<b>March/April (re-installation or first visit – flow dependent)</b>	X	X
<b>May</b>	--	--
<b>June</b>	X	--
<b>July</b>	--	--
<b>August</b>	X	--
<b>September</b>	--	--
<b>October/November (removal)</b>	X	X

X = visit, -- = no visit

- 4 monitoring locations accessed by boat or helicopter
- 3 monitoring locations accessed by foot or helicopter (check Rim Fire conditions)
- 8 monitoring locations accessed by foot

\*USFS SF-299 permit was approved on 4/22/15 for installations on Stanislaus Forest lands.





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## Current Site Installations (as of 5/4/15)

Location	River Mile	Equipment	Coordinates	Notes
TR above North Fork	TR 81.3	1 water temp, 1 stage	37.896630 -120.252864	
TR above South Fork	TR 97.0	1 water temp, 1 stage, 2 barometric	37.84076 -120.04611	
TR below Early Intake	TR 105.2	2 water temp	37.87582 -119.9597	Flow from USGS
North Fork above TR	NF 0.1	2 stage	37.897235 -120.253729	
North Fork at RM8 Bridge	NF 8.0	2 stage	37.985196 -120.204608	
South Fork above TR	SF 0.1	2 stage	37.83870 -120.04852	
Cherry Creek above TR	CC 0.6	2 water temp	37.89253 -119.97121	Flow from USGS
Cherry Creek above HPH	CC 1.2	2 water temp	37.89395 -119.94917	Flow from USGS
Clavey River above TR	CR 0.1	1 stage	37.864518 -120.115802	Runoff too high to complete full install
Clavey River at USFS Bridge	CR 8.4	1 water temp	37.899398 -120.071984	Runoff too high to complete full install



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## **Additional Work to be Completed**

- Revisit Tuolumne River near Indian Creek (via Indian Creek trail) to redeploy water temperature loggers.
- Revisit two Clavey River locations to complete stage recorder installations and measure flow. Install stage recorder in Tuolumne River upstream of Clavey.
- Install stage recorder equipment at either the Cherry and Eleanor creeks confluence or at location of identified fish passage barrier.



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## **Additional Work to be Completed**

### Potential Pool Stratification

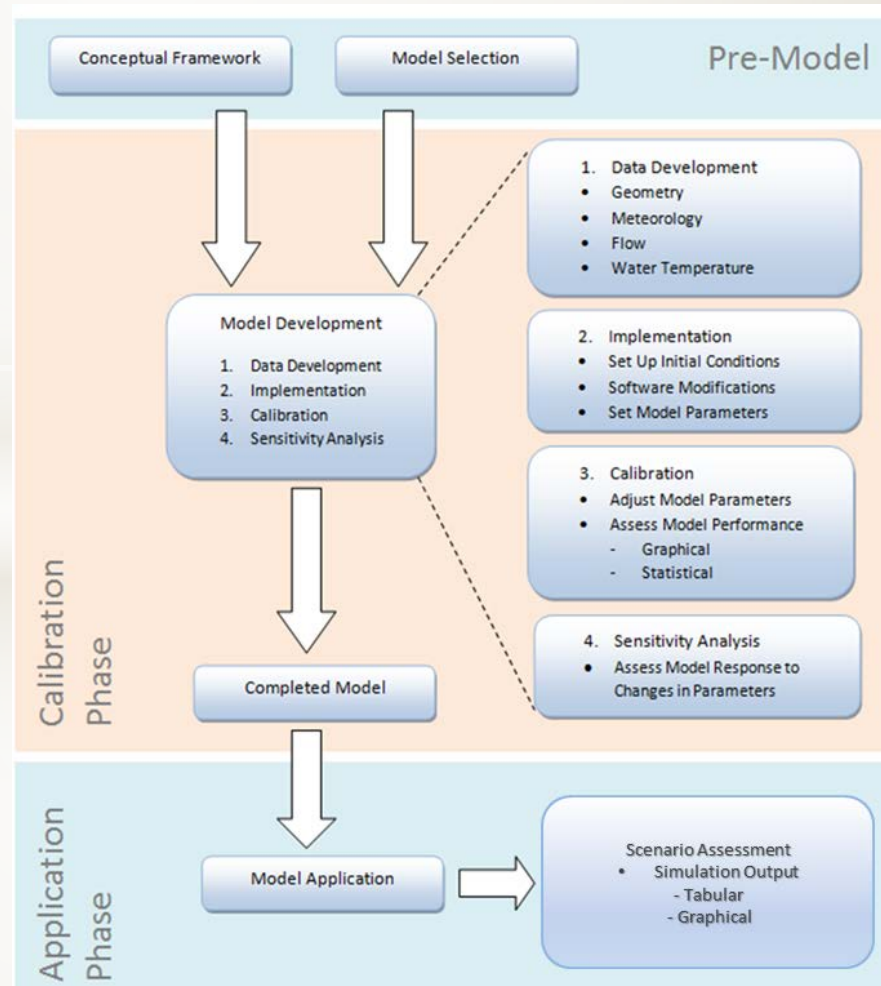
- Assess potential pool stratification via temperature monitoring
- Identify one large pool in each tributary and 2-3 pools in mainstem
- Assess with handheld temperature device (e.g., profile)
- Deploy loggers near bottom and surface to identify cold water presence and persistence through time



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# Water Temperature Modeling

- Model selection
- Data development
- Model calibration
- Model application





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## Model Selection Considerations

- System Characteristics
  - Steep channel gradient
  - Variable flow regime
  - Snowmelt hydrograph and thermal response
  - Low summer flows
  - Variable meteorology (spatial/temporal)
  - Topographic, riparian shade
- Previous model applications:
  - Upper Tuolumne River: Hetch Hetchy to Early Intake
  - Upper Tuolumne River: Without Dams Analysis – Tuolumne River above Hetch Hetchy to the San Joaquin River confluence
- RMA-2/RMA-11





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## RMA Models

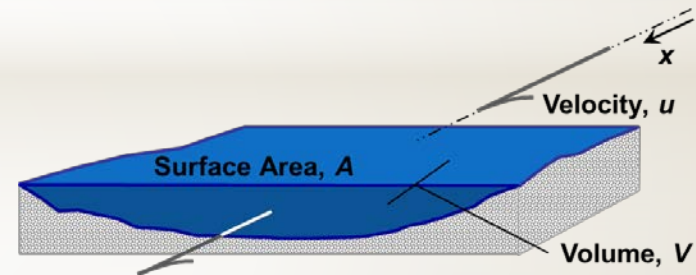
- A suite of modeling software, RMA-2 (v8) for hydrodynamics and RMA-11 (v8) for water temperature, is proposed to represent the Upper Tuolumne River as a one-dimensional (laterally and depth averaged) finite element model
- RMAGEN (v74): geometry file software (to build river grid)
- RMA-2 (v8): hydrodynamic model that calculates velocity, water surface elevation, and depth at defined nodes of each grid element
- RMA-11 (v8): water quality model that uses the depth and velocity results from RMA-2 to solve advection diffusion constituent transport equations for temperature.



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## RMA-2: Hydrodynamics

- Steady and unsteady (dynamic) flows can be analyzed (e.g., hydropower peaking) – solution of St Venant Equations
- Steep river reach capability
- Branching networks
- Low flow modeling ability
- $\Delta t = 1$  hr (maximum)
- $\Delta x = 25\text{-}50$  m (approximately)
- Open source code

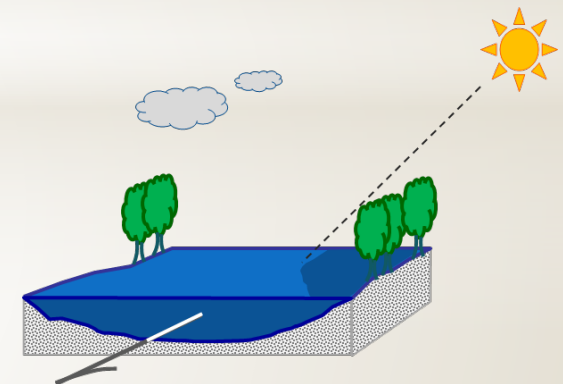
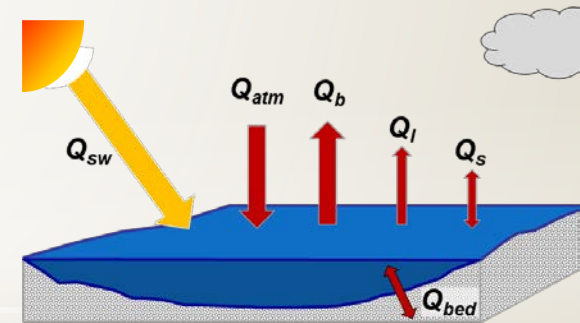




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## RMA-11: Water Temperature

- Solves advection-dispersion equation
- Comprehensive heat budget
  - $Q_n = (Q_{sw} + Q_{atm} - Q_b - Q_l + Q_s) + Q_b$
- Bed Conduction
- Topographic shade
- Riparian Shade (tributaries)
- Capable of variable meteorology zones
- $\Delta t = 1$  hr (maximum)
- $\Delta x = 25$ -50 m (approximately)
- Open source code





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## Stream Modeling

- Data needs
  - Geometry
  - Hydrology (time series)
  - Water temperature (time series)
  - Meteorological data (time series)
- Stream reaches
  - Tuolumne River mainstem: Early Intake to Don Pedro Reservoir
  - Cherry Creek: [TBD]
  - Clavey River: [TBD]
  - North Fork Tuolumne River: [TBD]



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## Stream Geometry

- Information needs:
  - Planform description of river (x-y information)
  - Longitudinal profile/bed slope
  - Channel cross sections
  - Riparian and topographic shade assumptions
- Data sources
  - LiDAR
  - DEMs
  - Previous studies (modeling, fisheries)
  - Other available information

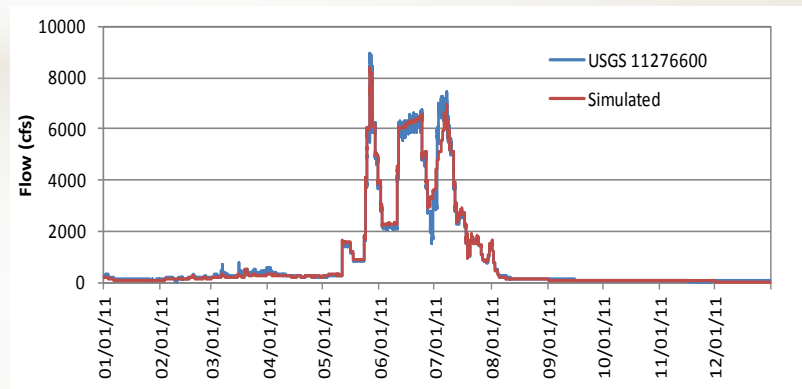
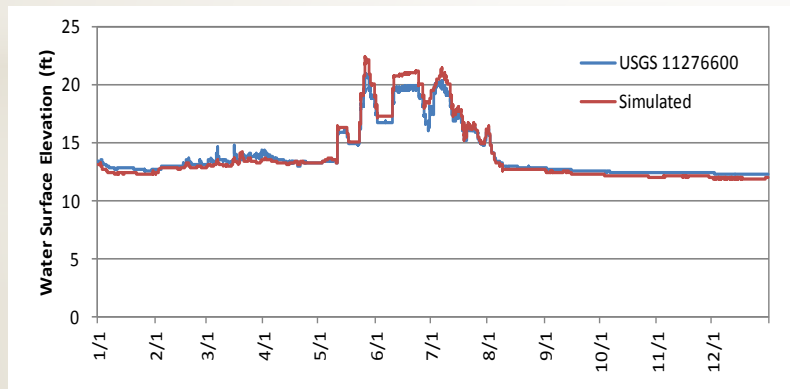




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## Hydrology

- Mainstem and tributary flows
  - Natural flow regimes (daily)
  - Hydropower peaking conditions (hourly)
- Accretions/depletions (calculated based on mass balance)
- Calibration data (within domain to test model)
  - Flow
  - Stage data (assess travel time (if multiple gages available))

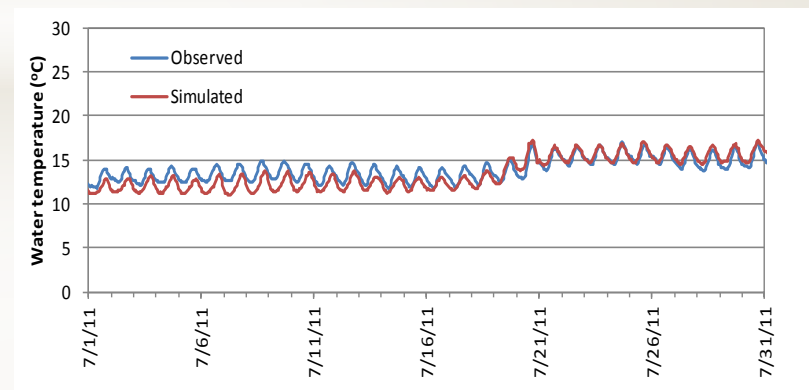
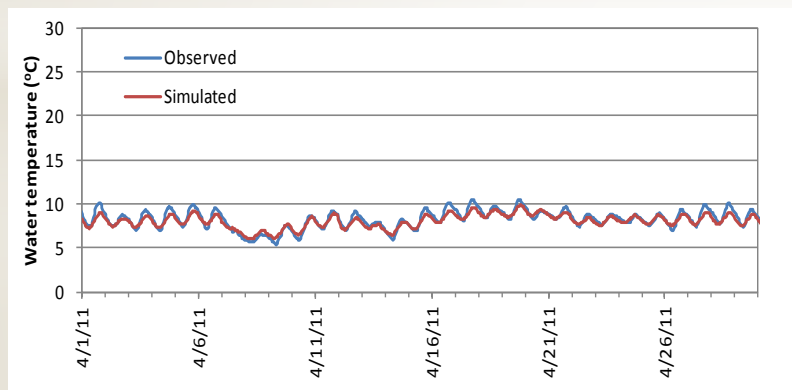




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## Water Temperature

- Mainstem and tributary inflow temperatures
  - Natural flow regimes (daily or hourly)
  - Hydropower peaking conditions (hourly)
- Accretions/depletions (daily, weekly, or at river temperature)
- Calibration data (within domain to test model)

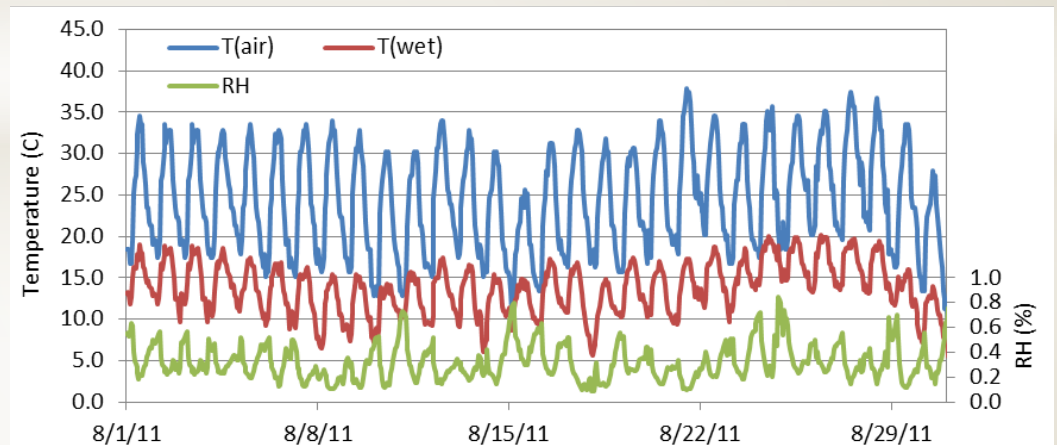




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## Meteorology

- Air temperature,  $T_{air}$
- Relative Humidity, RH
- Dew point (calculate using  $T_{air}$  and RH) or wet bulb temperature
- Cloud cover (estimate or calculate)
- Atmospheric pressure (calculate)
- Wind speed
- Solar radiation

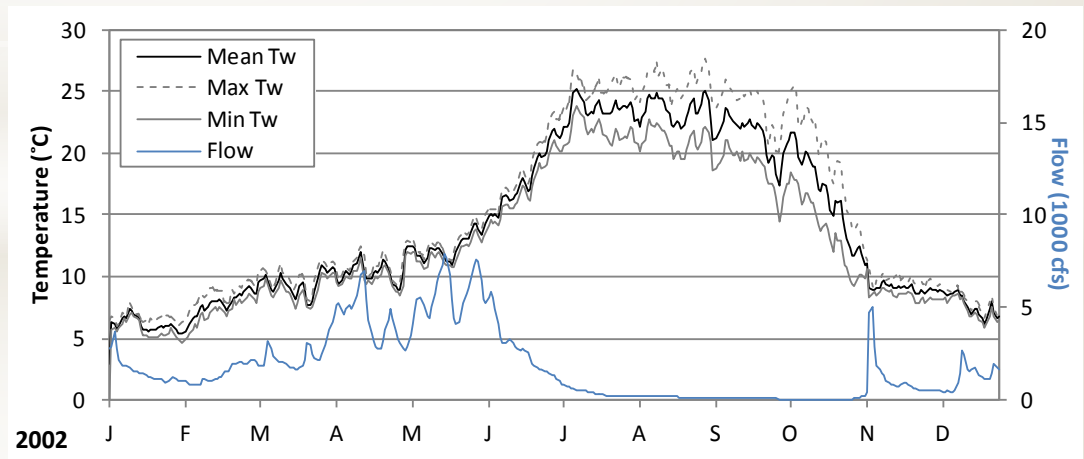




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# Model Implementation, Calibration, Application

- Implementation
- Calibration
  - Statistical performance
  - Graphical performance
- Hydrology
  - Flow
  - Travel time
  - Water temperature
    - Temperature
- Application
  - Comparative analysis
  - Potential years are 2007 to present





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## Next Steps

- 2015
  - Data synthesis and assessment (May)
  - Continue with field monitoring (through October 2016)
  - Ongoing coordination with project team on temperature assessment questions as they relate to barrier assessment
- 2016
  - Initial Study Report (February)
  - Develop temperature model based on 2015-16 information (March – November)
- 2017
  - Updated Study Report (February)



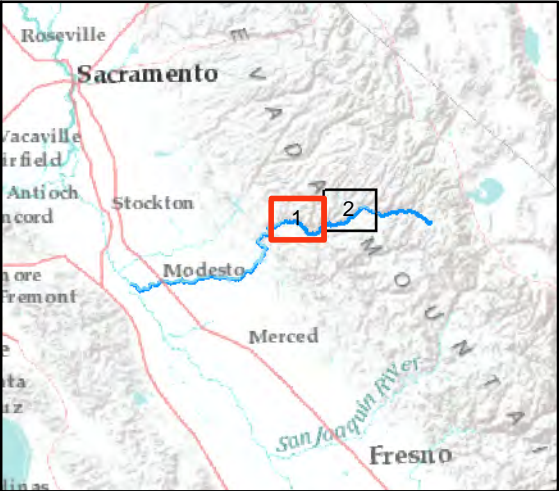
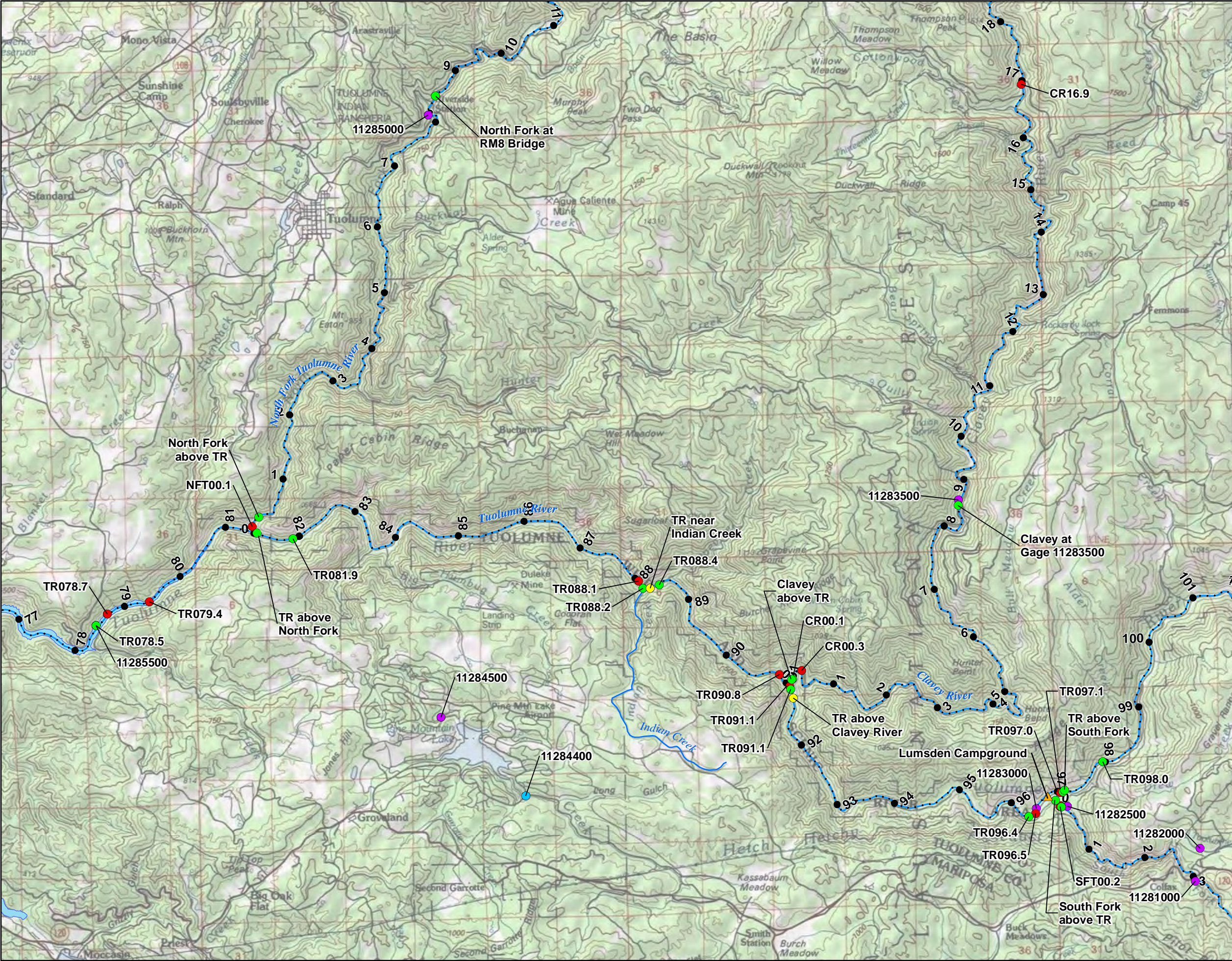
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**Questions or Comments?**









### Stream / Flow Gage

● Active    ● Inactive

Label	Agency	Active	Site Name
11281000	USGS	Inactive	SF TUOLUMNE R NR OAKLAND RECREATION CAMP CA
11282000	USGS	Inactive	MT TUOLUMNE R A OAKLAND RECREATION CAMP CA
11282500	USGS	Inactive	SF TUOLUMNE R NR BUCK MEADOWS CA
11283000	USGS	Inactive	TUOLUMNE R NR BUCK MEADOWS CA
11283500	USGS	Inactive	CLAVEY R NR BUCK MEADOWS CA
11284000	USGS	Active	BIG C AB WHITES GULCH NR GROVELAND CA
11284500	USGS	Inactive	BIG C NR GROVELAND CA
11285000	USGS	Inactive	NF TUOLUMNE R AB DYER C NR TUOLUMNE CA
11285500	USGS	Active	TUOLUMNE R A WARDS FERRY BR NR GROVELAND CA

### Water Temperature Logger

● Active    ● Inactive    ● Proposed\*

Label	Agency	Active	Site Locations
CR00.1	TID/MID	YES	Clavey above TR
CR00.1	NMFS	YES	Clavey R. just US of confluence
CR00.3	UC Davis	NO	Clavey River, upstream of Tuolumne River confluence
CR08.4	TID/MID	YES	Clavey River at USFS Bridge
CR16.9	CCSF	NO	Clavey River at 1N04 Bridge
NFT00.1	TID/MID	YES	North Fork above TR
NFT00.1	UC Davis	NO	North Fork Tuolumne above Tuolumne River
NFT08.0	TID/MID	YES	North Fork at RM8 Bridge
SFT00.1	TID/MID	YES	South Fork above TR
SFT00.2	CDFG	NO	South Fork of the Tuolumne River near confluence
SFT00.2	CCSF	NO	South Fork Tuolumne River near 1N10 Bridge
SFT00.2	NMFS	YES	S Fork Tuolumne R. just US of confluence
TR078.5	USGS	YES	Tuolumne River at Wards Ferry Bridge
TR078.7	CDFG	NO	Tuolumne River upstream of Wards Ferry Bridge
TR079.4	CCSF	NO	Tuolumne River, upstream of Ward's Ferry
TR081.3	TID/MID	YES	TR above North Fork
TR081.9	NMFS	YES	Tuolumne R DS of Mohecan Br.
TR088.1	UC Davis	NO	Tuolumne River, downstream of Indian Creek confluence
TR088.2	TID/MID	YES	Tuolumne River at Indian Creek Trail
TR088.4	NMFS	YES	Tuolumne R DS of Grapevine Cr.
TR090.8	UC Davis	NO	Tuolumne River, downstream of Clavey Creek confluence
TR091.1	UC Davis	NO	Tuolumne River, upstream of Clavey Creek confluence
TR091.1	NMFS	YES	Tuolumne R US of Clavey R.
TR096.4	NMFS	YES	Tuolumne R DS of Lumsden Campground
TR096.5	CDFG	NO	Tuolumne River below the South Fork
TR097.0	CDFG	NO	Tuolumne River above the South Fork
TR097.0	TID/MID	YES	TR above South Fork
TR097.1	CCSF	YES	Tuolumne River, upstream of South Fork
TR098.0	NMFS	YES	Tuolumne R DS of Lumsden Bridge

\* Proposed logger locations will be added to table when exact coordinates are known.

00.512

Miles

↑

N

### Upper Tuolumne River Gages

Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness. Data Sources: Gages - USGS, TID/MID Copyright:© 2013 National Geographic Society, i-cubed Sources: Esri, DeLorme, USGS, NPS Sources: Esri, USGS, NOAA Data is CA SPCS, Zone III, ft.

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